DEVELOPMENT OF DIGITAL GROUNDWATER MODELS AND SIMULATION OF GROUNDWATER FLOW OF THE RUSH SPRINGS AQUIFER IN WEST CENTRAL OKLAHOMA

By

QUALLA JO KETCHUM

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DEVELOPMENT OF DIGITAL GROUNDWATER MODELS AND SIMULATION OF GROUNDWATER FLOW OF THE RUSH SPRINGS AQUIFER IN WEST CENTRAL OKLAHOMA

Thesis Approved:

Garey A. Fox, Ph.D, P.E., D.WRE

Thesis Adviser

Todd Halihan, Ph.D.

Saleh Taghvaeian, Ph.D.

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Abstract: Groundwater modeling has been used since the 1970's as a way to analyze complex groundwater systems and to provide scientific evidence for management and policy determinations. The fundamental objective of this research was to develop a digital groundwater-flow model of the Rush Springs aquifer to assist in these determinations. The Rush Springs aquifer covers approximately 10,360 km^2 in west-central Oklahoma and is the state's second most developed aquifer. This model will be used by government agencies to inform management decisions as well as gain insight about the aquifer's response to different scenarios such as policy determinations, changes in climate, or groundwater use. A steady-state simulation was first generated from the model. Hydraulic conductivity and recharge parameters were adjusted during calibration of the model to the 1956 head observations. The relationship between observed and simulated heads had a R^2 value of 0.97 and a mean residual of -11 m. A transient model was constructed for 1956 to 2013 with monthly time steps. Specific yield, recharge, and specific storage were adjusted for this simulation. The average residuals for the analyzed years ranged from -8 to -13 m. The second objective of this research was to utilize these models to analyze how groundwater use affects stream baseflow throughout the aquifer. Three different groundwater use scenarios from 2013 – 2023 were generated to compare how various management practices affect baseflow conditions including current groundwater use rates, assigning a 6093 m^3/ha pumping rate out of every well in the model, as well as allowing for maximum irrigation use in the aquifer. Groundwater discharge to streams decreased for all three while recharge to the aquifer from the streams stayed relatively the same at approximately 1.5 m^3/s. Recharge was also found to be a contributing factor in baseflow. Like the groundwater use scenarios, stream leakage out of the aquifer was larger than flow into the aquifer for all of these recharge scenarios. Unlike the groundwater use scenarios, stream leakage from the streams to the aquifer changed during the simulation period. This indicates that recharge has a greater effect on losing streams within this groundwater system than groundwater use.

TABLE OF CONTENTS

Chapter Page

I. INTRODUCTION 1

Objectives 2
Background 2

II. MODEL CONSTRUCTION 6

Model Discretization 7
Boundary Conditions 10
Recharge 11
Surface Water 12
  Stream-flow Routing 12
  Drains 13
  Stream Gages 14
  Lakes 14
Hydraulic Properties 15
  Hydraulic Conductivity 15
  Specific Yield 16
  Specific Storage 17
Groundwater Withdrawals 19
Model Simplifications, Assumptions, & Limitations 20

III. STEADY-STATE SIMULATION 23

Model Adjustments 23
Simulations Results 25

Chapter Page

IV. TRANSIENT SIMULATION 33

Model Adjustments..34
Simulation Results 36
Model Evaluation...39

V. BASEFLOW ANALYSIS SIMULATIONS 42

Current Conditions Simulation 43
MAY Simulation..45
Maximum Irrigation Use Simulation 46
Baseflow Analysis 47

V. CONCLUSIONS AND FUTURE WORK 55

REFERENCES 59

APPENDICES 63

LIST OF TABLES

Table Page

1. Monthly demand patterns for each permitted use for groundwater wells in the Rush Springs groundwater flow model 20
2. Stream gage locations analyzed during calibration of steady-state model 30
3. Calibration results for the Fort Cobb Reservoir area gages in the steady-state model 31
4. Flow budget for the calibrated steady-state groundwater-flow model 32
5. Stream gage locations considered during baseflow analysis simulations..........43
6. Changes in baseflow for each groundwater use simulation from 2013 - 2023.....49
7. Total decrease in inflow to Fort Cobb Reservoir for each groundwater use scenario for the simulation period 50

LIST OF FIGURES

Figure Page

1. Modeling extent of the Rush Springs Aquifer in West-Central Oklahoma............2
2. Layer boundaries for the Rush Springs aquifer model. The Cloud Chief is modeled in layer one and the Rush Springs is simulated as layer two.........................7
3. Surface elevation for the Rush Springs aquifer from the USGS digital elevation model which was utilized as the top elevations for the groundwater flow model. This dataset is owned by the Oklahoma Water Resources Board who uses English units exclusively. Data in the figure can be converted from ft to m by dividing by 3.28. Surface elevation in the model ranged from 355 to 705 m. 8
4. Elevation of contact between the Cloud Chief Formation and the Rush Springs Sandstone which was utilized as the bottom elevation of layer one in the groundwater flow model. This dataset is owned by the Oklahoma Water Resources Board who uses English units exclusively. Data in the figure can be converted from ft to m by dividing by 3.28. This elevation ranged from 376 to 630 m. 9
5. Base elevation of Rush Spring Sandstone which was modeled as the bottom elevation for layer two. This dataset is owned by the Oklahoma Water Resources Board who uses English units exclusively. Data in the figure can be converted from ft to m by dividing by 3.28. This elevation ranged from 273 to 613 m. 9
6. Simulated boundary conditions for the Rush Springs groundwater-flow model. The general head boundary is denoted as the red line. All other boundaries are no flow boundaries. 11
7. Mean annual recharge rate from 1950 - 2013 for the Rush Springs aquifer generated using the Soil-Water Balance Code. This dataset is owned by the Oklahoma Water Resources Board who uses English units exclusively. Data in the figure can be converted from in to m by dividing by 39.4. The mean annual recharge rate was 0.03 m/yr for the entire area during this time period...12
8. Map of gridded streams for the SFR2 package as well as drain and stream gage locations simulated in the Rush Springs groundwater-flow model..........14
9. Hydraulic conductivity values for the Rush Springs Sandstone, layer two, in the groundwater-flow model. This dataset is owned by the Oklahoma Water Resources Board who uses English units exclusively. This was converted from ft to m by dividing by 3.28. The mean hydraulic conductivity value for this layer was 1.4 m/day.. 16

Figure Page

10. Specific yield values for the Rush Springs Sandstone, layer two for the groundwater-flow model. The mean value for this layer was 0.12 17
11. Specific storage values for the Rush Springs Sandstone, layer two in the groundwater-flow model. This dataset is owned by the Oklahoma Water Resources Board who uses English units exclusively. Data in the figure can be converted from ft to m by dividing by 3.28. The mean specific storage value for this layer was $3\text{x}10^{-5}$ m^{-1}. 18
12. Permitted groundwater well locations for the Rush Springs aquifer from 1956 – 2013. There were approximately 3000 different permits simulated in the groundwater-flow model. 20
13. Hydraulic conductivity was adjusted during calibration of the steady-state groundwater-flow model. This dataset is owned by the Oklahoma Water Resources Board who uses English units exclusively. Data in the figure can be converted from ft to m by dividing by 3.28. The new mean hydraulic conductivity value for layer two was 2.16 m/day.. 24
14. Recharge was adjusted during calibration of the steady-state groundwater flow model. This dataset is owned by the Oklahoma Water Resources Board who uses English units exclusively. Data in the figure can be converted from in to m by dividing by 39.36. The new mean annual recharge for the Rush Springs model was 0.04 m/yr. 25
15. Residuals from the steady-state groundwater-flow model for the1956 head observations. The mean residual was – 10.8 m. The negative value denotes that simulated heads are lower than those observed................................26
16. Spatial representation of the residuals of the 1956 head observations in the steady-state simulation. This dataset is owned by the Oklahoma Water Resources Board who uses English units exclusively. Data in the figure can be converted from ft to m by dividing by 3.28. 27
17. Simulated heads compared to observed head values in the steady-state model for the 1956 head observations and the corresponding equations for the linear regression relationship...28
18. Potentiometric surface map of simulated head in feet in the steady-state groundwater-flow model generated in GMS and calibrated to the 1956 head observations. This figure was generated in GMS which used English units. Data in the figure can be converted from ft to m by dividing by 3.28. The simulated heads ranged from 351 to 656 m. 29
19. Potentiometric surface map generated directly from and only considering the 1956 head observations. This dataset is owned by the Oklahoma Water Resources Board who uses English units exclusively. These water levels elevations can be converted from ft to m by dividing by 3.28.......................................30
20. Sensitivity analysis results for recharge, specific storage, and specific yield parameters for the transient simulation. The model was determined to be more sensitive to specific yield, recharge, and then specific storage, respectively..35

21. Observed versus computed head observations and corresponding equations at the end of the first time step (1/1/1957) 36
22. Observed versus computed head observations and their corresponding equations for the time step 1/1/1985 in the transient simulation...................................37
23. Observed versus computed head observations and corresponding equations at the end of the transient simulation on 1/1/2014 37
24. Comparison of estimated baseflow from the Upper Washita Surface Water Allocation Model to simulated baseflow at USGS gage 07325800 on Cobb Creek near Eakly, OK for the transient simulation time period, 1956 - 2013 39
25. Comparison of estimated baseflow from the Upper Washita Surface Allocation Model and simulated baseflow in the transient model at USGS gage 07325850 on Lake Creek near Eakly, OK...39
26. Observed versus computed head observations and corresponding equations for the time step 3/1/1980 of the transient simulation. 40
27. Observed versus computed head observations with the corresponding equations for time step 9/1/2000 of the transient simulation. 40
28. Simulated average annual baseflow for the USGS gage 07325800 on Cobb Creek near Eakly, OK for the simulation period, 2013 – 2023, for the first groundwater use scenario which extended 2013 groundwater use through the simulation period...44
29. Simulated average annual baseflow for the USGS gage 07325850 on Lake Creek near Eakly, OK for the simulation period, 2013 – 2023, (bottom) for the first groundwater use scenario which extended 2013 groundwater use through the simulation period...44
30. Simulated average annual baseflow for the USGS gage 07325800 on Cobb Creek near Eakly, OK for the simulation period, 2013 – 2023, for the second groundwater use scenario which simulated each well pumping at a rate of 6093 m^3/ha per year...45
31. Simulated average annual baseflow for the USGS gage 07325850 on Lake Creek near Eakly, OK for the simulation period, 2013 – 2023, for the second groundwater use scenario which simulated each well pumping at a rate of 6093 m^3/ha per year...46
32. Simulated average annual baseflow for the USGS gage 07325800 on Cobb Creek near Eakly, OK for the simulation period, 2013 – 2023for the third groundwater use scenario which simulated each well pumping at a rate of approximately 5.5 mm/day for irrigation use. 47
33. Simulated average annual baseflow for the USGS gage 07325850 on Lake Creek near Eakly, OK for the simulation period, 2013 – 2023 for the third groundwater use scenario which simulated each well pumping at a rate of approximately 5.5 mm/day for irrigation use. 47

Figure Page

34. Total stream leakage from groundwater system to all streams within the model for each of the groundwater use simulations for the simulation period, 2013 - 2023 48
35. Simulated average annual baseflow for the USGS gage 07325800 on Cobb Creek near Eakly, OK for the simulation period, 2013 – 2023, for the scenario which extended both the current groundwater use and the recharge rate for the simulation period. 51
36. Simulated average annual baseflow for the USGS gage 07325850 on Lake Creek near Eakly, OK for the simulation period, 2013 – 2023, for the scenario which extended both the current groundwater use and the recharge rate for the simulation period. 52
37. Simulated average annual baseflow for the USGS gage 07325800 on Cobb Creek near Eakly, OK for the simulation period, 2013 – 2023, for the scenario which extended the 2013 groundwater use and increased the recharge rate to an average of 0.05 m/yr for the model area. 52
38. Simulated average annual baseflow for the USGS gage 07325850 on Lake Creek near Eakly, OK for the simulation period, 2013 – 2023, for the scenario which extended the 2013 groundwater use and increased the recharge rate to an average of 0.05 m/yr for the model area. 53
39. Total stream leakage from all streams within the model to the groundwater system for each of the recharge simulations using the 2013 groundwater use data for the simulation period, 2013 – 2023 54
40. Total stream leakage from the groundwater system to all streams within the model area for each of the recharge simulations using the 2013 groundwater use data for the simulation period, 2013-2023 54

CHAPTER I

INTRODUCTION

Groundwater in the state of Oklahoma is considered a private property right that is subject to reasonable regulation by the Oklahoma Water Resources Board (OWRB). The OWRB is required by Oklahoma groundwater law to conduct hydrologic investigations of the state's aquifers to determine the maximum annual yield (MAY) and equal proportionate share (EPS) for each aquifer (Okla. Stat. § 82-1020.5, 2011). The MAY is defined as the amount of water that can be withdrawn from the aquifer annually while sustaining a minimum of a 20 year life of the aquifer. The EPS of an aquifer is defined as the amount of groundwater that is allocated to each acre of land based on the MAY (OWRB, 2010). Groundwater modeling has been used since the 1970's as a way to analyze complex groundwater systems (Anderson, 1995) as well as to provide scientific evidence for these policy determinations (for example, Christenson et al., 2011). The digital groundwater/surface-water-flow model of the Rush Springs aquifer, referred to in this report as the "groundwater-flow model" is a computer program that solves equations to describe groundwater flow in the aquifer and is used to analyze dynamic water flow systems. These models can then be used to predict and analyze a system's reaction to future scenarios and stresses, such as different management policies (for example, Mittelstet et al., 2011).

Objectives

The fundamental objective of this research was to develop both a steady-state and a transient digital groundwater-flow model of the Rush Springs aquifer to simulate groundwater flow and generate flow budgets for this system. The second objective was to utilize these models to analyze how different groundwater use scenarios affect stream baseflow throughout the aquifer.

Background

The Rush Springs aquifer is located in west-central Oklahoma and includes portions of Blaine, Caddo, Canadian, Comanche, Custer, Grady, Stephens, and Washita counties (Figure 1). This aquifer is the second most developed aquifer in the state after the Ogallala and covers approximately 10,360 km^2 (Neel et al., 2015). The primary uses for groundwater in this area are municipal and irrigation, especially in Caddo County, which is one of the largest groundwater users by county in the state (Lurry and Tortorelli, 1995).

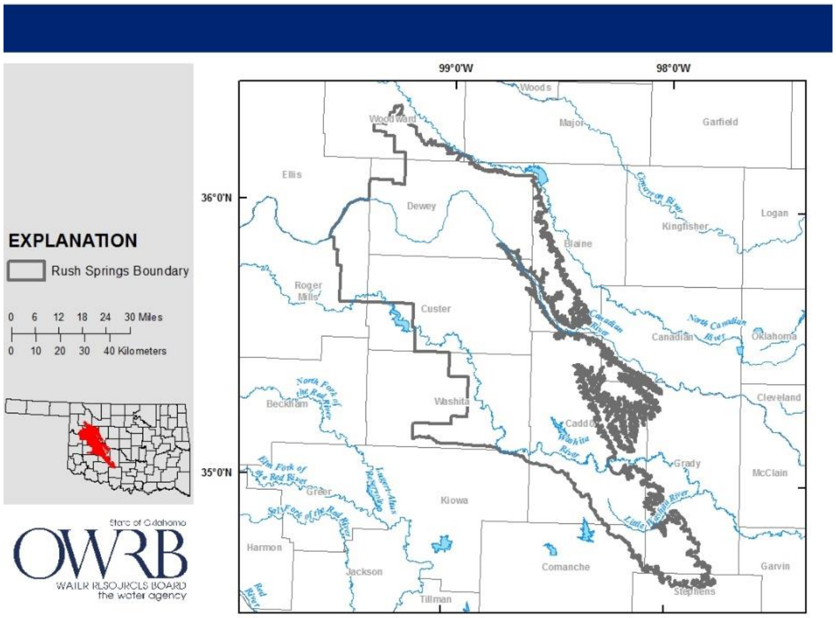


Figure 1: Modeling extent of the Rush Springs Aquifer in West-Central Oklahoma

The predominant water-bearing geologic formation for this aquifer is the Permian-age Rush Springs Formation which consists of red, fine-grained sandstone with a maximum thickness of 100 m (Neel et al., 2015). Below the Rush Springs Sandstone lies the Marlow Formation, which is widely regarded as a confining unit, restricting natural movement of water out of the Rush Springs aquifer (Becker and Runkle, 1998a). The other major geologic unit is the Cloud Chief Formation, which covers the Rush Springs Sandstone in the northwestern portions of the aquifer. The Cloud Chief is only present in this area as it has been eroded in the eastern and southern parts of the model area. The Cloud Chief is comprised of sandstone and siltstone with several gypsum layers acting as a confining unit and minimizing recharge in that area of the aquifer (Neel et al., 2015). This formation reaches a maximum thickness of approximately 30 m within the study area (Becker and Runkle, 1998a).

As this is the second most developed aquifer in the state of Oklahoma (OWRB, 2012), there have been a number of studies completed in the area as far back as 1905 from a number of different agencies (Gould, 1905). These studies cover a variety of topics including the geology (Davis, 1955), water chemistry (Magers, 2011), water levels (Church, 1966), and sedimentology (Poland, 2011) of the area.

There were two previous studies in particular that were of great significance to this research as the goals and objectives of these studies were similar. However, neither of the previous studies were able to fully accomplish these goals. The first was completed in 1998 by the United State Geological Survey in cooperation with the OWRB and the Oklahoma Geological Survey. This was a complete hydrogeologic study on the Rush Springs aquifer for the purpose of generating a groundwater-flow model for the OWRB (Becker and Runke, 1998a). A steady-state groundwater flow model was produced (Becker and Runke, 1998b) but the model did not accurately represent the aquifer in that it showed major flooding in the southeastern portion. This flooding made it difficult to create a transient model and as such no management scenarios could be completed.

During this same period, another steady-state model was built by Oklahoma State University and the Oklahoma Water Resources Board for this region (Penderson, 1999). This model was a simulation of groundwater flow in the Rush Springs aquifer but only for the portion within the Cobb Creek Basin in Caddo County. This model had some of the same issues of the previous study and only a steady-state model was completed. As such, neither of these models provided the Board with enough information to determine the MAY. It was the primary goal of this research to provide the Board with working models from which these management scenarios can be created.

Surface water also plays a major part in the aquifer system with a number of major rivers and streams having a baseflow connection from the Rush Springs. These include Cobb Creek, Deer Creek, and Sugar Creek, as well as the Washita, Canadian, and North Canadian Rivers (Neel et al., 2015).The only major lake within the Rush Springs aquifer is Fort Cobb Reservoir. A lake was determined to be a major lake if it has an area of 4 km^2 or greater. Fort Cobb was constructed in 1958 by the Bureau of Reclamation for the purpose of providing water to the surrounding communities, including Clinton, Cordell, and Chickasha.

Groundwater use has been seen to reduce baseflow in streams, which has a number of implications including surface water quality (Fox et al., 2011). Each state manages its water resources differently especially in regards to groundwater-surface water interactions. For example, New Mexico recognizes this interaction and permits its water resources in such a way that any proposed groundwater use must not interfere with any water rights associated with surface water or groundwater (N.M. Stat. 72-5-5 and 12-3). However, groundwater permits in the state of Oklahoma are issued without assessing any possible effect on surface water availability except where sole-source aquifers are involved (Okla. Stat. 82:1020.9A-B1).

It was the second goal of this research to analyze how different groundwater use scenarios change baseflow levels in streams within the aquifer. Stream gage locations on Cobb Creek, Lake Creek, Little Washita River, and Washita River were evaluated in these scenarios. Both Cobb Creek and Lake Creek are the main inflows of water to Fort Cobb Reservoir. Changes in baseflow due to groundwater use affects inflow to Fort Cobb and thus, water availability for public water supply use. Generated model simulations analyzing baseflow under different groundwater use scenarios will provide a better understanding of these effects to better manage these resources.

CHAPTER II

MODEL CONSTRUCTION

A groundwater-flow model was developed to simulate groundwater flow in the Rush Springs aquifer using Groundwater Modeling Software (GMS) from Aquaveo. This is a front-loading graphical user interface that utilizes MODFLOW-2005, referred to in this report as MODFLOW, to model the groundwater in the aquifer (Harbaugh, 2005). MODFLOW is a three-dimensional, finite difference model developed by the USGS and available as a public domain code (Harbaugh, 2000). MODFLOW is the choice program for groundwater modeling especially for government agencies for a number of reasons, most notably that the program is easy to understand, the extensive testing on each of its features, and the acceptance by U.S. courts as a valid approach to analyzing groundwater systems (Leake, 1997). Using MODFLOW to simulate groundwater flow does require several assumptions about the modeled aquifer system, as is the case with any model. The basic assumptions of MODFLOW are that the aquifer acts as a porous material while flow within the system is saturated and obeys Darcy's Law (Christenson et al., 2011). Further assumptions and simplifications were made to utilize MODFLOW for modeling the Rush Springs aquifer specifically. These are discussed in the Model Simplifications, Assumptions, and Limitations section of this chapter.

Model Discretization

The model is comprised of a grid with 415 rows and 330 columns. The grid has a cell size of 500 m by 500 m. The model is a two layer system with layers representing the two main geological formations of the aquifer. The Cloud Chief Formation is represented as the top, layer one in the model, while the Rush Springs sandstone is the bottom, layer two in the model. The boundaries for each layer were determined by the Oklahoma Water Resources Board (Neel, et al., 2015) utilizing new geology maps from the Oklahoma Geological Survey (Stanley et al., 2002; Stanley, 2002; Johnson et al., 2003; Stanley and Miller, 2004; Chang and Stanley, 2010; Fay, 2010; Fay, 2010; and Stanley and Miller, 2005) as well as reported water use and well yields (Figure 2).

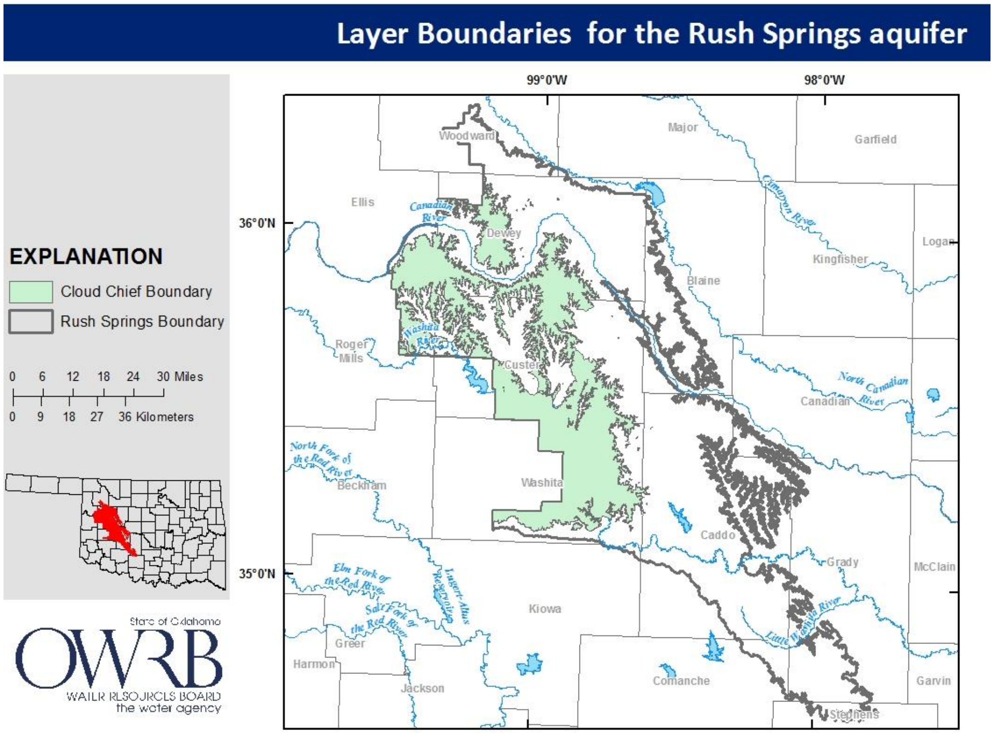


Figure 2: Layer boundaries for the Rush Springs aquifer model. The Cloud Chief is modeled in layer one and the Rush Springs is simulated as layer two.

A 500 m DEM file from the USGS was used as the top elevation of layer one as well as the top of layer two where layer one was not present (Figure 3). Well log analysis, core sample lithologies, and geophysical logs were used to determine the elevation of the Cloud Chief- Rush Springs contact, known in the model as the bottom of layer one and the top of layer two (Figure 4). These logs were also used to determine the base of the Rush Spring Sandstone (the bottom of layer two) (Figure 5).

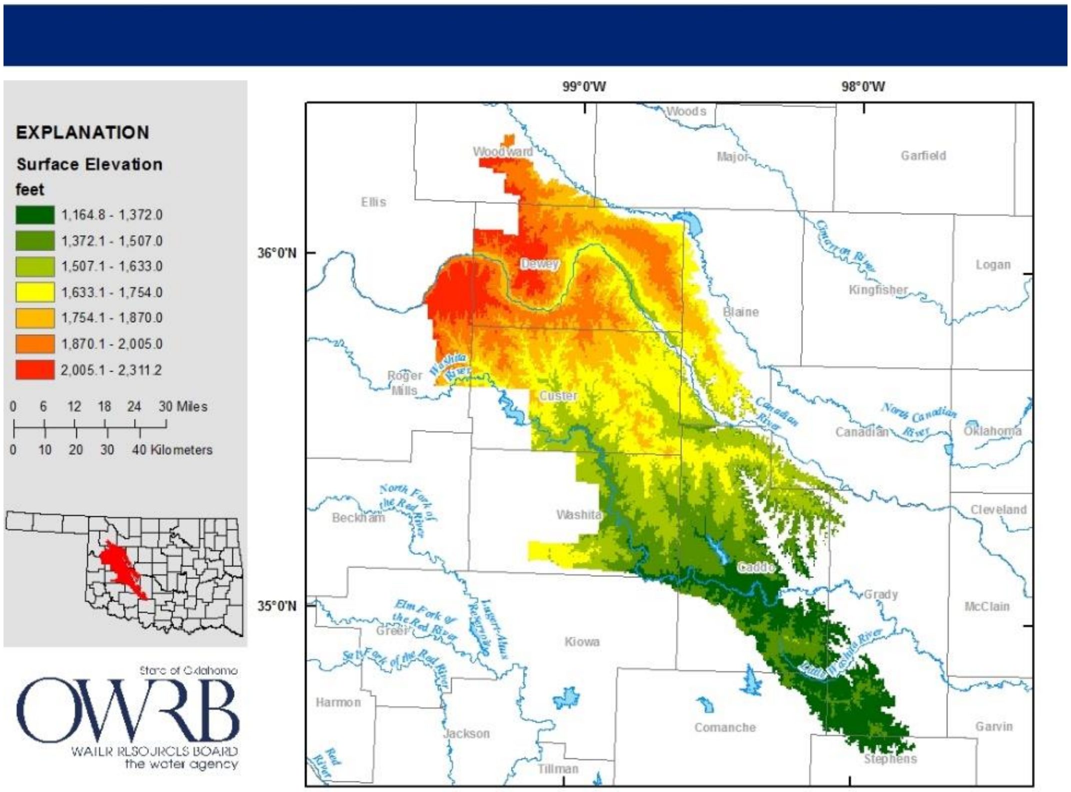


Figure 3. Surface elevation for the Rush Springs aquifer from the USGS digital elevation model which was utilized as the top elevations for the groundwater flow model. This dataset is owned by the Oklahoma Water Resources Board who uses English units exclusively. Data in the figure can be converted from ft to m by dividing by 3.28. Surface elevation in the model ranged from 355 to 705 m.

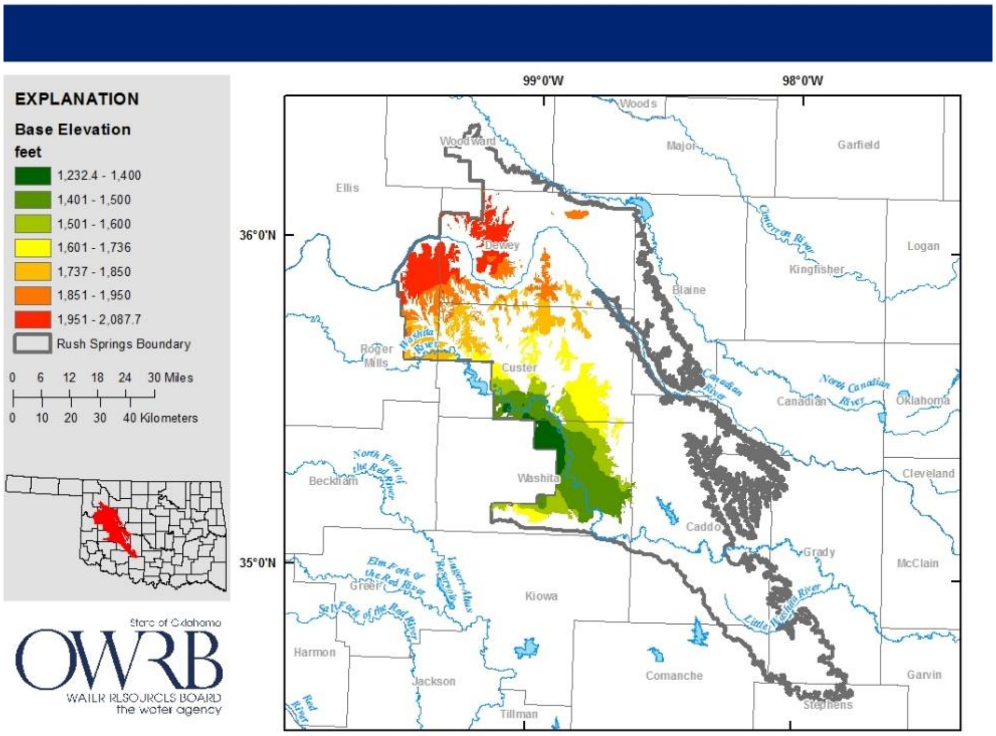


Figure 4. Elevation of contact between the Cloud Chief Formation and the Rush Springs Sandstone which was utilized as the bottom elevation of layer one in the groundwater flow model. This dataset is owned by the Oklahoma Water Resources Board who uses English units exclusively. Data in the figure can be converted from ft to m by dividing by 3.28. This elevation ranged from 376 to 630 m.

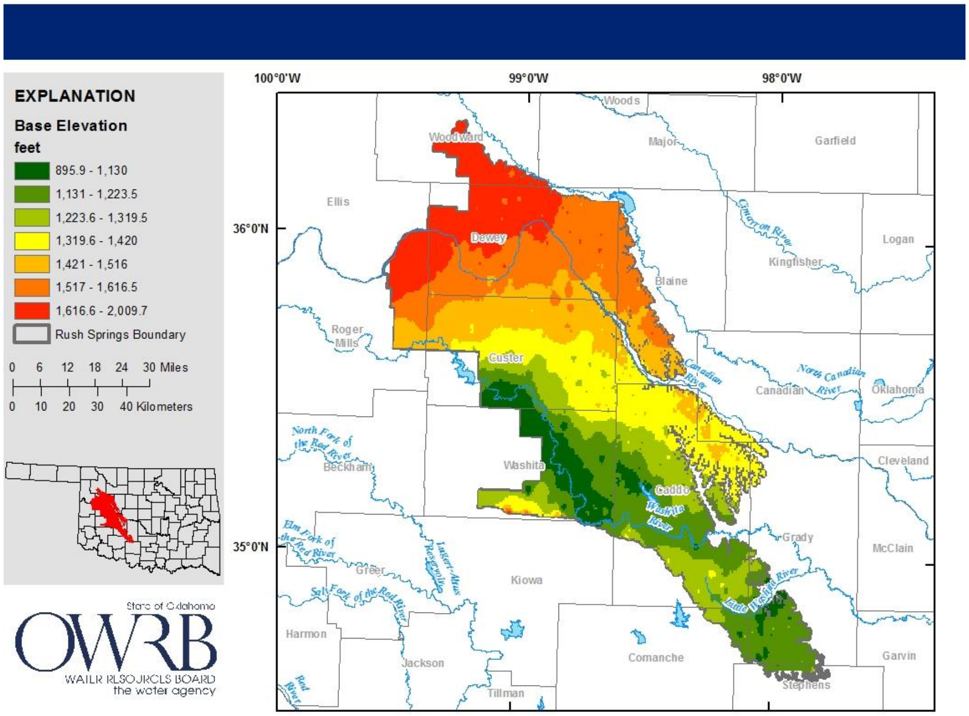


Figure 5. Base elevation of Rush Spring Sandstone which was modeled as the bottom elevation for layer two. This dataset is owned by the Oklahoma Water Resources Board who uses English units exclusively. Data in the figure can be converted from ft to m by dividing by 3.28. This elevation ranged from 273 to 613 m.

Boundary Conditions

In GMS, the model boundaries are no-flow boundaries unless otherwise denoted. These include the base of the Rush Springs as well as the eastern and southern boundaries. This boundary type allows no water to enter or leave the system horizontally through the boundaries. As discussed previously, the Marlow Formation below the Rush Springs restricts groundwater movement from the aquifer. The Rush Springs sandstone is eroded and crops out in the eastern and southern portions of the aquifer. This allows these boundaries to be modeled under this boundary condition.

The general-head boundary package simulates the flux as always proportional to the difference in head utilizing the following equation:

$$Q = -C(h_1 - h_0), \qquad (1)$$

where Q is the groundwater flow over the boundary, C is conductance, and $h_1 - h_0$ is the change in head. Conductance is the combination of the hydraulic conductivity, area, and position terms in Darcy's law. The general-head boundary uses a conductance factor to determine conductance. This factor is multiplied by the head of the boundary to provide MODFLOW with a conductance value (Winston, 2015). The northwestern boundary of layer two of the aquifer was determined to have a general-head boundary. The head for this boundary was set as the potentiometric head for the aquifer with a conductance factor of 100 $ft^2d^{-1}ft^{-1}$ (Figure 6). The conductance factor was an assumed value made from recommendations of other more experienced modelers. This value was not found to be the driving force behind flow changes at this boundary. Flow was much more dependent on the change in head over the boundary than conductance.

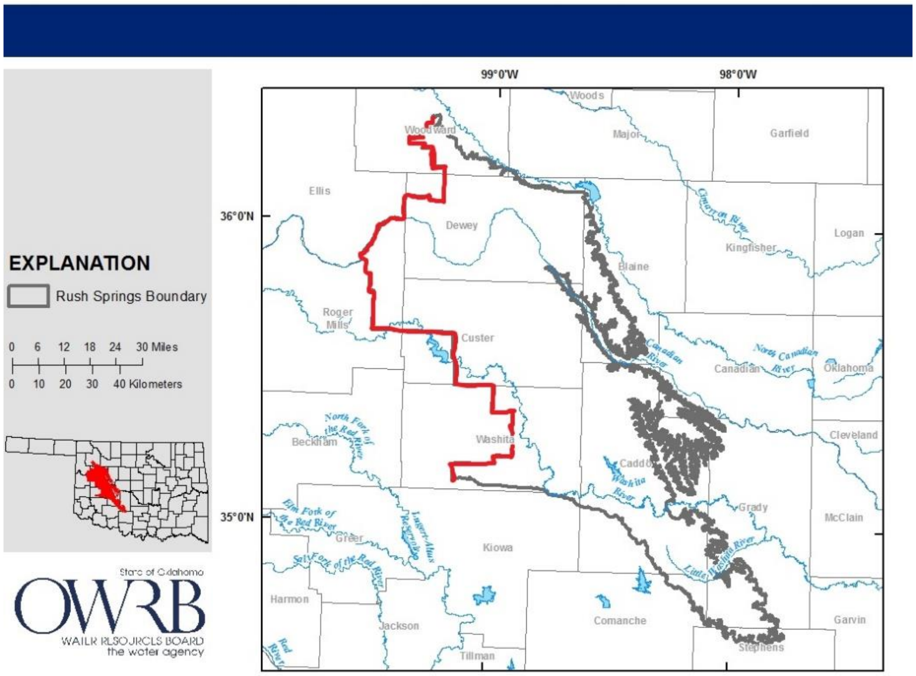


Figure 6. Simulated boundary conditions for the Rush Springs groundwater-flow model. The general head boundary is denoted as the red line. All other boundaries are no flow boundaries.

Recharge

Recharge was determined by the OWRB (Neel, et al., 2015) using Soil-Water-Balance (SWB) code (Westenbroek, et al., 2010). Mesonet and co-op station climate data as well as soil conditions were utilized within the code to produce a spatially gridded estimation of recharge for the coverage area. Datasets were generated for both annual and monthly time periods from 1950 to 2013. The average annual recharge for the Rush Springs ranged from 0 to 0.2 m/yr with a mean value of 0.03 m/yr (Figure 7). These recharge rates were applied to the highest active cell which MODFLOW multiplies by the horizontal area of the cells to determine the volumetric flux rate (Winston, 2015). As seen in Figure 7, recharge increased from west to east in the aquifer. This could be attributed to the fact that precipitation follows a similar pattern in this area.

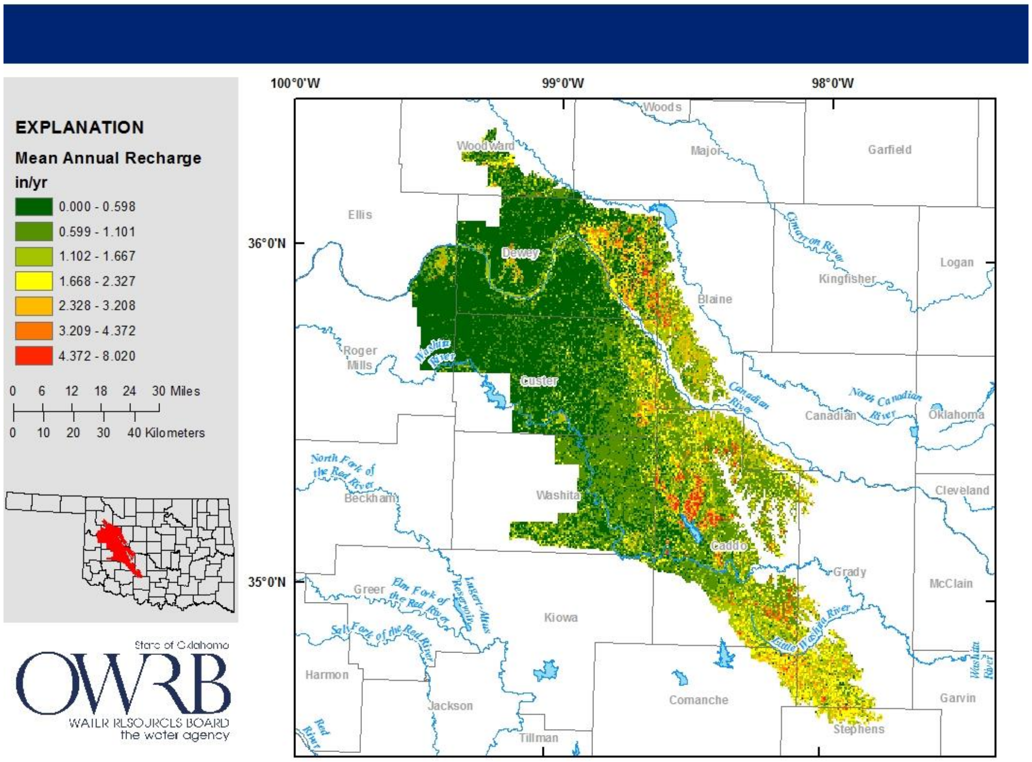


Figure 7. Mean annual recharge rate from 1950 - 2013 for the Rush Springs aquifer generated using the Soil-Water Balance Code. This dataset is owned by the Oklahoma Water Resources Board who uses English units exclusively. Data in the figure can be converted from in to m by dividing by 39.4. The mean annual recharge rate was 0.03 m/yr for the entire area during this time period.

Surface Water

Stream-flow Routing

Rivers and streams within the aquifer were modeled using the Stream-flow Routing (SFR2) package of MODFLOW, which routes flow in a stream instantaneously to a downstream segment (or lakes specified in the lake package) (Figure 8). The SFR2 package is not properly supported by the GMS software but it provides the most flexibility in modeling streams. ArcGIS was used to construct the SFR2 packages and the following assumptions were made. Manning's roughness coefficient was set at 0.034 and streambed thickness was assumed to be 0.3 m Streambed conductivity ranged from 0.003 - 3 m/day. Streambed conductivity is the hydraulic conductivity of the streambed (Winston, 2015). These values were chosen through recommendations from experienced USGS modelers who have generated models in the state of Oklahoma. This assumed manning's roughness coefficient corresponds with the value for main channels that are clean and straight with stones and weeds (Chow, 1959). This was verified as a reasonable assumption through personal field observations.

Drains

A majority of the eastern boundaries of the aquifer are no-flow boundaries with small streams exiting the aquifer boundary. These streams are too small to be effectively modeled using the SFR2 package and, therefore, were modeled using drains. The drain package was used to properly simulate the removal of water out of the groundwater-flow system to streams (Figure 8). A total of approximately 1000 drains were placed in individual cells along the southern and eastern boundaries of the model at stream locations determined from the OWRB stream shapefiles in ArcGIS. The elevation of the drain was set to the surface elevation where the streams are located and the drain conductance was assumed to be 3000 m^2/day after recommendations from other modelers.

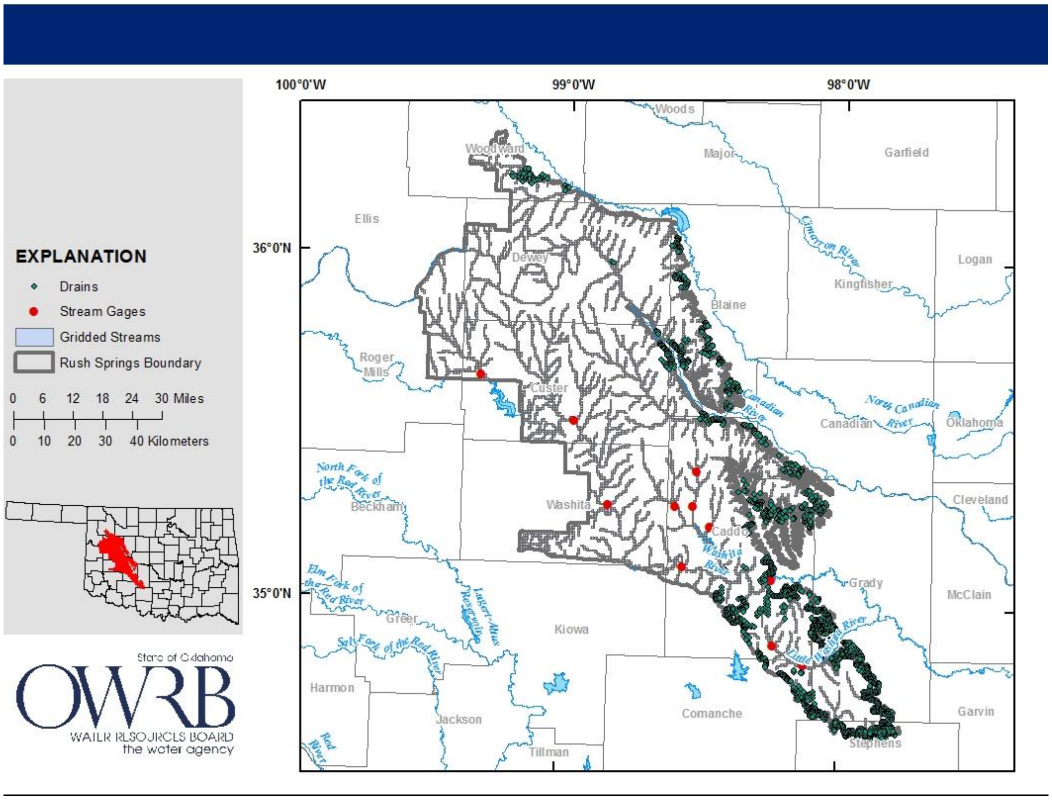


Figure 8. Map of gridded streams for the SFR2 package as well as drain and stream gage locations simulated in the Rush Springs groundwater-flow model.

Stream Gages

Gaging stations can be modeled utilizing the gage package to compare the simulated flow to the actual flow in either streams or lakes. For each designated stream, a separate output file can be written with flow information for each time step (Winston, 2015). There are several USGS, OWRB, and Bureau of Reclamation gages located within the model domain (Figure 8). Historic flow data from the stations was used in the calibration of the model for the streams.

Lakes

The only major lake within the model boundary is Fort Cobb Reservoir, located in the east-central portion of the aquifer. Fort Cobb was simulated in the model using the general head boundary package. Historic lake stage data was input as the head values for this package while the lakebed leakance factor was estimated to be 0.1 d^{-1}. This value was chosen from researching recent USGS models on Oklahoma aquifers as well as visiting with experienced modelers.

Hydraulic Properties

Hydraulic properties were input into the model utilizing the Layer-Property Flow (LPF) package. These properties include hydraulic conductivity, vertical and horizontal anisotropy, specific yield, and specific storage. Vertical anisotropy (K_h/K_v) was assumed to be 5 for layer one and 10 for layer two. The horizontal anisotropy was assumed to be one for both layers in this model. There was no data available for either vertical or horizontal anisotropy for this area. As such, these values were determined through recommendations of experienced modelers.

Hydraulic Conductivity

Hydraulic conductivity is defined as the volume of a fluid that will move in unit time through a unit area under a unit hydraulic gradient (Lohman, 1972). Hydraulic conductivity for layer one was set to $1.8x10^{-5}$ m/day which is the median value for siltstone (Domenico and Schwartz, 1990). The hydraulic conductivity for layer two utilized drawdown test data and slug test results. Rasters were generated for each separate dataset using the inverse distance weighted tool in ArcGIS. The two rasters were then combined in ArcGIS using the weighted sum tool. The drawdown test data was analyzed using the OWRB Groundwater Utilities Program, software developed by the OWRB using Theis and Neuman equations to estimate hydraulic conductivity and transmissivity. There were 573 groundwater wells with drawdown data that were given a weight of 0.2 in the weighted sum raster. Slug test data was collected in the field (Neel et al., 2015) and analyzed using AQTESOLV (Duffield, 2014). There were 54 slug test wells that were given a weight of 0.8 in the weighted sum raster. These different weights were used to appropriately combine the two datasets. Hydraulic conductivity values determined from slug test results were given a higher weight than those determined from drawdown test results because there was less uncertainty with these values. This also accounted for the discrepancy between the total number of points in each dataset. The combined dataset had a minimum value of 0.3 m/day and a maximum value of 13 m/day as well as a mean of 1.4 m/day (Figure 9). Some of the patterns seen in this data included higher hydraulic conductivity values in areas with a higher density of streams as seen in the southeastern portion of the aquifer. Other noticeable areas of high conductivity include the southeastern corner of Custer County in which several streams converge such as Deer and Little Deer Creeks.

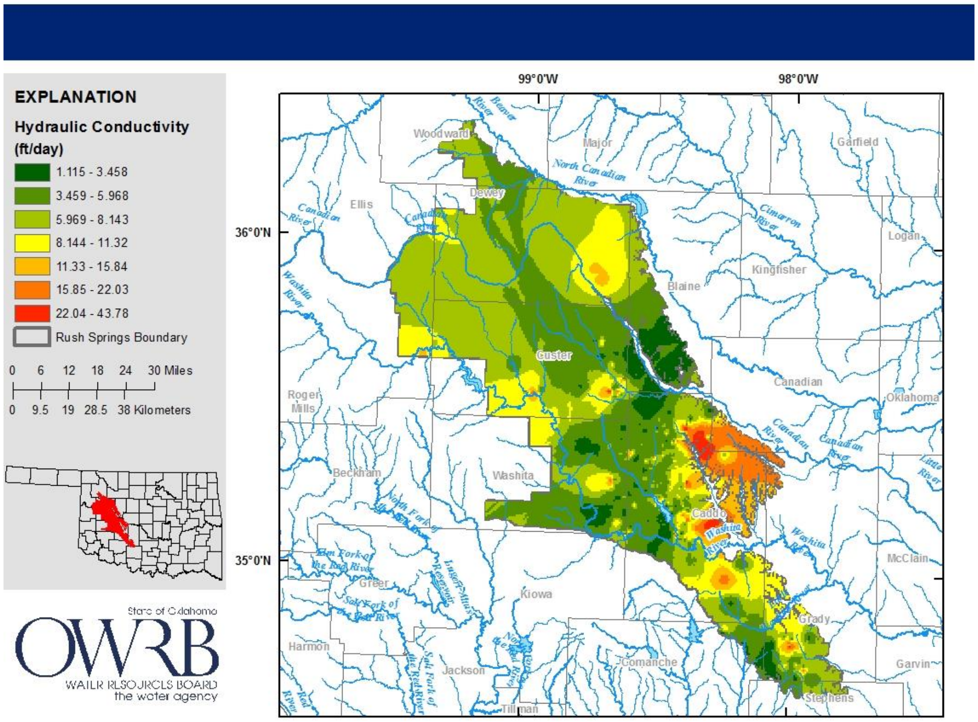


Figure 9. Hydraulic conductivity values for the Rush Springs Sandstone, layer two, in the groundwater-flow model. This dataset is owned by the Oklahoma Water Resources Board who uses English units exclusively. This was converted from ft to m by dividing by 3.28. The mean hydraulic conductivity value for this layer was 1.4 m/day.

Specific Yield

Specific yield is defined as the ratio of the volume of water which will be removed by gravity from the porous medium after it is saturated to the total volume of the porous medium (Lohman et al., 1972). These values range from 0.10 to 0.33 in the literature from field testing in the Rush Springs Sandstone (Tanaka and Davis, 1963). Specific yield of the Rush Springs in the model was determined to be dependent on hydraulic conductivity to spatially distribute these specific yield values throughout the aquifer. As hydraulic conductivity increases, specific yield was increased linearly. Specific yield in the model ranged from 0.10 – 0.33 with a mean value of 0.12 (Figure 10). Specific yield for the Cloud Chief in layer one was set to 0.12 which is the published value for siltstone in the literature (Tanaka and Davis, 1963).

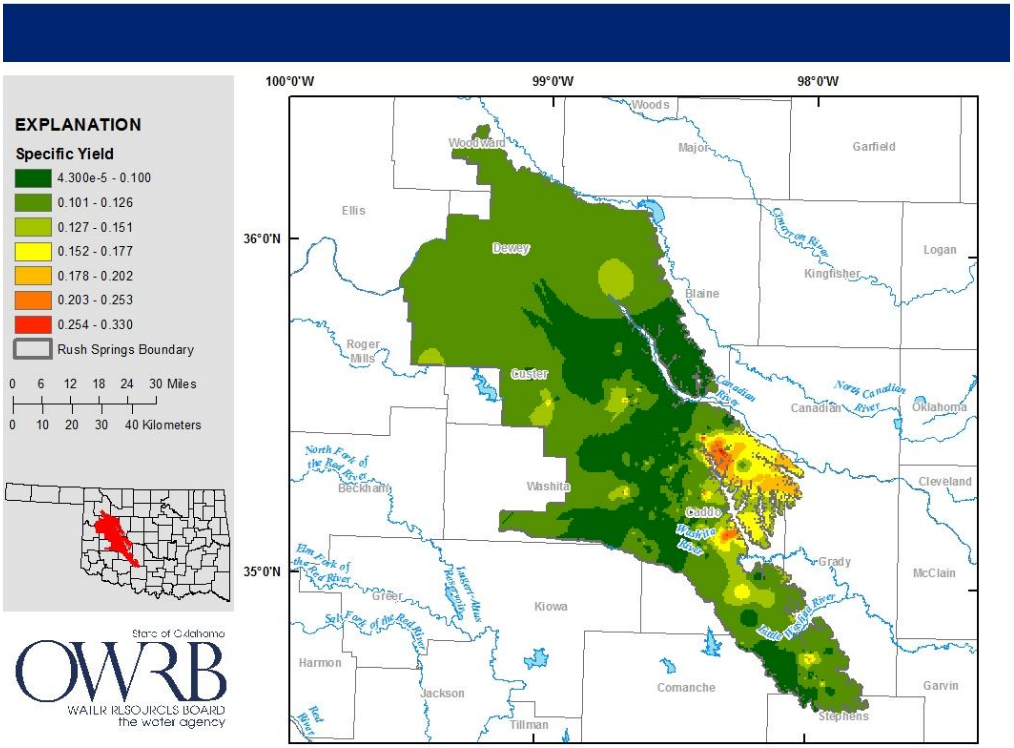


Figure 10. Specific yield values for the Rush Springs Sandstone, layer two for the groundwater-flow model. The mean value for this layer was 0.12.

Specific Storage

Specific storage is the amount of water released from storage per unit mass or volume of the aquifer, per unit hydraulic head change (Christensen et al., 2011). Specific storage for the Rush Springs was estimated from the storage coefficient by dividing it by the thickness of the aquifer. The storage coefficient for the Rush Springs was determined to be 1.6×10^{-2} during aquifer tests conducted by the OWRB (Neel et al., 2015). ArcGIS was used to estimate the specific storage utilizing this coefficient value and the saturated thickness for each gridded cell. Using this approach, specific storage for layer two ranged from $3x10^{-7}$ m^{-1} to $5x10^{-3}$ m^{-1} with a mean value of $3x10^{-5}$ m^{-1} (Figure 11). As the saturated thickness increased, the specific storage for the cell decreased. The specific storage of layer one was estimated to be two orders of magnitude smaller than the mean value of layer two.

Both specific storage and specific yield are hydraulic properties associated with storage. As such, these are required parameters for transient simulations but are not included in steady-state simulations.

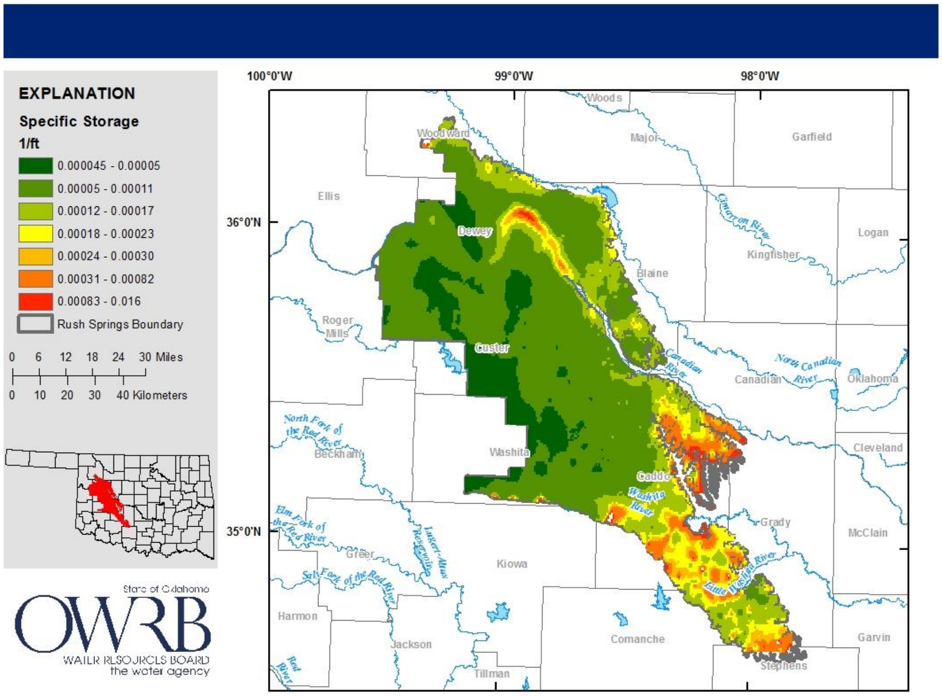


Figure 11. Specific storage values for the Rush Springs Sandstone, layer two in the groundwater-flow model. This dataset is owned by the Oklahoma Water Resources Board who uses English units exclusively. Data in the figure can be converted from ft to m by dividing by 3.28. The mean specific storage value for this layer was $3x10^{-5}$ m^{-1}.

Groundwater Withdrawals

Groundwater use from the Rush Springs aquifer was simulated using the well package (WEL) in MODFLOW. The WEL package in MODFLOW simulates a specific flow, *Q*, to an individual cell. This flow is the volumetric recharge rate. A positive value denotes recharge to the aquifer, while a negative value signifies discharge or pumping (Winston, 2015). The Oklahoma Water Resources Board started keeping records of groundwater use in 1967 for uses including public water supply, irrigation, industrial, power, mining, commercial, and fish/recreation/wildlife. Permitted users are required to submit water use reports annually to the OWRB (OWRB, 2010). Water use data was compiled for the simulated years of the model (Figure 12) and was allocated monthly using the demand model tool built for the Oklahoma Comprehensive Water Plan (OWRB, 2011). This demand tool allows for the reported annual use to be allotted monthly depending on the county in which the permit is located as well as the designated permitted use. The average percentage was determined from the Dewey, Custer, Washita, and Caddo County's monthly uses for each permitted use type as these are the main counties within the model boundary (Table 1). These values were utilized to determine the monthly pumping rates for wells during the transient simulation. Irrigation use ranged the most temporally with no irrigation in certain months. This accounted for the distribution of growing seasons for the different crops grown in this area as well as temporal variation in climate. This can be seen in months, such as December, when crops are dormant. The decrease in groundwater use for irrigation in the month of May could also be attributed to increased precipitation which decreases the demand for groundwater-supplied irrigation.

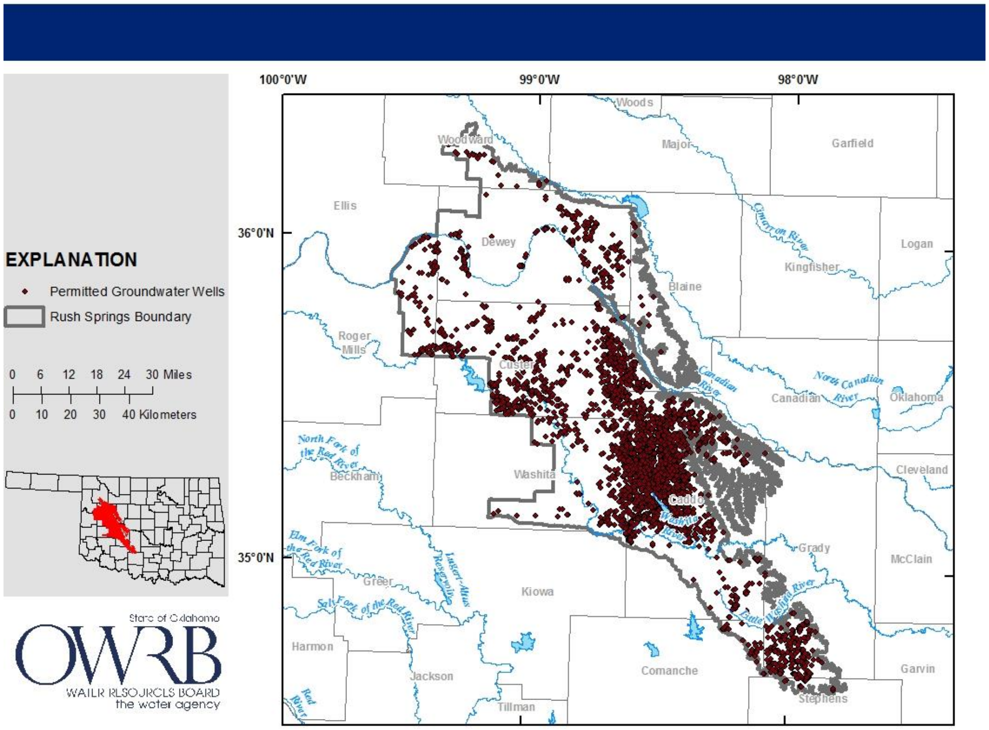


Figure 12. Permitted groundwater well locations for the Rush Springs aquifer from 1956 – 2013. There were approximately 3000 different permits simulated in the groundwater-flow model.

Table 1. Monthly demand patterns for each permitted use for groundwater wells in the Rush Springs groundwater flow model.

Monthly Demand Patterns by Permitted Use												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Irrigation	0.0%	0.0%	0.0%	14.0%	1.0%	13.0%	30.0%	31.0%	10.0%	0.0%	0.0%	0.0%
Municipal	7.3%	6.6%	7.4%	7.6%	8.6%	9.4%	11.0%	10.8%	8.9%	8.2%	7.3%	6.9%
Industrial	7.3%	6.6%	7.4%	7.6%	8.6%	9.4%	11.0%	10.8%	8.9%	8.2%	7.3%	6.9%
Other	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%

Model Simplifications, Assumptions, and Limitations

All models are, by definition, a simplification of a much larger, more complex system and as such, are based on specific simplifications, assumptions, and limitations. The Rush Springs aquifer fits the basic assumptions for the use of MODFLOW as stated previously. However, during the construction of this groundwater-flow model, further assumptions and implications were made to properly represent the aquifer. Due to the expansive size of this aquifer, the model is a regional-scale model that uses relatively large cells. As such, the model is limited by the spatial design of the model grid.

Specific assumptions for particular model inputs were discussed in their perspective sections. However, data entry of groundwater use reports into the model required additional assumptions. Groundwater use reported to the OWRB is inherently an assumption. Exact amounts of groundwater use are unknown as groundwater wells are not metered and use is reported by the landowner. Landowners do not report higher groundwater use than their permitted amount for fear of being fined. In the same way, landowners do not turn in water use reports with actual use lower than their permitted amount to ensure that their permit remains active and that there can't be any argument for lowering their permitted amount. However, these reports contain the most complete information for groundwater use during the entire period of record and so were used to complete this model.

The transient model period begins before the state of Oklahoma started keeping groundwater permit records in 1967. At this time, landowners who previously had wells were asked to report the year the well was drilled as well as to approximate the groundwater use for each year the well was utilized. This reported use is very spotty and inaccurate. In order to accurately depict this water use, the average reported water use for wells that were constructed before 1967 was input for the use before this year.

Only lakes with an area of over 4 km^2 within the aquifer model boundary were detailed in this model. There are a number of smaller lakes and ponds within the boundary that were not considered, making the model limited in its ability to analyze the interaction between these lakes and the aquifer. This model also does not consider any alluvium and terrace deposits on top of the Rush Springs aquifer. The streams and rivers were depicted in the model as previously discussed. However, no water budget can be created by this model to analyze the exchange of water between the alluvium and terrace deposits and the Rush Springs aquifer. Model construction and calibration were both optimized for simulating groundwater discharge to streams and rivers within the aquifer. These streams were calibrated utilizing streamflow observations at stream gages. This allows the model to be used for simulations of daily or seasonal stream flows as well as the long-term effects of groundwater use on these streams.

CHAPTER III

STEADY-STATE SIMULATION

A steady-state simulation of the Rush Springs aquifer was run by adjusting hydraulic conductivity as well as areal recharge to minimize the difference between computed and observation water levels in the aquifer. The main objective for this steady-state model was to accurately simulate the aquifer at long-term equilibrium at predevelopment conditions. This steady-state groundwater flow model was calibrated to a set of National Water Information System (NWIS) synoptic head measurements that were taken during 1956. Over a hundred head observations were measured during this year. However, after further analysis, a few of these wells were determined to be completed in the alluvium terraces above the aquifer. Others were outside the model boundary and as such were not utilized in this calibration. After this analysis, there were 86 head observations taken in 1956 that were considered in the steady-state model calibration. Calibration is important because it demonstrates how well the model depicts real world observations. This process includes finding a set of parameters that match simulated heads and fluxes to observation values within a determined range of error (Anderson and Woessner, 1992).

Model Adjustments

Initial values for parameters were discussed in the Model Construction chapter. However, some adjustments were made during the calibration process. Hydraulic conductivity and recharge were the main components of this procedure. Through a parameter sensitivity analysis, the model was determined to be more sensitive to changes in hydraulic conductivity than recharge. As such, hydraulic conductivity was the parameter that was primarily altered during calibration. This was accomplished by method of zone calibration. Zones were determined from areas of similar residual results in the simulated head observations and verified by aquifer test data completed in the area. The final dataset for hydraulic conductivity in the Rush Springs ranged from 0.08 to 20.6 m/day with a mean value of 1.62 m/d and a standard deviation of 2.16 m/day (Figure 13). Hydraulic conductivity in the layer one was increased to 0.03 m/day which still falls into the published range for siltstone by Domenico and Schultz.

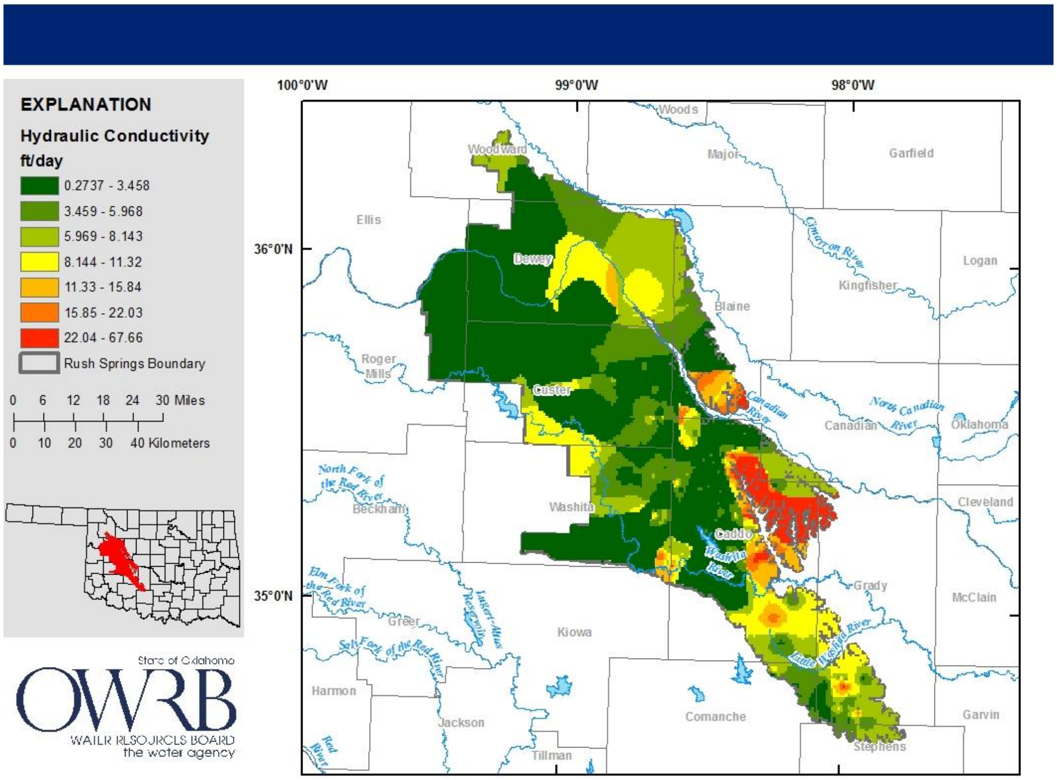


Figure 13. Hydraulic conductivity was adjusted during calibration of the steady-state groundwater-flow model. This dataset is owned by the Oklahoma Water Resources Board who uses English units exclusively. Data in the figure can be converted from ft to m by dividing by 3.28. The new mean hydraulic conductivity value for layer two was 2.16 m/day.

The mean annual recharge was inputted into the steady-state model. During calibration, this was adjusted by a multiplier of 1.5. This increased recharge to have a mean value of 0.04 m/yr and a range of 0 to 0.3 m/yr (Figure 14).

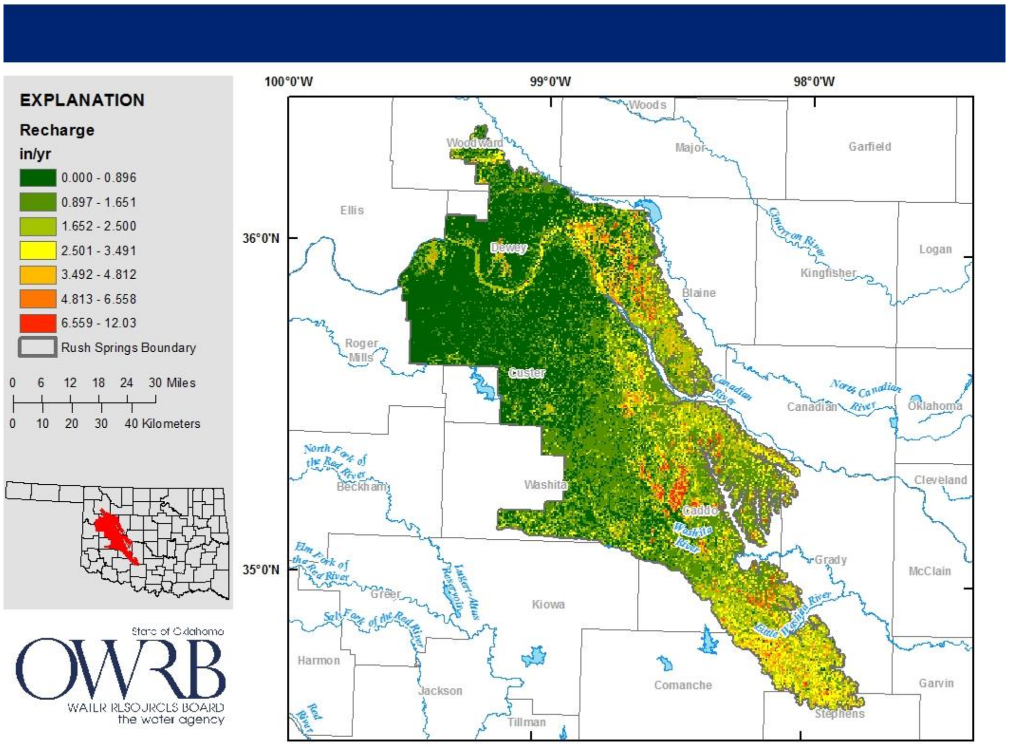


Figure 14. Recharge was adjusted during calibration of the steady-state groundwater flow model. This dataset is owned by the Oklahoma Water Resources Board who uses English units exclusively. Data in the figure can be converted from in to m by dividing by 39.36. The new mean annual recharge for the Rush Springs model was 0.04 m/yr.

It is important to note that, since the steady-state simulation is simulating predevelopment, no water use was considered. Ft. Cobb was also not considered because it was not constructed until 1958.

Simulation Results

The goal for calibration was to simulate heads within 30.5 m of those observed with a percent error of 10% or less. This goal was achieved in all 86 head observations. The difference between the simulated and the observed head is known as the residual for each observation. A histogram of the residuals was generated that had a mean of -10.8 m, ranged from -27.3 to -17.2 m, and skewed positive (Figure 15). This skew indicates that simulated heads are slightly lower than the observed heads but all head observations had a percent error of less than 10%.

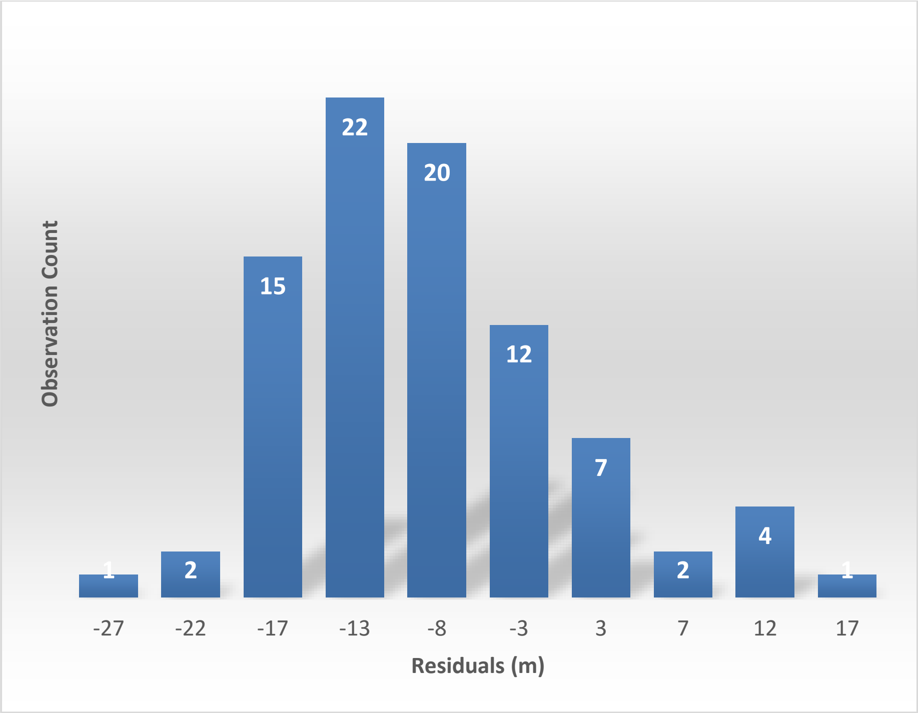


Figure 15. Residuals from the steady-state groundwater-flow model for the1956 head observations. The mean residual was – 10.8 m. The negative value denotes that simulated heads are lower than those observed.

It is also important to look at the residuals spatially (Figure 16). The spatial distribution of the head observations in 1956 was less than ideal for calibration of the entire aquifer as it was concentrated in the northern and east-central portions. However, having a steady-state model calibrated to pre-development conditions was found to be more important to the completion of this simulation than spatial distribution. The NWIS 1956 measurements provided the best compromise of both for this particular aquifer.

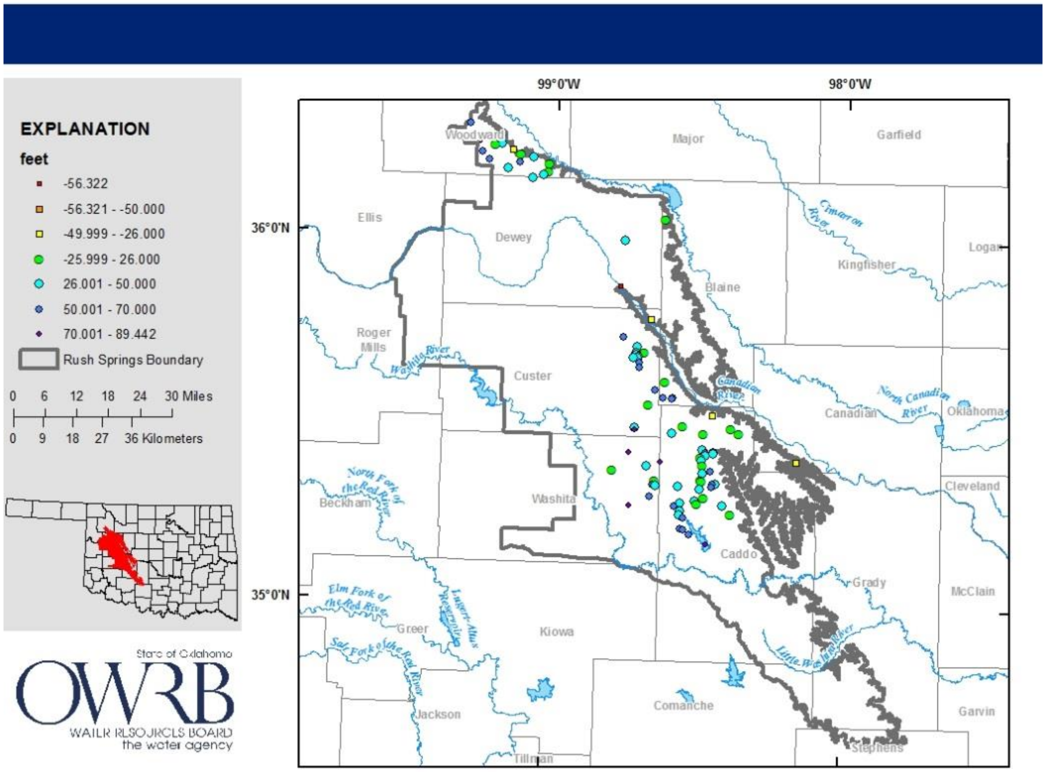


Figure 16. Spatial representation of the residuals of the 1956 head observations in the steady-state simulation. This dataset is owned by the Oklahoma Water Resources Board who uses English units exclusively. Data in the figure can be converted from ft to m by dividing by 3.28.

The simulated heads were compared to the observed 1956 head observations as shown in Figure 17. This regression analysis depicted a slope of 0.99 and a R^2 value of 0.97. The observed head elevations ranged from 405 to 605 m while the simulated head elevations ranged from 383 to 585 m. Based on this analysis, the model accounts for 97% of the variance which suggests that the model accurately simulated water levels that correspond with the observed 1956 head observations within the aquifer for the steady-state simulation.

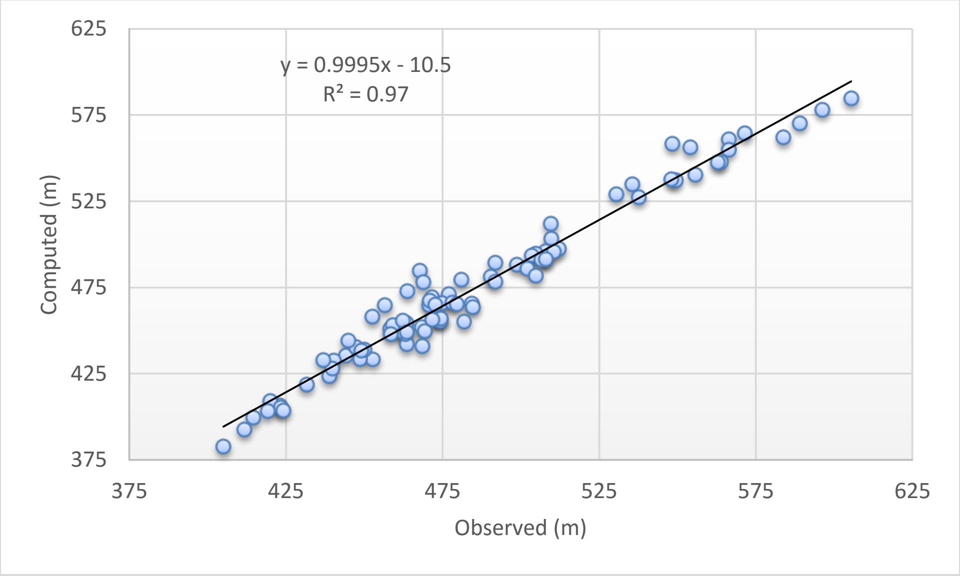


Figure 17. Simulated heads compared to observed head values in the steady-state model for the 1956 head observations and the corresponding equations for the linear regression relationship.

The simulated potentiometric-surface map generated from the steady-state model (Figure 18) compares similarly to that of the potentiometric-surface map made directly from the 1956 synoptic measurements (Figure 19). The steady-state model was calibrated to the initial measurements and does not take into account the contours of the potentiometric-surface map making them independent of each other. As such, the two can be compared and conclusions drawn on the similarities and differences between the two maps. The potentiometric-surface map generated from the measurements themselves does not include the areas of the aquifer in which there are no head observations. The simulated map uses the head observation data as well as the aquifer properties to estimate the head in these regions. However, in areas where the original surface map does have contours, the areas of higher water level elevations corresponded to areas of higher water level elevations on the simulated potentiometric-surface map. The simulated map has simulated heads that are either equal to or higher than that of the 1956 potentiometric-surface map. This can be attributed to the fact that the model was simulating pre-development conditions which can be assumed to be slightly higher than that of the 1956 measurements. This can be seen when looking at heads over the entire aquifer, even though the simulated heads at specific head observation points seem to be lower than that of the observed water levels in 1956.

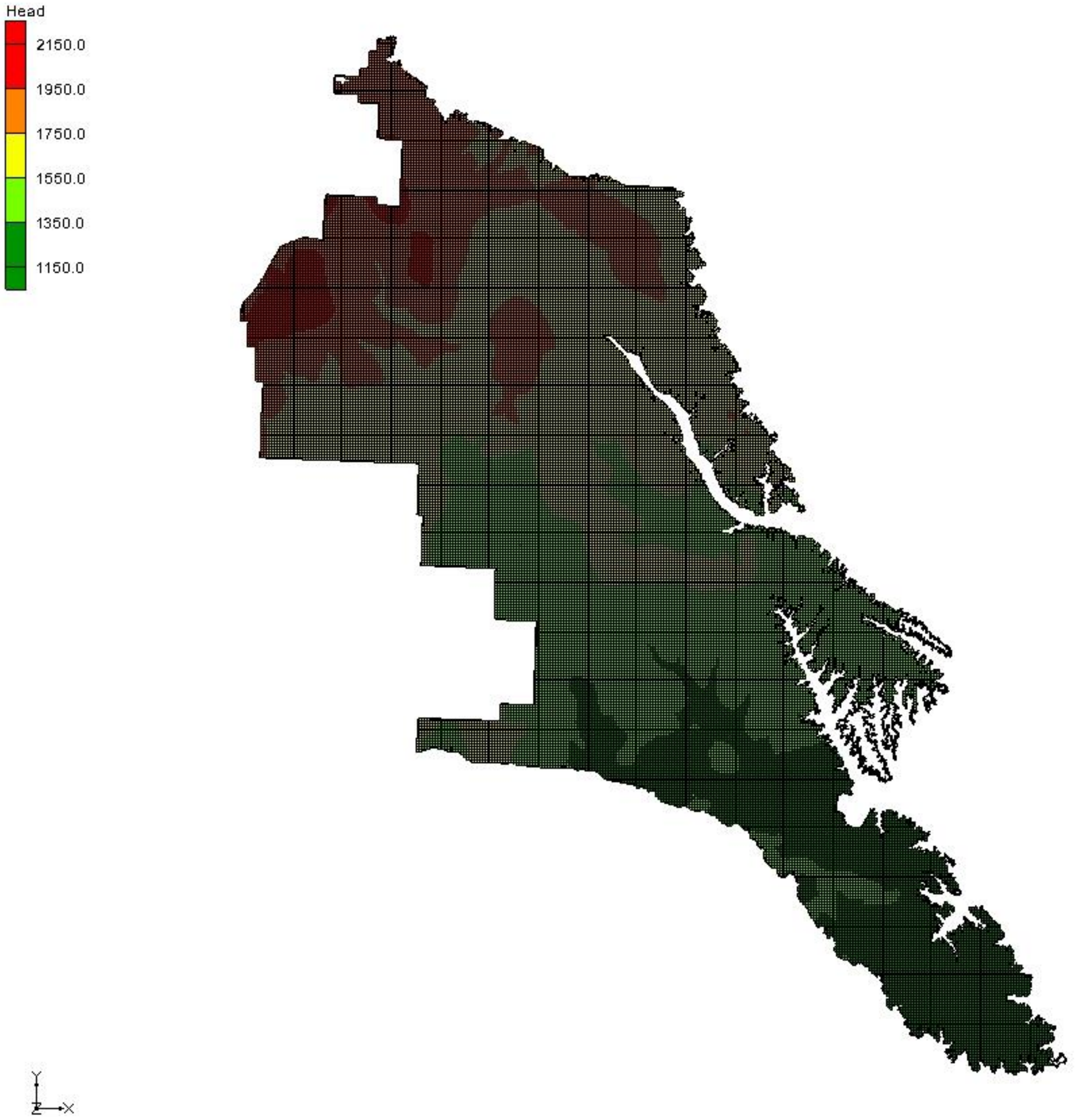


Figure 18. Potentiometric surface map of simulated head in feet in the steady-state groundwater-flow model generated in GMS and calibrated to the 1956 head observations. This figure was generated in GMS which used English units. Data in the figure can be converted from ft to m by dividing by 3.28. The simulated heads ranged from 351 to 656 m.

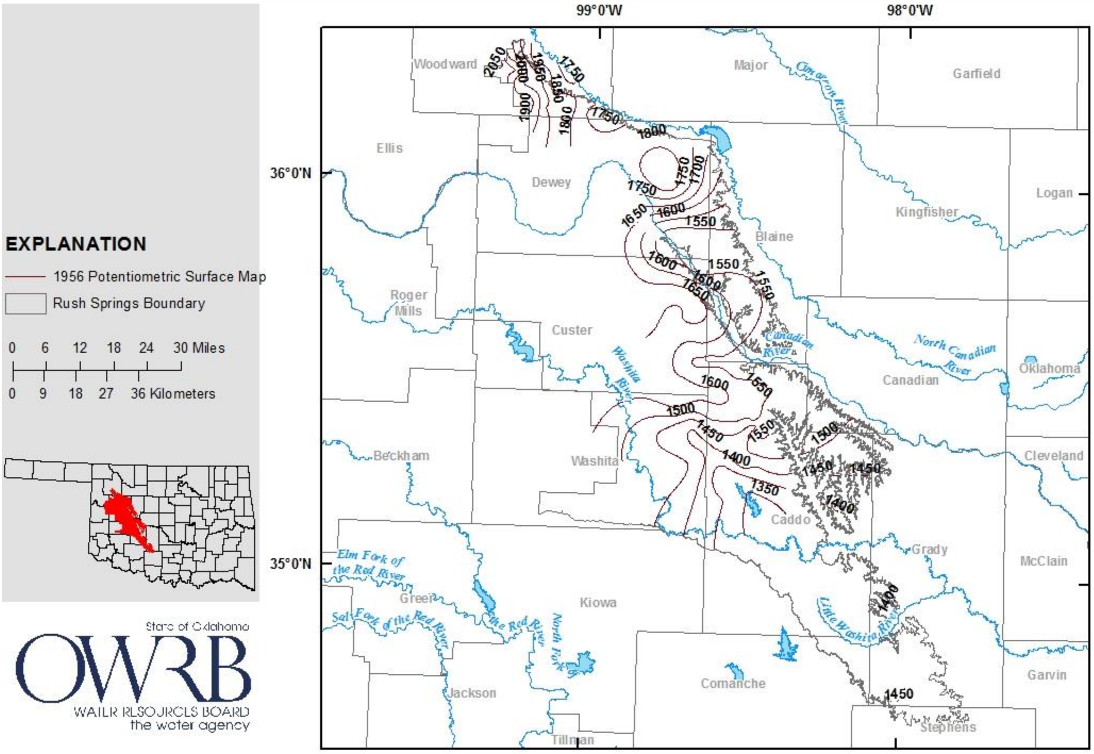


Figure 19. Potentiometric surface map generated directly from and only considering the 1956 head observations. This dataset is owned by the Oklahoma Water Resources Board who uses English units exclusively. These water levels elevations can be converted from ft to m by dividing by 3.28.

The model was also calibrated utilizing stream gage observations to ensure proper simulation of streams within the aquifer. This calibration process was focused on the Fort Cobb Reservoir area as this is the area of most concern for the governing agencies utilizing this model for future analysis (Table 2).

Table 2. Stream gage locations analyzed during calibration of steady-state model.

Steady-State Model Stream Gages	
Name	Number
Cobb near Eakly	USGS 07325800
Lake near Eakly	USGS 07325850

The gage package of MODFLOW only outputs baseflow while the stream gage is measuring observed streamflow at the gage. Baseflow for the Rush Springs was estimated through use of OWRB's Upper Washita Surface Water Allocation model (OWRB, 2015). This surface water allocation model provided daily baseflow numbers from which the statistics were compared to the simulated baseflow from the groundwater model (Table 3). Although the model simulates baseflow as higher than that of the average stream baseflow for 1956, the modeled baseflow is within the range for the year for Cobb Creek. The simulated baseflow for Lake Creek was also slightly higher than those determined by the surface water allocation model. Cobb Creek has the greatest influence on the watershed as it is the largest of the streams in this area. As such, calibration was optimized for this gage before the others.

Table 3. Calibration results for the Fort Cobb Reservoir area gages in the steady-state model.

Baseflow Calibration Results (m^3/s)		
	Cobb Creek	Lake Creek
Min	0.35	0.03
Max	0.61	0.19
Mean	0.40	0.05
Median	0.35	0.03
Simulated	0.46	0.26

The steady-state groundwater-flow model also outputs a volumetric flow budget (Table 4). This flow budget is a tabulation of groundwater flows into and out of the aquifer.

Table 4. Volumetric flow budget for the calibrated steady-state groundwater-flow model.

Steady-State Volumetric Flow Budget		
Sources/Sinks	Flow IN m^3/d	Flow OUT m^3/d
Drains	0.00E+00	-3.63E+05
Head Dep Bounds	8.68E+05	-2.04E+04
Recharge	1.13E+06	0.00E+00
Stream Leakage	1.45E+05	-1.76E+06
Total Source/Sink	2.14E+06	-2.14E+06
Summary	In - Out	% difference
Total	223.2	0.0003

This steady-state simulation was used to construct the transient simulation and thus, the management scenarios used by the Oklahoma Water Resources Board as well as the simulations generated for this research.

CHAPTER IV

TRANSIENT SIMULATION

A transient simulation was generated from the steady-state simulation in the previous chapter. The transient model covers the period from the steady-state year of 1956 through 2013. The first stress period for this simulation covers the entire year of 1956 as the steady-state year. The simulation has monthly stress periods after to analyze recharge rates on a monthly scale. Since the stress periods cover a relatively short period of time in the model simulation, each stress period only contained one time step. Hydraulic conductivity and vertical anisotropy were input from the steady-state simulation and were not adjusted in the calibration of the transient model. All other inputs were also from the steady-state simulation.

Two packages were used in this simulation that were not included in the steady-state simulation. Water use was considered in the transient model using the well (WEL) package as discussed in the Groundwater Withdrawal section of the Model Construction chapter. There were over 3000 groundwater permits considered in this simulation at approximately 500 model locations. Fort Cobb Reservoir was also included in this simulation by use of the general head boundary (GHB) package. Originally, the lake package was intended for use in modeling the reservoir. However, complications arose during the construction of the transient model. Use of the lake package caused an error in the GMS software changing the row and columns of the cell-to-cell flow (CCF) output file. The corruption of this file made the flow data and flow budget for the model unreadable. This error was removed when the lake was simulated utilizing the GHB package. This is the package used for modeling lakes before the development of the lake package or in models where the lakes are of lesser importance (Anderson and Woessner, 1992). Fort Cobb was constructed in 1958 so lake data begins at the start of 1959. Assumptions made for the use of these packages were discussed in the Model Limitations, Simplifications, and Assumptions section of the Model Construction chapter.

Model Adjustments

A sensitivity analysis was performed on the completed transient model in order to optimize calibration. This analysis determined the sensitivity of the simulation to changes in calibration parameters. The sensitivity of simulated heads to changes in these parameters is important because the uncertainty associated with these parameters can potentially have a drastic effect on simulation results. Nine years of observations throughout the transient time period were used for this analysis. The parameters changed were recharge, specific yield, and specific storage as these are the main parameters utilized for calibration of the transient model. The model was found to be the most sensitive to changes in specific yield followed by recharge and specific storage (Figure 20). Changes in specific storage appeared to have little effect on the model's simulated head values.

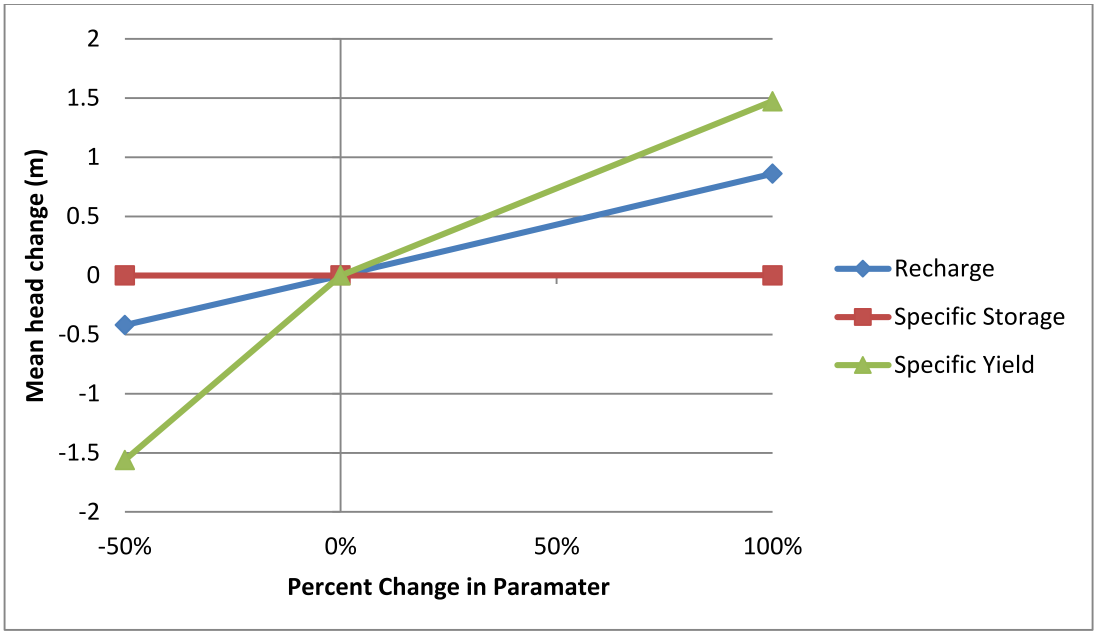


Figure 10. Sensitivity analysis results for recharge, specific storage, and specific yield parameters for the transient simulation. The model was determined to be more sensitive to specific yield, recharge, and then specific storage, respectively.

Utilizing this information, as well as observing changes in head observations and stream gages, the calibration process was completed. Recharge was increased for the transient time steps to range from 0 to 0.9 m/yr during the entire time period with an average recharge rate of 0.04 m/yr. Specific yield was decreased by a multiplier of 0.25 which resulted in a range of 0.03 to 0.08 with a mean value of 0.03 for the Rush Springs (layer two). Specific yield for the Cloud Chief in layer one was also decreased to a value of 0.06. These values fit within the range of published values for specific yield for unconsolidated sandstone (Heath, 1983).

These two changes resulted in the best results for simulated groundwater levels as well as baseflow calibration. However, in order to achieve model convergence and thus, a working model, specific storage needed to be adjusted as well. Specific storage was increased by an order of magnitude to range from $2x10^{-4}$ to 0.07 m^{-1} with a mean specific storage value of $5x10^{-4}$ m^{-1}.

Simulation Results

All available head observations for the transient time period were utilized for calibration of the simulation. These observations include mass and synoptic measurements taken at over 400 well locations over the 57 year time period for the simulation.

The last month of nine particular years were chosen for head observation regression analysis (Appendix A). The trends seen in this analysis were very similar between each year (Figure 21 – 23). Trend lines were generated for each of these regression plots with the smallest R^2 value for all the plots being 0.93. Residuals for these plots did fit within acceptable ranges from the observed head observations although not as well as the steady-state model. The average residuals for these analyzed years ranged from -7.9 to -13 m. These negative average residual values indicated that the simulated heads tended to be lower than the observed head values. This analysis suggests that the model was adequately calibrated to these years.

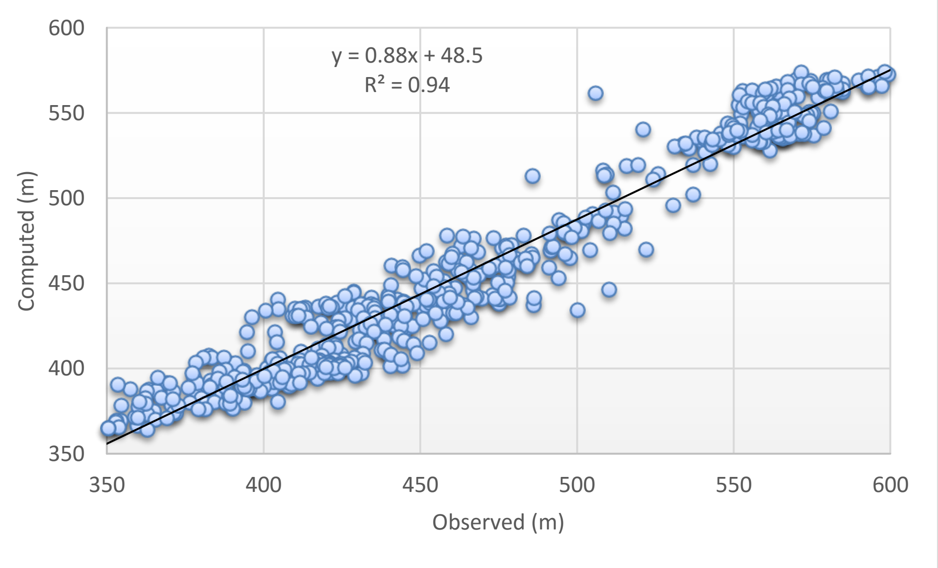


Figure 11. Observed versus computed head observations and corresponding equations at the end of the first time step (1/1/1957).

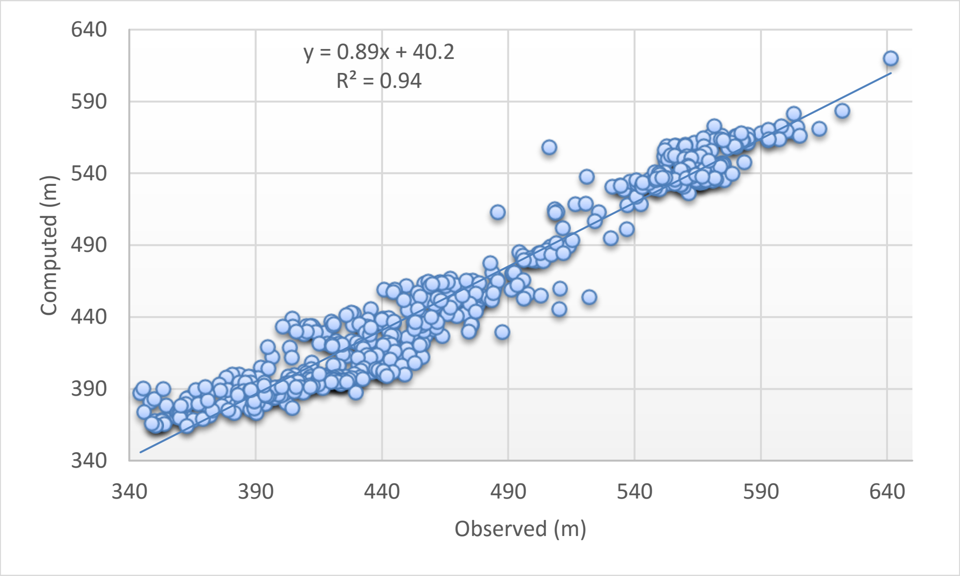


Figure 22. Observed versus computed head observations and their corresponding equations for the time step 1/1/1985 in the transient simulation.

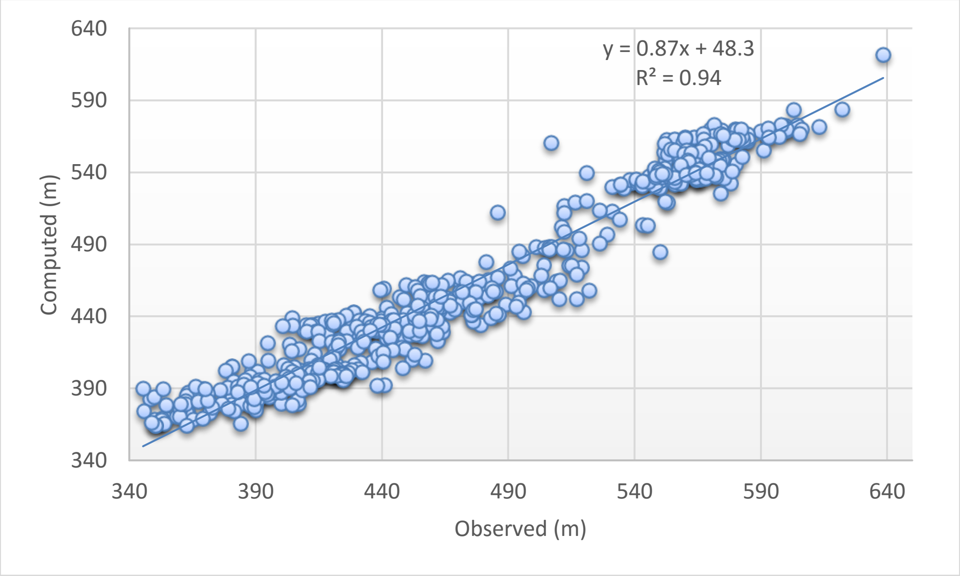


Figure 23. Observed versus computed head observations and corresponding equations at the end of the transient simulation on 1/1/2014.

Baseflow was also an important factor in the transient model calibration. In particular, baseflow in Cobb Creek at the USGS Eakly gage was used to optimize baseflow calibration as this specific site will be under further consideration in future studies. Estimated baseflow was determined using the Upper Washita Surface Water Allocation Model (OWRB, 2015) and compared to the simulated baseflow by the model for the Cobb Creek gage (Figure 24) as well as the Lake Creek at Eakly USGS gage (Figure 25).

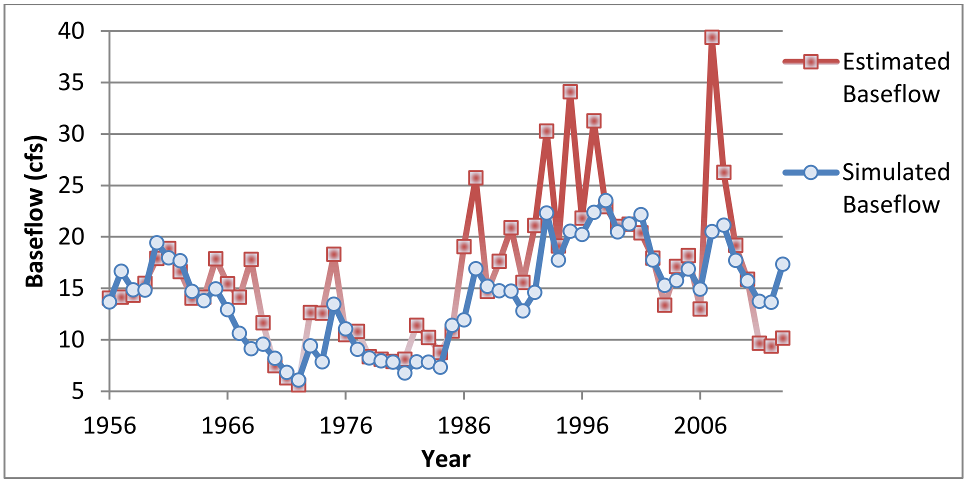


Figure 24. Comparison of estimated baseflow from the Upper Washita Surface Water Allocation Model to simulated baseflow at USGS gage 07325800 on Cobb Creek near Eakly, OK for the transient simulation time period, 1956 – 2013.

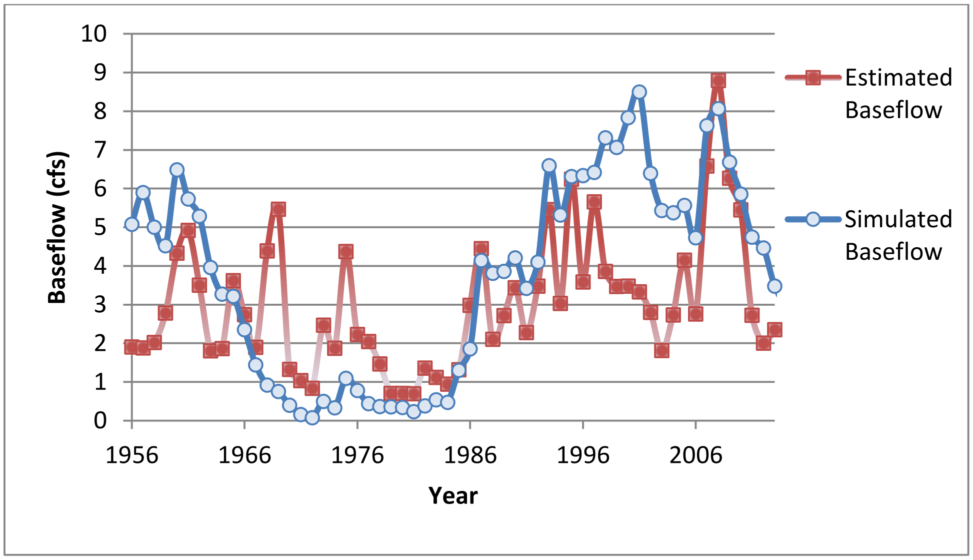


Figure 25. Comparison of estimated baseflow from the Upper Washita Surface Allocation Model and simulated baseflow in the transient model at USGS gage 07325850 on Lake Creek near Eakly, OK.

The model flow budget shows the inflows and outflows of the model for each simulated time step (Appendix B). The greatest percent discrepancy for the entire transient model run was 0.26 %, while the mean discrepancy was 0.03 %. Inflow to the transient model was dominated by recharge, while movement of water into the aquifer from general head boundaries as well as stream recharge to the aquifer were smaller amounts of inflow. The largest outflow to the model was baseflow to streams as well as pumping wells and storage outflow. More groundwater was removed from the aquifer than what was input as indicated by the negative difference values for the majority of the time step flow budgets.

Since the GHB package was used for both the lake and the western boundary of the model, flow was not separated between the two in the flow budget. However, using the equation utilized in the GHB package, as described in the Boundary Conditions section of the Model Construction chapter, an estimation was made on the impact the Fort Cobb Reservoir had on the underlying aquifer. It was estimated that recharge from the lake to the aquifer accounts for approximately 15% of the total flow into the aquifer from the GHB package. This varies slightly temporally throughout the transient simulation as well as spatially within the lake. This suggests that although the lake is a recharge component to the aquifer, it does not have as much of an impact as other factors in the model.

Model Evaluation

As previously stated, only nine years of the available head observations were analyzed during the calibration process of this model. This allowed for the other head observations to be used for evaluation of the model’s performance. Four years were chosen to analyze this performance including 1980, 1990, 2000, and 2010. Regression analysis was completed on different time steps throughout each of these years (Appendix C). Two of these plots can be seen in Figures 26 and 27.

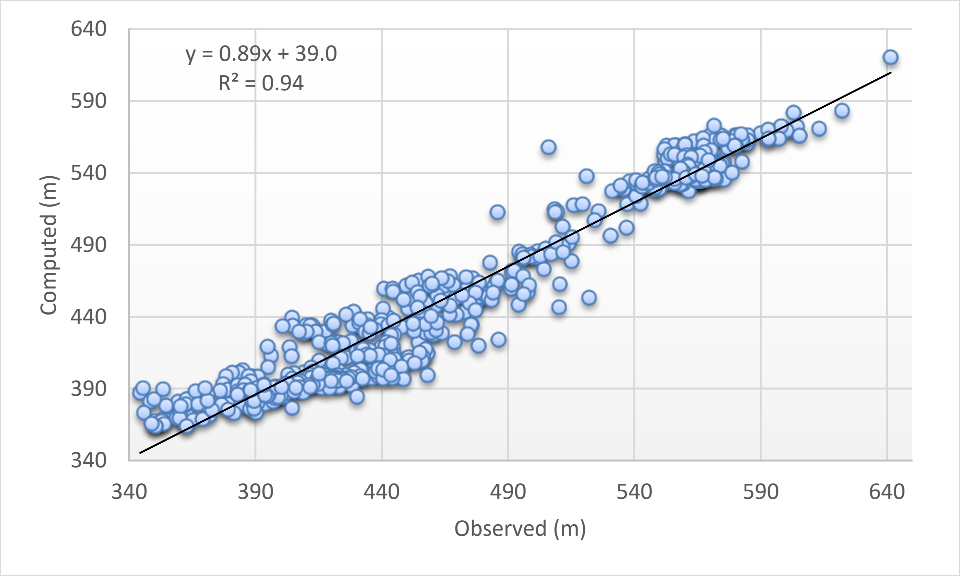


Figure 26. Observed versus computed head observations and corresponding equations for the time step 3/1/1980 of the transient simulation.

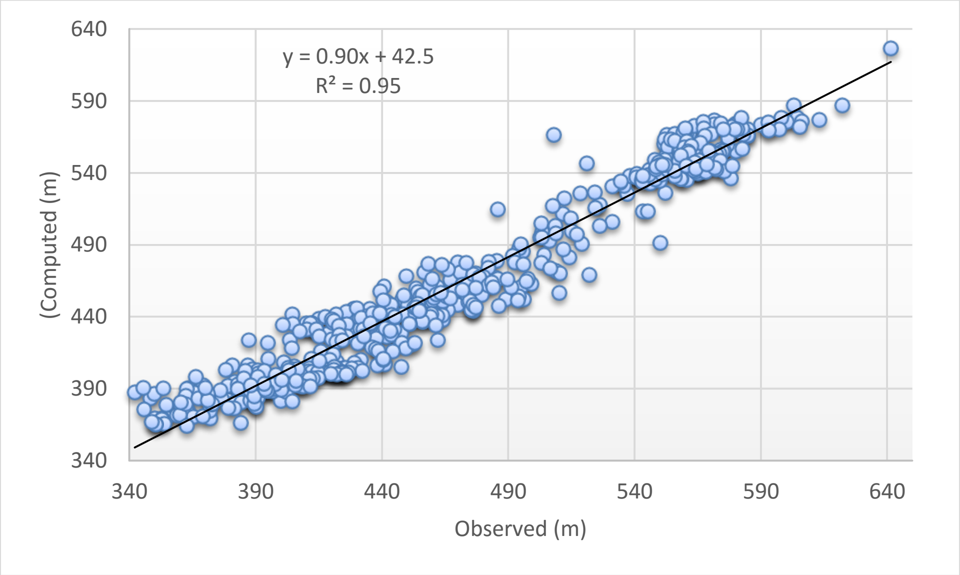


Figure 27. Observed versus computed head observations with the corresponding equations for time step 9/1/2000 of the transient simulation.

Parameters were not adjusted to generate a better fit to these head observations. As such, these plots demonstrate the model's ability to predict water level elevations within the aquifer. The regression plot slope ranged from 0.87 to 0.90 with R^2 values of 0.94 and 0.95. The linear positive correlation indicates that the model predicts 94% of groundwater levels over time in the aquifer. This allowed for the model to be used to simulate the aquifer’s response to future scenarios like the scenarios described in the next chapter as well as those needed for policy determinations.

CHAPTER V

BASEFLOW ANALYSIS SIMULATIONS

As previously discussed, groundwater – surface water interactions are not considered when issuing groundwater permits in the state of Oklahoma. Other states, however, do recognize this connection between streams and aquifers and it is becoming increasingly important to understand these relationships to manage water resources.

Three different groundwater use simulations were conducted to analyze baseflow change affected by varying degrees of groundwater usage. For all of these scenarios, the unadjusted mean annual recharge was utilized as recharge inputs for the simulations with a mean value of 0.03 m/yr as discussed in the Model Construction Chapter. The simulation period of all three scenarios was the same, running through years 2013 to 2023.

The first scenario investigated the effects of prolonged groundwater usage under current conditions. The year 2013 had the largest groundwater use for the period of record. These conditions were continued for a ten year groundwater use scenario. The second simulation analyzed groundwater use throughout the aquifer as two acre-feet per acre per year or 6093 m^3/ha per year. This usage rate is the permitted amount assigned to aquifers in Oklahoma where MAY determinations have not been made. The third and final scenario simulated unlimited groundwater use for irrigation throughout the aquifer. For all these simulations, four main gage sites were used to analyze baseflow changes (Table 5). Each of these scenarios are specifically described in their own section with the results for each presented. Results from each scenario are discussed and compared to the other simulation results in the Baseflow Analysis section of this chapter.

Table 5: Stream gage locations considered during baseflow analysis simulations

Baseflow Simulation Stream Gages	
Name	Number
Cobb near Eakly	USGS 07325800
Lake near Eakly	USGS 07325850
Washita near Clinton	USGS 07325000
Little Washita near Cement	USGS 07327447

Current Conditions Simulation

The year 2013 had the highest groundwater use rates during the period of record with approximately 110,000 acre-feet or 1.4×10^8 m^3 of water being used from the aquifer that year. As such, the first scenario simulated how this groundwater use rate will affect stream baseflow if continued for a ten year period. There were 711 active well locations in 2013 that were continue for the whole simulation pumping groundwater at the reported water use rate for 2013 to the OWRB for each well. This annual water use was allocated to the monthly time steps using the monthly demand use pattern for each permitted use as described in the Groundwater Use section of the Model Construction chapter.

Stream gage data was retrieved from the model using the gage package at the previously mentioned locations. Baseflow graphs for the entire period of record were generated as well as plots specifically depicting baseflow change caused during the simulated time period from 2013 to 2023 (Appendix D). An example of which can be seen in Figures 28 and 29 for the Cobb Creek and Lake Creek gage sites for the simulated time period.

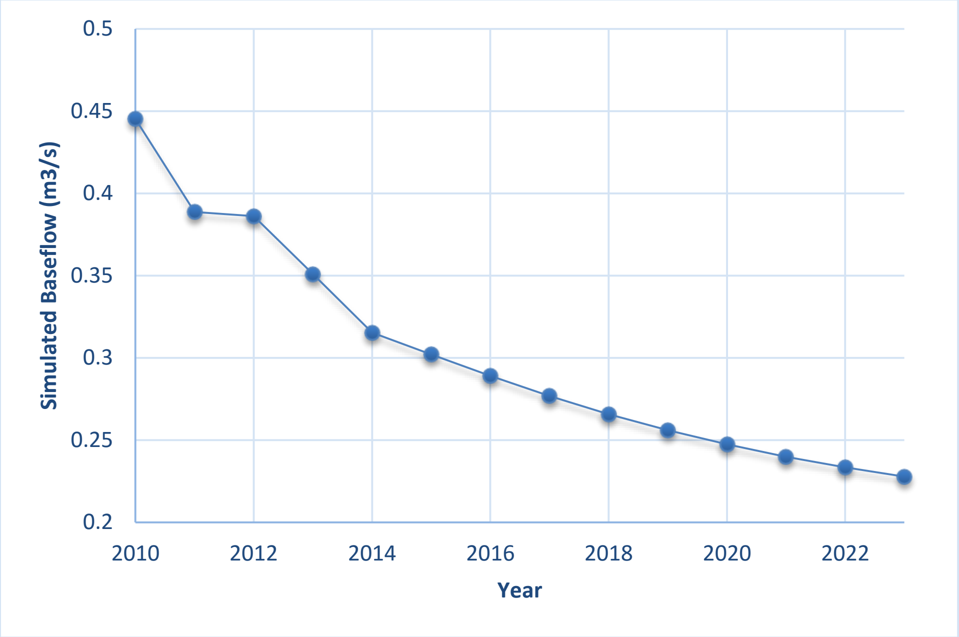


Figure 28. Simulated average annual baseflow for the USGS gage 07325800 on Cobb Creek near Eakly, OK for the simulation period, 2013 – 2023 for the first groundwater use scenario which extended 2013 groundwater use through the simulation period.

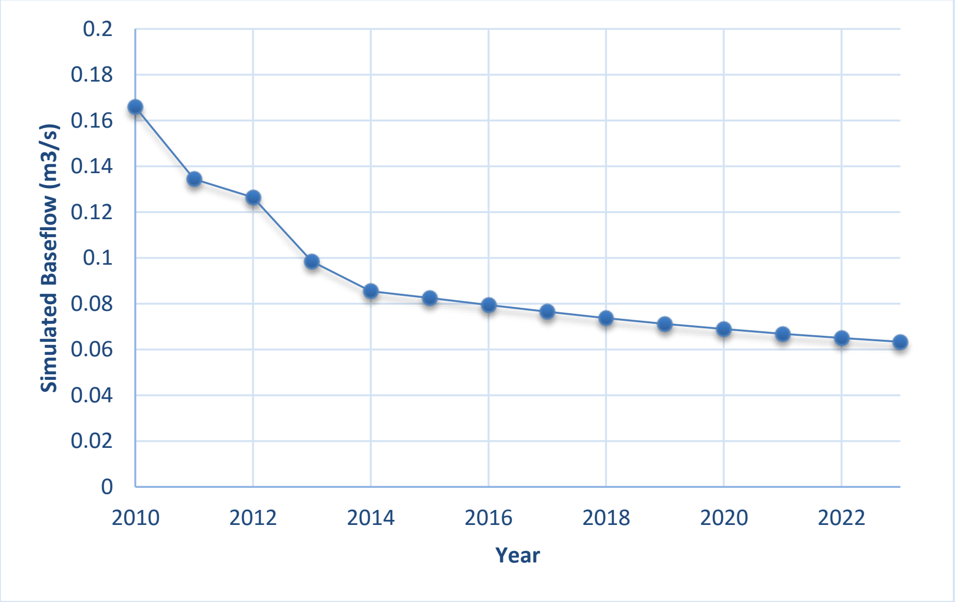


Figure 29. Simulated average annual baseflow for the USGS gage 07325850 on Lake Creek near Eakly, OK for the simulation period, 2013 – 2023 for the first groundwater use scenario which extended 2013 groundwater use through the simulation period.

MAY Simulation

This simulation was not an official MAY Simulation as defined by the OWRB and state of Oklahoma (Okla. Stat. 82:1020.11B). However, this simulation was designed to model the basic concepts of this management policy on this groundwater system. One well was placed in every cell in which a well was located during the transient model simulation for a total of 1764 wells. These wells were simulated to be pumping two acre-feet per acre per year or 6093 m^3/ha for the area of the cell ($2.5x10^5$ m^2) for a total pumping rate of $1.5x10^5$ m^3/yr. Each well was assumed to be an irrigation well and was allocated using the monthly demand pattern for irrigation as previously discussed. This is consistent with previous studies simulating groundwater use (Mittelstet et al., 2011) and with the findings that irrigation wells account for the bulk of stream depletion (Zume and Tarhule, 2007). The resulting baseflow graphs from this simulation for Cobb Creek and Lake Creek can be seen in Figures 30 and 31 while the complete graphs can be found in Appendix D along with the rest of the baseflow analysis graphs.

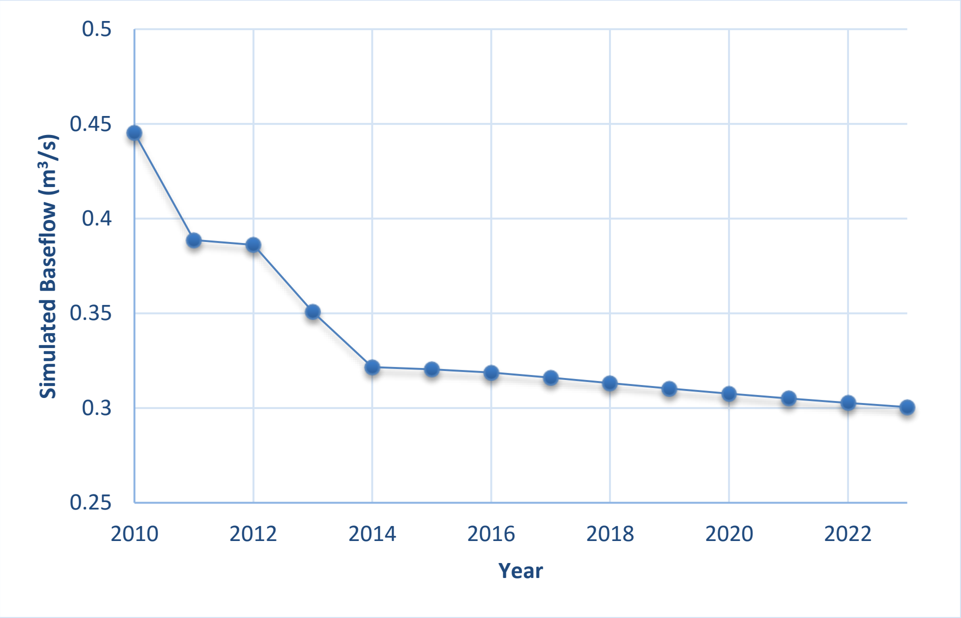


Figure 30. Simulated average annual baseflow for the USGS gage 07325800 on Cobb Creek near Eakly, OK for the simulation period, 2013 – 2023, for the second groundwater use scenario which simulated each well pumping at a rate of 6093 m^3/ha per year.

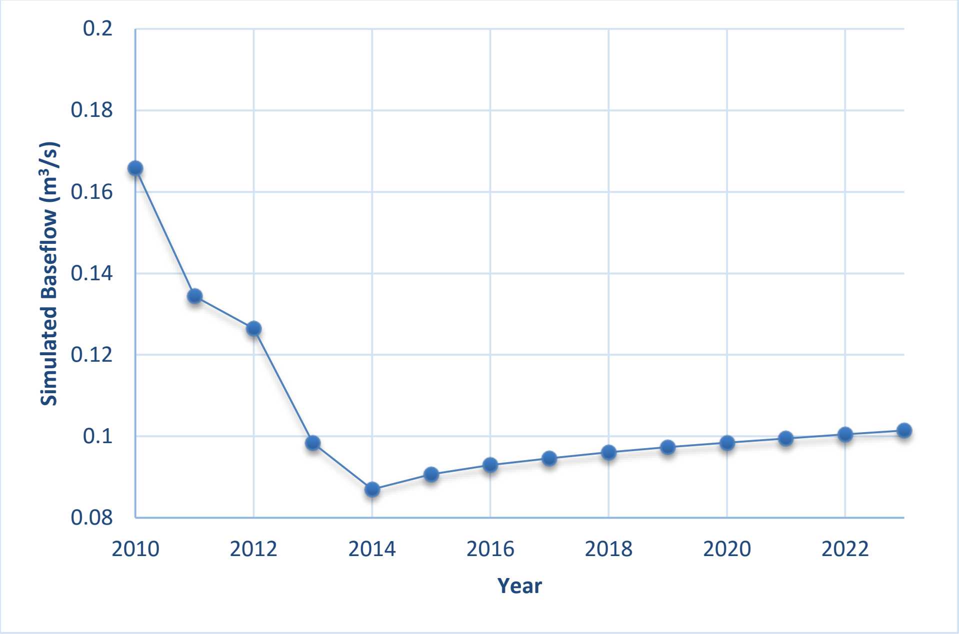


Figure 31. Simulated average annual baseflow for the USGS gage 07325850 on Lake Creek near Eakly, OK for the simulation period, 2013 – 2023, for the second groundwater use scenario which simulated each well pumping at a rate of 6093 m^3/ha per year.

Maximum Irrigation Use Simulation

The third scenario was generated to simulate an unlimited amount of irrigation use of groundwater wells in the aquifer. The three main crops for this areas are wheat, cotton, and peanuts (C. Neel, Oklahoma Water Resources Board, October 2015, personal communication). The crop with the largest irrigation demand is cotton with an average total seasonal demand at 1000 mm (FAO, 2015). As in the previous simulation, all wells were assumed to be irrigation wells and this rate was distributed throughout the year using the monthly demand pattern for irrigation. One well was placed in every cell where a well was located during the transient model simulation for a total of 1764 wells. This water demand is approximately an annual rate of 5.5 mm/day which was applied to the entire cell area for a total pumping rate of 2.5×10^5 m^3/yr for each well. Simulated baseflow for the Cobb Creek and Lake Creek gages can be seen in Figures 32 and 33 while the complete baseflow analysis figures are located in Appendix D.

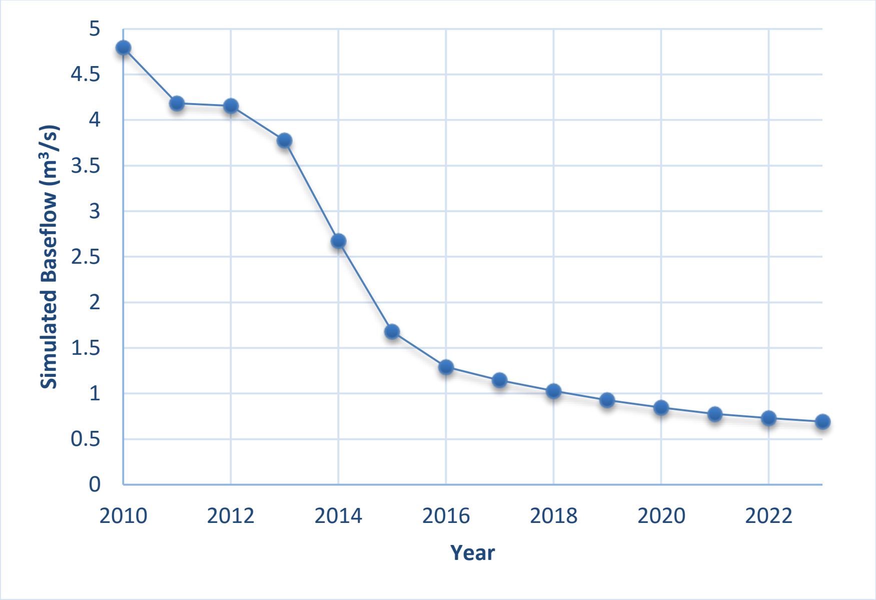


Figure 32. Simulated average annual baseflow for the USGS gage 07325800 on Cobb Creek near Eakly, OK for the simulation period, 2013 – 2023for the third groundwater use scenario which simulated each well pumping at a rate of approximately 5.5 mm/day for irrigation use.

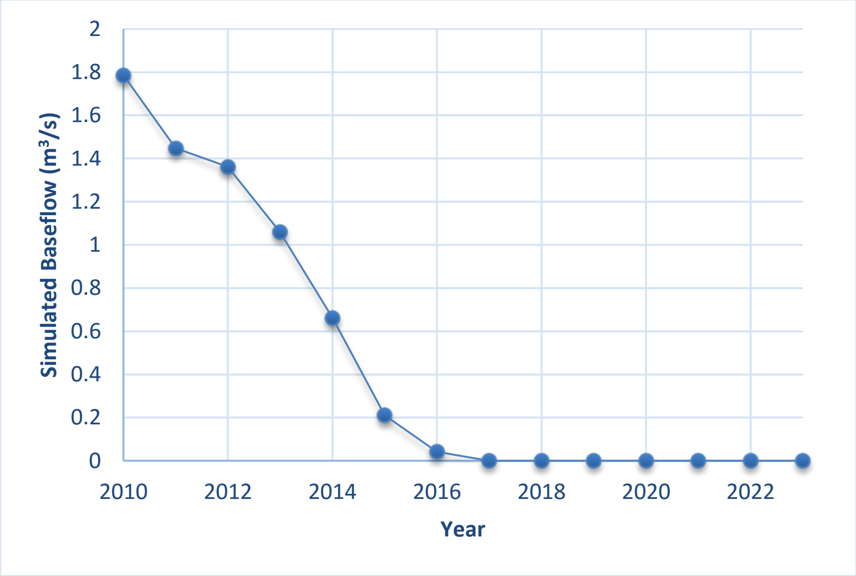


Figure 33. Simulated average annual baseflow for the USGS gage 07325850 on Lake Creek near Eakly, OK for the simulation period, 2013 – 2023 for the third groundwater use scenario which simulated each well pumping at a rate of approximately 5.5 mm/day for irrigation use.

Baseflow Analysis

Stream leakage out of the aquifer was larger than flow into the aquifer for all three of the groundwater use simulations. This indicates that overall streams in this region are gaining streams meaning that the aquifer provides water to the streams. This is consistent with personal observations in the area where water is still running in streams during hot and dry summer months with little precipitation. Stream leakage from the streams to groundwater stays relatively the same throughout the simulation period of 2013 to 2023 at approximately 1.6 m^3/s for all three scenarios. Leakage from the groundwater system to the streams did change over time from scenario to scenario (Figure 34). For both the MAY and the extended current conditions simulations, leakage to the streams initially increases for the first few years. This can be attributed to the increase in recharge as the study area was in a drought in 2013 with significantly lower recharge during that year. The maximum irrigation scenario, however, has decreasing stream leakage for the whole simulation period. The total amount of usage for this scenario is $4.4x10^8$ m^3/day, which is similar to the total use in the current conditions simulation at $1.4x10^8$ m^3/yr. However, this amount is being removed from the system at over twice the amount of wells from the 2013 groundwater use. This increases the overall effect of this groundwater use by increasing the proximity of the wells to the streams throughout the aquifer.

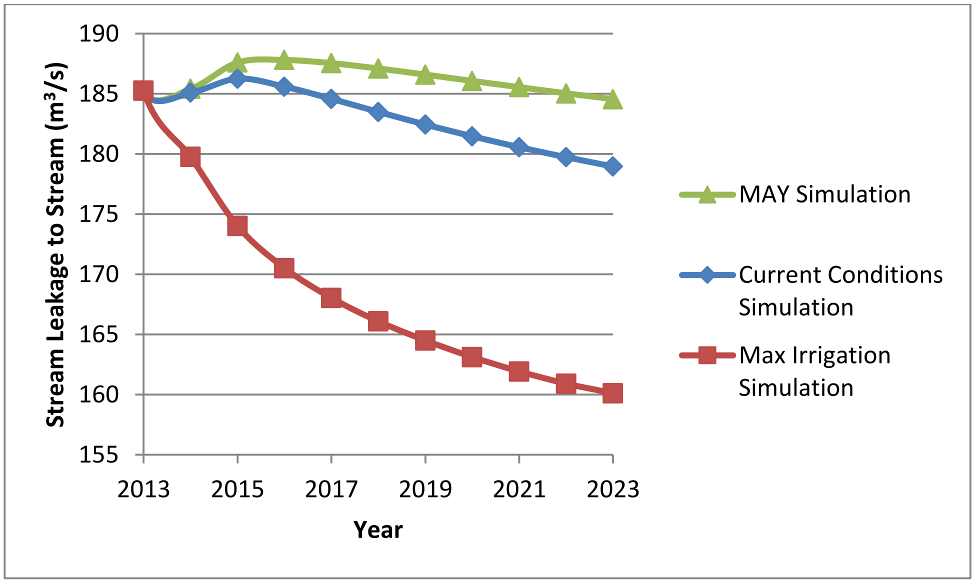


Figure 34. Total stream leakage from groundwater system to all streams within the model for each of the groundwater use simulations for the simulation period, 2013 – 2023.

Changes in baseflow at each gage location were also compared between the different groundwater use scenarios for the simulation period of 2013 to 2023 (Table 6). These results support the findings in the stream leakage analysis that the maximum irrigation simulation has the greatest effect on stream baseflow.

Table 6. Changes in baseflow for each groundwater use simulation from 2013 to 2023.

Change in Baseflow from 2013 to 2023 (m^3/s)			
Gage Location	Current Conditions	MAY Simulation	Max Irrigation Simulation
Cobb near Eakly	-0.12	-0.05	-3.09
Lake near Eakly	-0.04	0.003	-3.47
Washita near Clinton	-0.06	-0.05	-2.40
Little Washita near Cement	0.05	0.04	0.44

It is interesting to note that the MAY scenario generates the least amount of change. This can be attributed to the fact that although there are the same amount of wells as in the maximum irrigation simulation, the total groundwater use for this scenario is much less than the other two at approximately 2.2×10^7 m^3/yr. The current permitted amount in this basin is two acre-feet per acre per year or 6093 m^3/ha per year. However, most of the current permits are for much larger areas than the 2.5×10^5 m^2 of a gridded cell. As such, although there are more wells simulated in the MAY scenario the overall area of use is lower in this simulation.

Another point of discussion is the fact that the stream baseflow to the Little Washita River increases slightly in all three of the groundwater use scenarios. This supports the findings of previous model studies in which groundwater flows to the southeastern portion of the aquifer where the Little Washita is located.

Both Cobb and Lake Creeks provide water to Fort Cobb Reservoir which serves as a public water supply source for several of the surrounding communities. Decreases in baseflow in these two streams can have a dramatic impact on the Fort Cobb water supply. The total decrease in inflow from these streams to Fort Cobb for the simulation period was determined in

Table 7. Withdrawal from Fort Cobb began in 1970 and data was available from 1970 to 2010. The mean yearly withdrawal for the reservoir was 4.0x10^7 m^3. Each of the groundwater uses simulated show a significant decrease in discharge which would affect the availability of water for public use. The current conditions simulation and the MAY simulation also reduced inflow to the reservoir by 5.0x10^6 m^3 and 1.5x10^7 m^3, respectively. The maximum irrigation simulation reduced inflow by more than the whole mean yearly withdrawal value for the reservoir. This is due to the fact that baseflow in Lake Creek decreased to zero during this simulation. This does not indicate that streamflow will be completed depleted under these conditions. However, it does suggest that Lake Creek will switch from a gaining stream to a losing stream. As streamflow is lost to the aquifer from this creek, the decrease in inflow to Fort Cobb could be even greater than indicated under these conditions.

Table 7. Total decrease in inflow to Fort Cobb Reservoir for each groundwater use scenario for the simulation period of 2013 to 2023.

Units	Current Conditions	MAY Simulation	Maximum Irrigation
m^3/s	-0.16	-0.05	-6.56
m^3/d	-13677	-4090	-566766
m^3/yr	-5.0E+06	-1.5E+07	-2.07E+08

Recharge to the groundwater system can also have an effect on baseflow levels. To test this relationship, the current conditions groundwater use scenario was used with varying recharge levels. First, recharge was decreased to the 2013 drought levels with a mean recharge rate of 0.005 m/yr. The resulting baseflow graphs from this simulation for the same chosen stream gage locations as the groundwater use scenarios can be seen in Appendix E. The results of the Cobb Creek and Lake Creek gage sites are given as examples in Figures 35 and 36. Recharge was also increased to further analyze its effect on baseflow levels. For this simulation, the current conditions groundwater use scenario was again utilized but the mean annual recharge was increased to an average of 0.05 m/yr over the model area for the simulation period of 2013 to 2023. Baseflow from this simulation can be seen with the rest of the recharge baseflow analysis scenario results in Appendix E with examples in Figures 37 and 38.

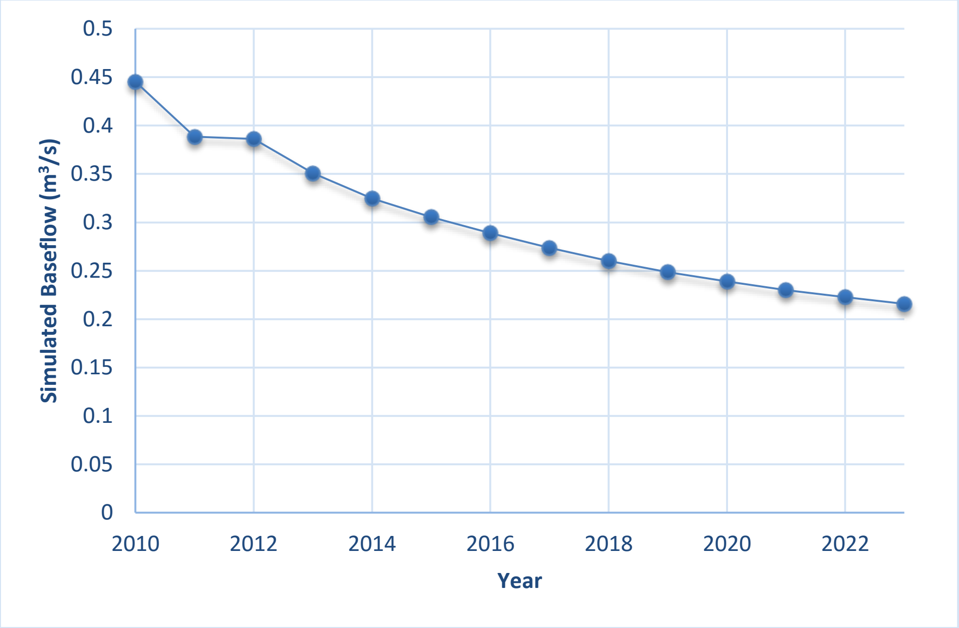


Figure 35. Simulated average annual baseflow for the USGS gage 07325800 on Cobb Creek near Eakly, OK for the simulation period, 2013 – 2023, for the scenario which extended both the current groundwater use and the recharge rate for the simulation period.

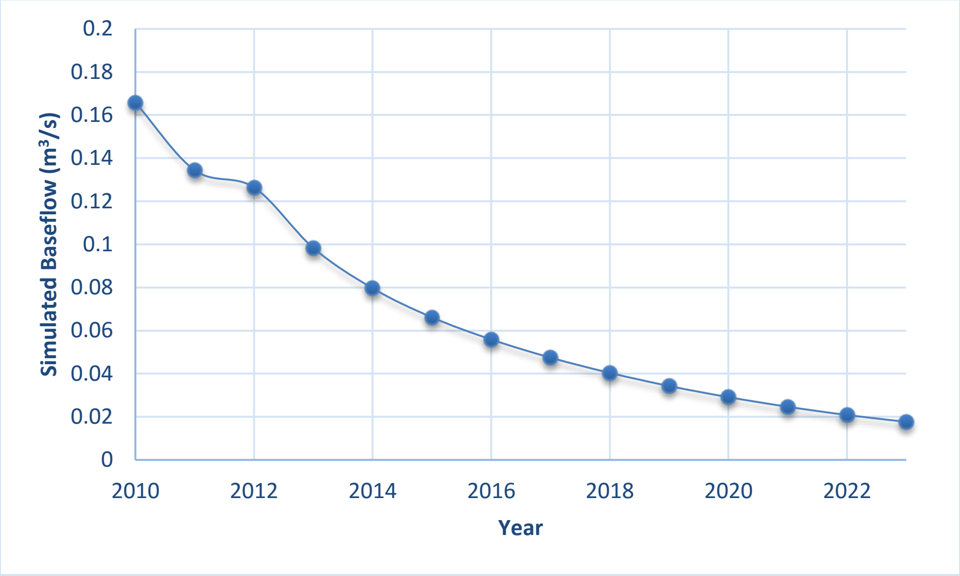


Figure 36. Simulated average annual baseflow for the USGS gage 07325850 on Lake Creek near Eakly, OK for the simulation period, 2013 – 2023, for the scenario which extended both the current groundwater use and the recharge rate for the simulation period.

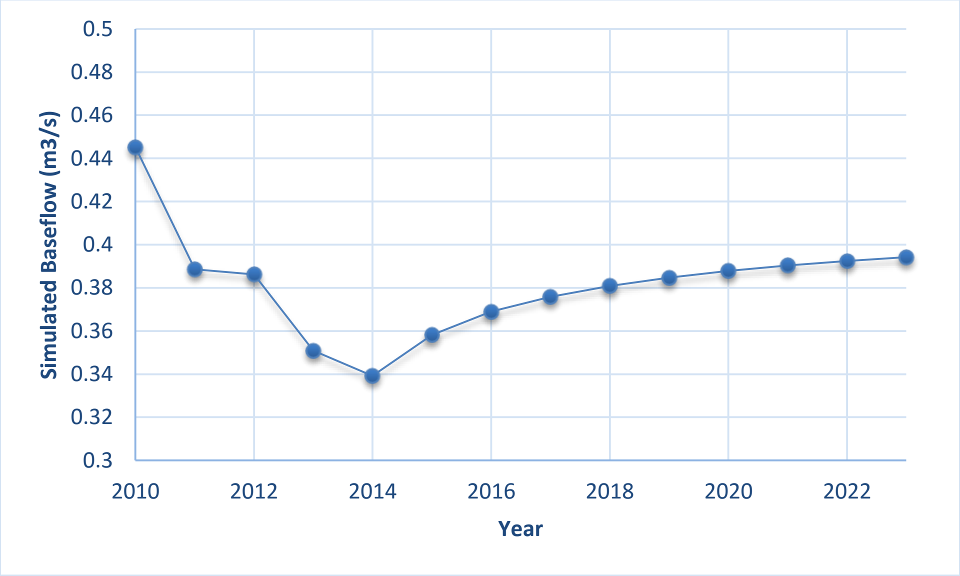


Figure 37. Simulated average annual baseflow for the USGS gage 07325800 on Cobb Creek near Eakly, OK for the simulation period, 2013 – 2023, for the scenario which extended the 2013 groundwater use and increased the recharge rate to an average of 0.05 m/yr for the model area.

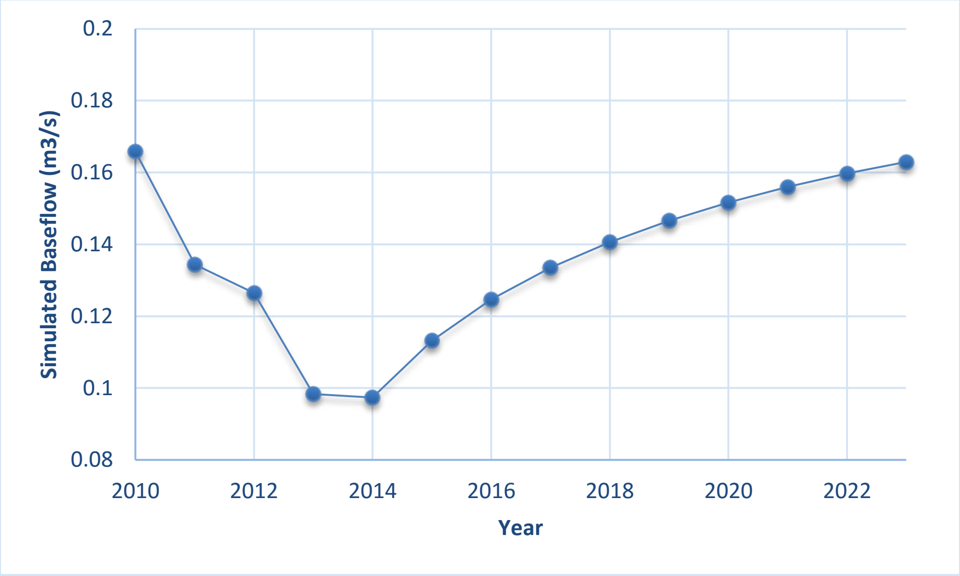


Figure 38. Simulated average annual baseflow for the USGS gage 07325850 on Lake Creek near Eakly, OK for the simulation period, 2013 – 2023, for the scenario which extended the 2013 groundwater use and increased the recharge rate to an average of 0.05 m/yr for the model area.

Like the groundwater use scenarios, stream leakage out of the aquifer was larger than flow into the aquifer for all of these recharge scenarios. Unlike the groundwater use scenarios, however, stream leakage from the streams to the aquifer changed during the simulation period of 2013 to 2023 (Figure 39). This indicates that recharge has a greater effect on losing streams within this groundwater system than groundwater use. The most impact to stream leakage to the groundwater system was in decreasing recharge. Leakage from the groundwater system to the streams also changed over time from scenario to scenario (Figure 40). This change, however, was more equally distributed between increasing and decreasing recharge.

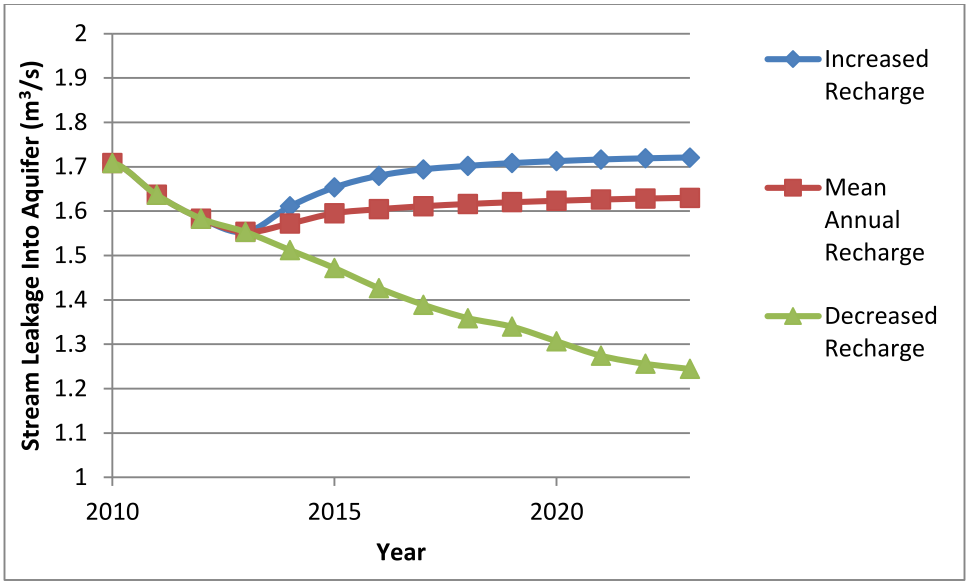


Figure 39. Total stream leakage from all streams within the model to the groundwater system for each of the recharge simulations using the 2013 groundwater use data for the simulation period, 2013 – 2023.

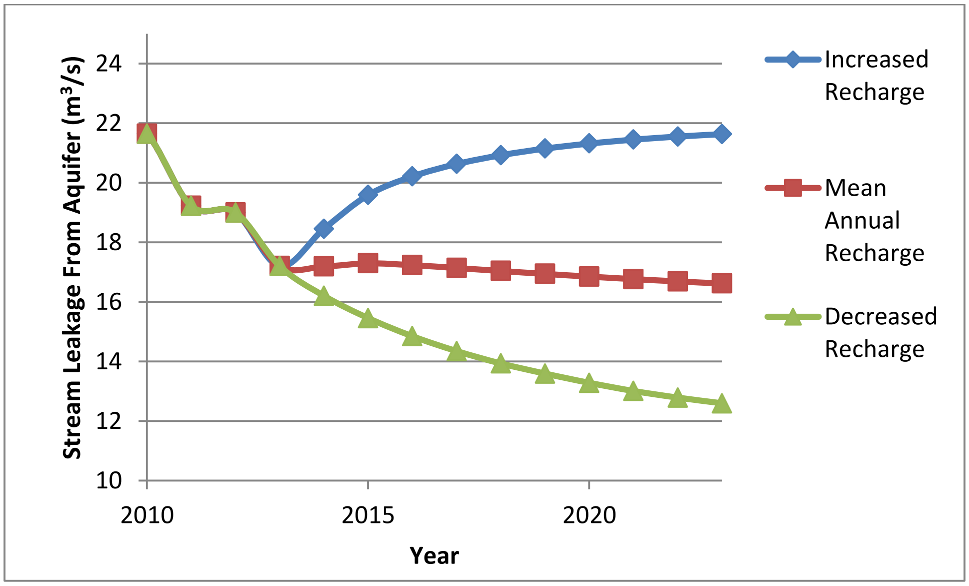


Figure 40. Total stream leakage from the groundwater system to all streams within the model area for each of the recharge simulations using the 2013 groundwater use data for the simulation period, 2013-2023.

CHAPTER VI

CONCLUSIONS AND FUTURE WORK

The use of groundwater models has become the choice method for the analysis of complex groundwater systems for a number of reasons including their simplicity as well as acceptance by U.S. courts as valid evidence for management determinations. Previous models have failed in the development of transient simulations from which these management scenarios and determination can be made. It was the main goal of this research to provide the OWRB with models from which MAY and EPS determinations can be set. The Rush Springs digital groundwater-flow model was generated with hopes of achieving this goal. This model solved the problem of flooding seen in previous models by removing water from the southern and eastern portions of the aquifer through streams as mentioned in the drains section of the model construction. This was the only problem found with the previous models as there was no documentation on the issues with the models. However, after solving this problem as well as others specific to this model such as the defunct lake package, a working transient simulation was able to be generated from the steady-state simulation of this model that accurately imitated field water level observations during a 57 year period of time. This had not previously been completed by any modeler for this area and provides the ability to create scenarios in which aquifer conditions can be modeled under different circumstances and stresses which fulfilled the first objective of this research.

Simulations were also completed to analyze the effects of different groundwater use scenarios on stream baseflow in this aquifer. Groundwater use has been seen to reduce baseflow in streams within close proximity of groundwater wells. Each state manages its water resources differently especially in regards to groundwater-surface water interactions. Although the state of Oklahoma only recognizes groundwater and surface water interactions within sole-source aquifers, it is clear that this interaction is an important portion of the water budget for the Rush Springs aquifer as well. Groundwater discharge to streams was one of the largest portions of the flow budget for all simulations of this model. This is also supported by results of OWRB's Upper Washita Surface Allocation Model which determined that the majority of flow in Cobb, Lake, and Willow Creeks can be attributed to baseflow from the aquifer (OWRB, 2015).

Increased groundwater use depletes stream levels by decreasing stream leakage out of the aquifer. Results from the different simulated groundwater use scenarios show that total baseflow to the streams can be reduced anywhere from $2.0x10^7$ m^3/yr to almost $8.0x10^8$ m^3/yr. Water withdrawal from Fort Cobb Reservoir in 2010 for public water supply was approximately $5.0x10^7$ m^3 making this possible reduction of baseflow an important factor in predicting water availability for this area.

Although these results seem quite troubling and large, especially from the maximum irrigation simulation, they represent worse-case scenarios. Future conditions should not be expected to reach these levels simply from these simulations as even the "current conditions" scenario is modeling groundwater use during a severe drought year. These results simply demonstrate that there is a relationship present between groundwater and surface water within this aquifer and the impacts the two have on each other.

The Rush Springs aquifer is not considered a sole-source aquifer by the state of Oklahoma and thus, no groundwater-surface water interactions are considered in management decisions for this aquifer. The impacts found during this analysis indicate that groundwater depletion can and does impact surface water availability by decreasing baseflow levels. This relationship between groundwater and surface water is one that is managed effectively in other states and is a relationship that must be recognized in the state of Oklahoma. The impact of this interaction was first recognized by Oklahoma in 2011 but, as previously stated, only applies to sole-source aquifers. As there is only one sole-source aquifer in the state, models like this one should be completed to demonstrate this interaction on aquifers throughout the state to provide scientific evidence to state policy makers of the possible impacts groundwater use can have of this area's surface water availability.

Recharge was also determined to be an important factor in baseflow for the Rush Springs aquifer. Recharge had a greater effect on the movement of water from streams into the aquifer than groundwater use. Recharge also affected discharge of groundwater to the streams by approximately 4.3 m^3/s in the corresponding direction when recharge was decreased and then increased. These results indicate how future droughts and climate variability might affect groundwater-surface water interactions in this aquifer. Although wetter conditions increased recharge from streams into the aquifer, the increase was not proportional to the decrease seen in the drought simulation. This follows how periods of intense rain do not have has dramatic an impact on groundwater levels as might be thought by the public. Intense rain can also lead to increased runoff which can increase sediment transport in the streams. This sediment transport can also lead to the clogging of pore spaces downstream which decreases flow between the groundwater and stream system (Hancock, 2002). Drought conditions were seen in the model to decrease both recharge from streams as well as baseflow to streams. These results demonstrate the importance of planning for changes in climate patterns is becoming increasingly important to the management of water resources. The Oklahoma USGS Water Science Center will also use this model to generate climate simulations which will expand on these recharge results to look at the effects of climate change on the whole aquifer system. This will provide local management agencies with the ability to better plan for the future of these resources.

Future work in this research will be conducted in conjunction with the OWRB, the Bureau of Reclamation, as well as the Oklahoma USGS Water Science Center. The Rush Springs digital groundwater-flow model created through this research will be used in the completion of official MAY simulations as well as the aforementioned climate scenarios. All of these agencies are working together to conduct extensive research on the water resources of this area and this model is an integral part of that research. It is the hopes of this research that this model will be used by these agencies to better understand groundwater flow within the Rush Springs aquifer and to determine management practices that will protect these water resources for generations to come.

REFERENCES

Al-Kaisi, M.M., and Shanahan, J.F., 1999, Irrigation of Winter Wheat, Colorado State University, Crop Series, Irrigation, no. 0.556, accessed on October 22, 2015 at http://www.extension.umn.edu/agriculture/small-grains/soil-water/docs/irrigation-of-winter-wheat.pdf

Anderson, M.P., 1995, Groundwater modeling in the 21st century, in El-Kadi, A.I., ed., Groundwater models for resource analysis and management: Lewis Publishers, p. 81-93.

Anderson, M.P., and Woessner, W.W., 1992, Applied Groundwater Modeling: Simulation of Flow and Advective Transport, Academic Press, Inc., San Diego, California.

Becker, M.F., and Runkle, D.L., 1998a, Hydrogeology, Water Quality, and Geochemistry of the Rush Springs Aquifer, Western Oklahoma: U.S. Geological Survey Water-Resources Investigations Report 98-4081

Becker, M.F., and Runkle, D.L., 1998b, Steady-State Simulation of Ground-Water Flow in the Rush Springs Aquifer, Western Oklahoma: U.S. Geological Survey Water-Resources Investigations Report 98-4082.

Boman, R., and Warren, J., Understanding Cotton Irrigation Requirements in Oklahoma, accessed October 22, 2015 at http://cotton.okstate.edu/irrigation/PSS-2406web.pdf

Chang, J.M. and Stanley, T.M., 2010, Geologic map of the Pauls Valley 30’ X 60’ quadrangle (Preliminary), Carter, Cleveland, Garvin, Grady, McClain, Murray, Pottawatomie, and Stephens Counties, Oklahoma: Oklahoma Geological Quadrangle 81, scale 1:100,000.

Chow, V.T., 1959, Open-Channel Hydraulics: McGraw-Hill, New York.

Christenson, S., Osborn, N.I., Neel, C.R., Faith, J.R., Blome, C.D., Puckette, J., and Pantea, M.P., 2011, Hydrogeology and Simulation of Groundwater Flow in the Arbuckle-Simpson Aquifer, South-Central Oklahoma: U.S. Geological Survey Scientific Investigations Report 2011-5029

Church, 1966, Ground Water in the Rush Springs Sandstone Caddo County Area: Oklahoma Water Resources Board Publication no. 15.

Davis, L.V., 1955, Geology and Ground Water Resources of Grady and Northern Stephen Counties, Oklahoma: Oklahoma Geological Survey Bulletin no. 73.

Domenico, P.A., and Schwartz, F.W., 1990, Physical and Chemical Hydrogeology, John Wiley and Sons, New York, Brisbane, Toronto, Singapore.

Duffield, G.M., Slug Tests: Aquifer Testing 101. Hydrosolv Inc., accessed December 12, 2014, at http://www.aqtesolv.com/slug-tests/slug-tests.html

Fay, R.O., 2010a, Preliminary geologic map of the Foss Reservoir 30’ X 60’ quadrangle, Beckham, Custer, Dewey, Ellis, and Roger Mills Counties, Oklahoma: Oklahoma Geologic Quadrangle 78A, scale 1:100,000.

Fay, R.O., 2010b, Preliminary geologic map of the Watonga 30’ x 60’ quadrangle, Blaine, Caddo, Canadian, Custer, Dewey, and Kingfisher Counties, Oklahoma: Oklahoma Geological Quadrangle 77A, scale 1:100,000.

Food and Agriculture Organization of the United Nations, 2015, FAO: Water Development, Crop Information: Cotton, accessed December 2, 2015 at http://www.fao.org/nr/water/cropinfo_cotton.html

Fox, G.A., Heeren, D.M., and Kizer, M.A., 2011, Evaluation of a Stream-Aquifer Test for Deriving Reach-Scale Streambed Conductance: Transactions of the ASABE, v. 54, no. 2, p. 473-479.

Gould, C.N., 1905, Geology and Water Resources of Oklahoma: U.S. Geological Survey Water Supply Paper 148

Godsey, C., 2012, Water Requirements of Peanuts, Department of Plant & Soil Sciences Extension News, accessed on October 22, 2015 at http://extensionnews.okstate.edu/archived-articles-1/2012-archived-articles/Irrigation%20and%20water%20use%20Peanut.pdf

Hancock, P.J., 2002, Human Impacts on the Stream-Groundwater Exchange Zone: Environmental Management, v. 29, no. 6, p. 763-781.

Harbaugh, A.W., 2005, MODFLOW-2005, The U.S. Geological Survey Modular Ground-Water Model-The Ground-Water Flow Process: U.S. Geological Survey Techniques and Methods.

Harbaugh, A.W., Banta, E.R., Hill, M.C., and McDonald, M.G., 2000, MODFLOW-2000, the U.S. Geological Survey Modular Ground-Water Model – User Guide to Modularization Concepts and the Ground-Water Flow Process: U.S. Geological Survey Open-File Report 00-92.

Heath, C.R., 1983, Basic Ground-Water Hydrology: U.S. Geological Survey Water-Supply Paper 2220

Johnson, K.S., Stanley, T.M., and Miller, G.W., 2003, Geologic map of the Elk City 30’ X 60’ quadrangle, Beckham, Custer, Greer, Harmon, Kiowa, Roger Mills, and Washita Counties, Oklahoma: Oklahoma Geological Quadrangle 44, scale 1:100,000.

Leake, S.A., 1997, Modeling Ground-Water Flow with MODFLOW and Related Programs: U.S. Geological Survey Fact Sheet FS-121-97, p. 4.

Lohman, S.W., 1972, Ground-Water Hydraulics: U.S. Geological Survey Professional Paper 708, p. 70.

Lohman, S.W., Bennett, R.R., Brown, R.H., Cooper, H.H., Drescher, W.J., Ferris, J.G., Johnson, A.I., McGuiness, C.L., Piper, A.M., Rorabaugh, M.I., Stallman, R.W., and Theis, C.V., 1972, Definitions of Selected Ground-Water Terms – Revisions and Conceptual Refinements: U.S. Geological Survey Water-Supply Paper 1988, p. 21.

Lurry, D.L., and Tortorelli, R.L., 1995, Estimated Freshwater Withdrawals in Oklahoma, 1990: U.S. Geological Survey Water Resources Investigations Report 95-4276.

Magers, J.S., 2011, Occurrence of Arsenic in the Rush Springs Sandstone and Its Implications on Groundwater Chemistry: Caddo County, Oklahoma, Oklahoma State Univeristy, Stillwater, Oklahoma.

Mittelstet, A.R., Smolen, M.D., Fox, G.A., and Adams, D.C., 2011, Comparison of Aquifer Sustainability under Groundwater Administrations in Oklahoma and Texas: Journal of the American Water Resources Association, v. 47, no. 2, p. 424-431.

Neel, C.R., Wagner, D., Correll, J., Waltman, B., Spears, K., Hernadez, J., Sanford, J., Ketchum, Q., 2015, Hydrologic Investigations Report of the Rush Springs Aquifer in West-Central Oklahoma: Oklahoma Water Resources Board Publication 2015-XX, publication in review.

New Mexico Statutes Chapter 72 Article 5.5, 2011, Objection to Applications; Publication of Notice; Filing of Protests; Definition of Standing.

New Mexico Statutes Chapter 72 Article 12.3, 2011, Application for Use of Underground Water; Publication of Notice; Permit.

Oklahoma Statutes Title 82 Section 1020.5, 2011, Determination of Maximum Annual Yield.

Oklahoma Statutes Title 82 Section 1020.9, 2011, Sensitive Sole Source Groundwater Basins or Subbasins-Moratorium on Issuance of Certain Temporary Permits.

Oklahoma Statutes Title 82 Section 1020.11, 2011, Types of Permits.

Oklahoma Water Resources Board, 2010, Taking and use of groundwater, Title 785, Chapter 30: accessed May 1, 2014, at http://www.owrb.ok.gov/util/rules/pdf_rul/RulesCurrent2010/Ch30.pdf

Oklahoma Water Resources Board, 2012, Rush Springs Aquifer of Oklahoma: Hydrologic Study Newsletter.

Oklahoma Water Resources Board, 2011, Oklahoma Comprehensive Water Plan Physical Water Supply Availability Report: Final Report, p. 3-5 – 3-7.

Oklahoma Water Resources Board, 2015, Upper Washita Surface Allocation Model, report in progress

Penderson, L.R., 1999, Steady-state Simulation of Ground-Water Flow in the Rush Springs Aquifer, Cobb Creek Basin, Caddo County, Oklahoma, Oklahoma State University, Stillwater, Oklahoma.

Poland, Z.A., 2011, Sedimentology of the Rush Springs Sandstone (Permian/Guadalupian), Western Oklahoma: Evidence of an Erg-Erg Margin Depositional System, Oklahoma State University, Stillwater, Oklahoma.

Stanley, T.M., 2002, Geologic map of the Woodward 30’ x 60’ quadrangle, Ellis, Dewey, Roger Mills, and Woodward Counties, Oklahoma: Oklahoma Geological Quadrangle 40, scale 1:100,000.

Stanley, T.M and Miller, T.M., 2004, Geologic map of the Anadarko 30’ X 60’ quadrangle, Caddo, Canadian, Custer, Grady, Kiowa, and Washita Counties, Oklahoma: Oklahoma Geological Quadrangle 58, scale 1:100,000.

Stanley, T.M. and Miller, G.W, 2005, Geologic map of the Lawton 30’ X 60’ quadrangle, Caddo, Comanche, Cotton, Grady, Kiowa, Stephens, and Tillman Counties, Oklahoma: Oklahoma Geological Quadrangle 63, scale 1:100,000.

Stanley, T.M., Miller, T.M., and Suneson, N.H., 2002, Geologic map of the Fairview 30’ x 60’ quadrangle, Alfalfa, Blaine, Dewey, Garfield, Kingfisher, Major, Woods, and Woodward Counties, Oklahoma: Oklahoma Geological Quadrangle 41, scale 1:100,000.

Tanaka, H.H., and Davis, L.V., 1963, Ground Water Rush Springs Sandstone: Oklahoma Geological Survey, Circular 61.

Westenbroek, S.M., Kelson, V.A., Dripps, W.R., Hunt, R.J., and Bradbury, K.R., 2010, SWB-A Modified Thornthwaite-Mather Soil-Water-Balance Code for Estimating Groundwater Recharge: U.S. Geological Survey Techniques and Methods.

Winston, R.B., 2015, U.S. Geological Survey: Online Guide to MODFLOW-2005, accessed December 1, 2014, at http://water.usgs.gov/ogw/modflow/MODFLOW-2005-Guide/

Zume, J., and Tarhule, A., 2007, Simulating the Impacts of Groundwater Pumping on Stream-Aquifer Dynamics in Semiarid Northwestern Oklahoma, USA, Hydrogeology Journal, v. 16, p. 797 - 810.

APPENDICES

Appendix A: Regression plots for the time steps analyzed for transient model calibration.

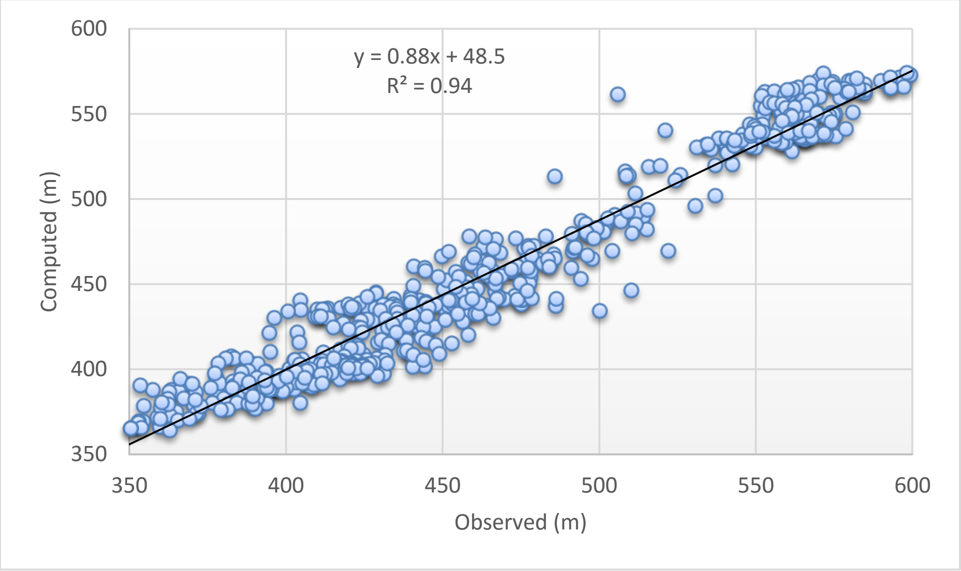


Figure 1. Observed versus computed head observations and corresponding equations at the end of the first time step (1/1/1957).

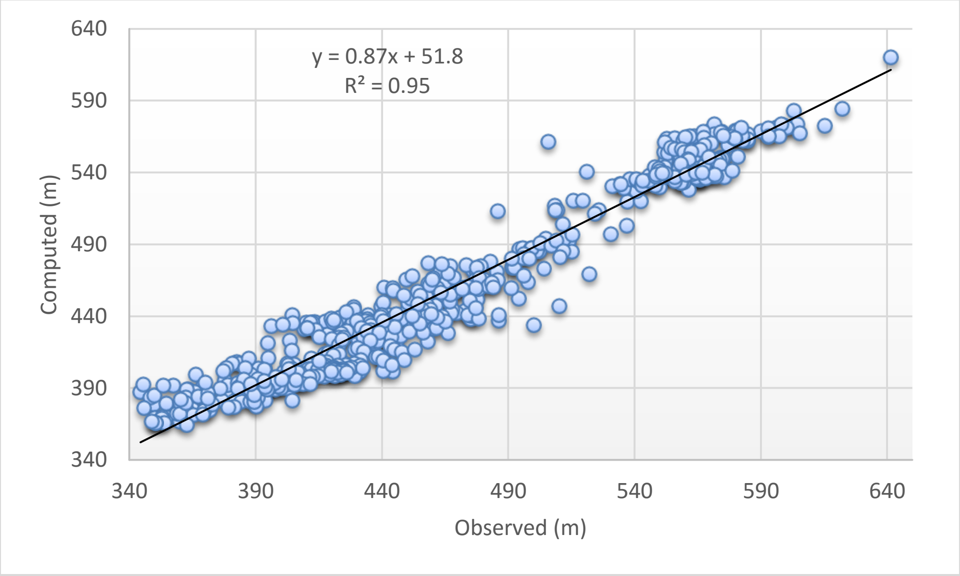


Figure 12. Observed verses computed head observations with corresponding equations for the time step 1/1/1960 of the transient simulation.

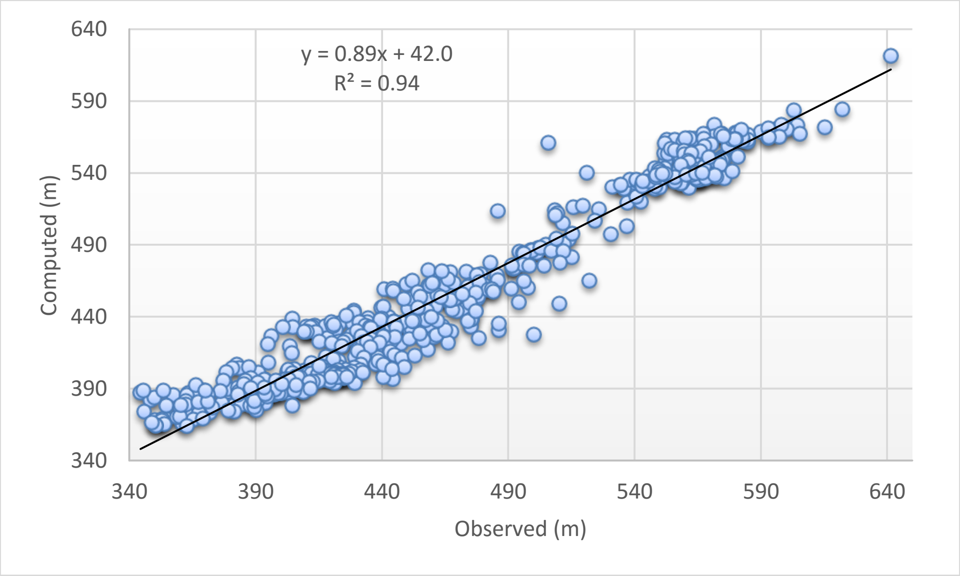


Figure 13. Observed versus computed head observations with the corresponding equations for time step 1/1/1966 of the transient simulation.

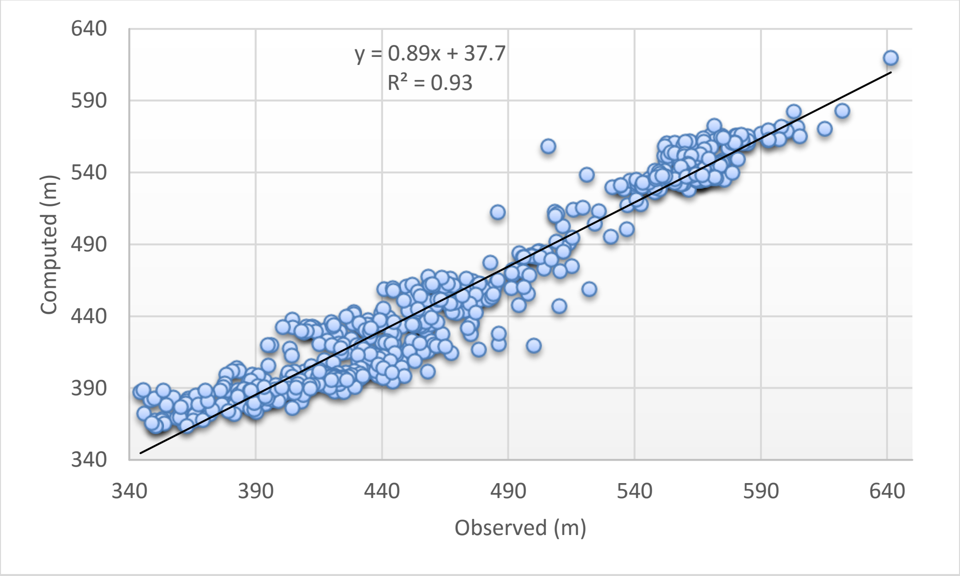


Figure 14: Observed versus computed head observations and the corresponding equations for the time step 1/1/1970 in the transient simulation.

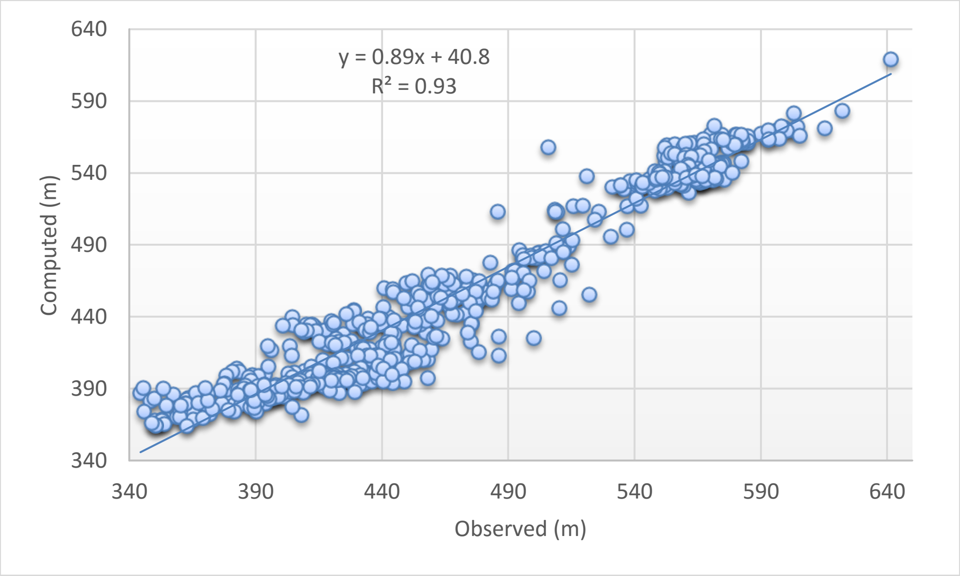


Figure 5. Observed versus computed head observations and the corresponding equations for the time step 1/1/1975 in the transient simulation.

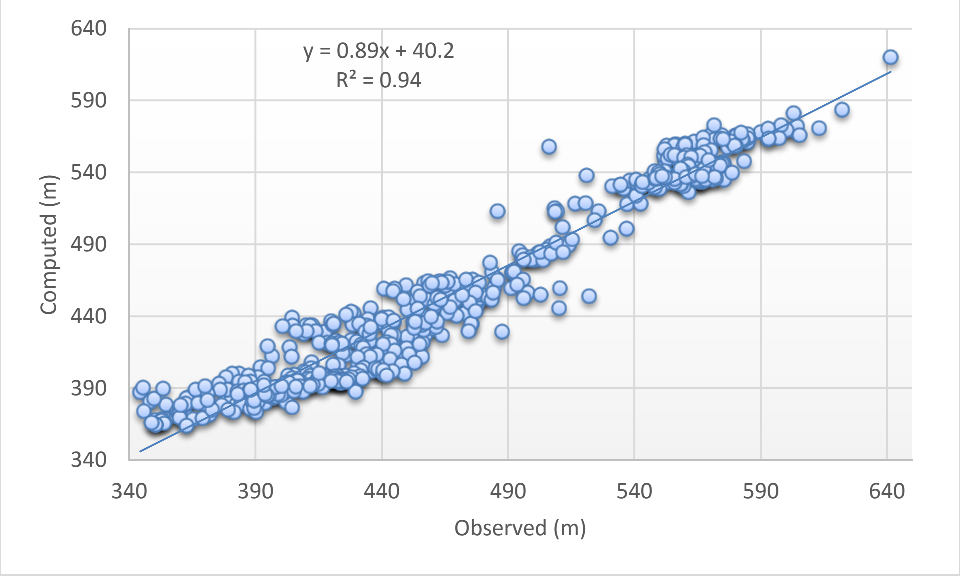


Figure 6. Observed versus computed head observations and their corresponding equations for the time step 1/1/1985 in the transient simulation.

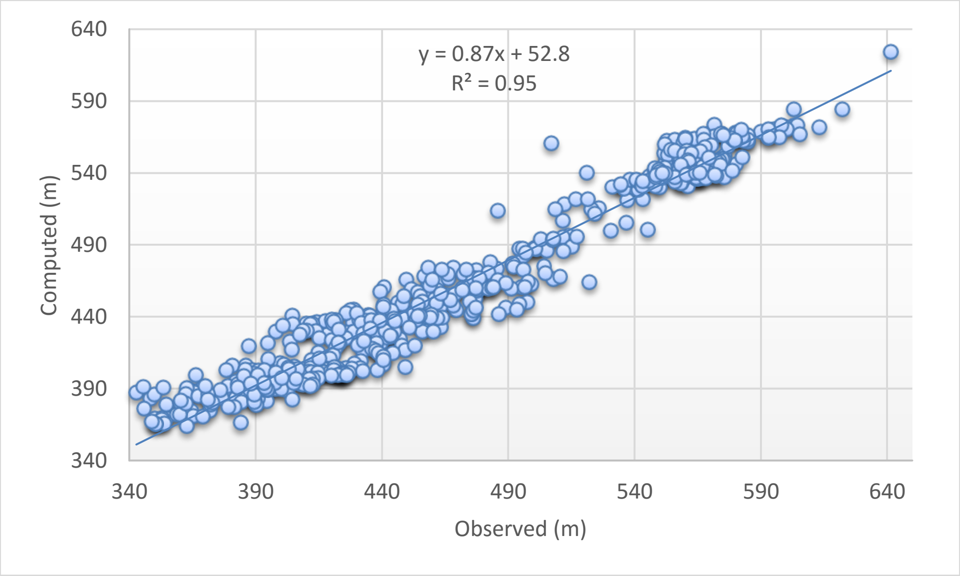


Figure 7. Observed versus computed head observations and the corresponding equations for the time step 1/1/1995 in the transient simulation.

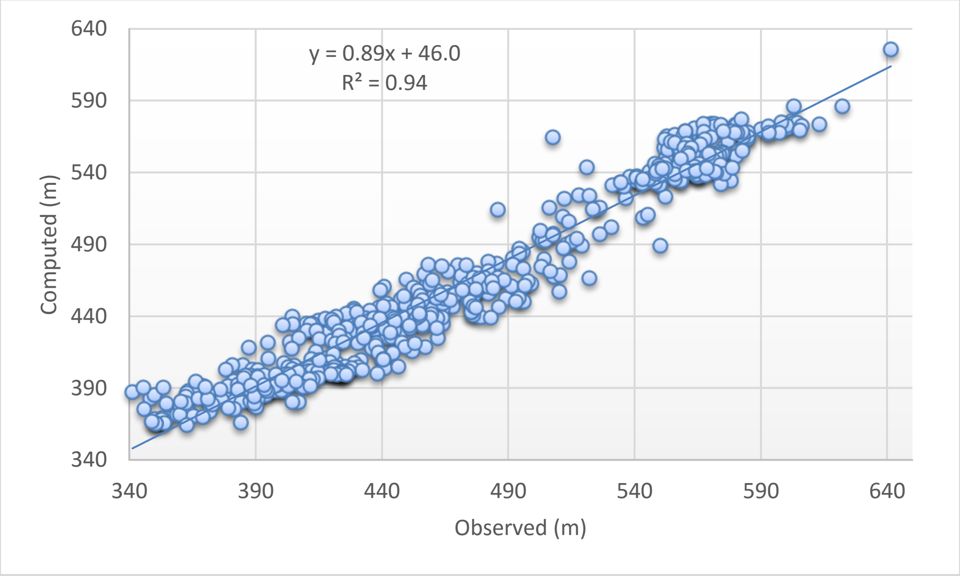


Figure 8. Observed versus computed head observations and corresponding equations for time step 1/1/2005 of the transient simulation.

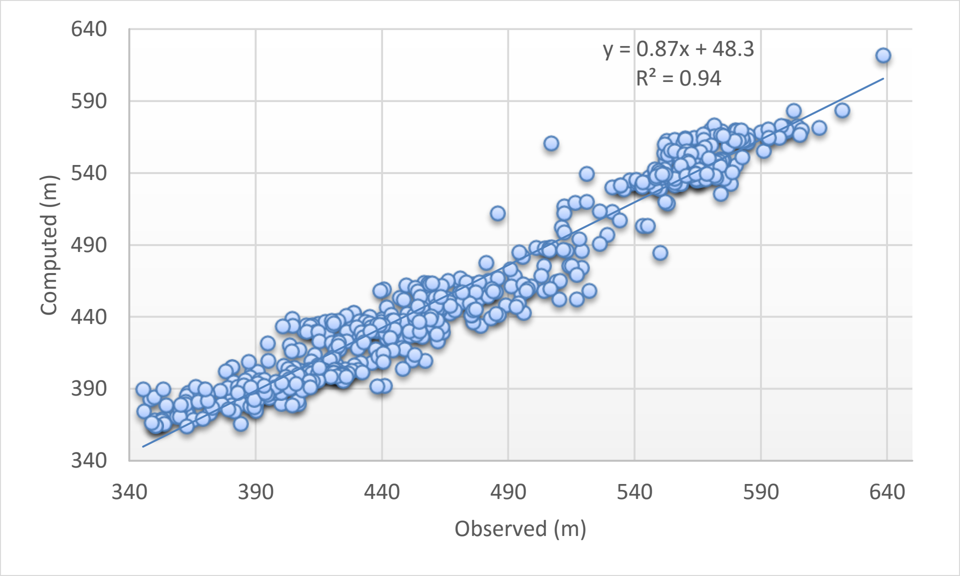


Figure 9. Observed versus computed head observations and corresponding equations at the end of the transient simulation on 1/1/2014.

Appendix B: Table of flow budget results for each time step in the transient simulation of the Rush Spring groundwater-flow model

FLOW BUDGET FOR EACH TIMESTEP IN THE RUSH SPRINGS MODEL TRANSIENT SIMULATION									
	FLOW IN				FLOW OUT				
	GHB	Recharge	SFR2	Storage	WEL	DRN	GHB	SFR2	Storage
Time step	(CFD)	(CFD)	(CFD)	(CFD)	(CFD)	(CFD)	(CFD)	(CFD)	(CFD)
1	3.06E+07	3.98E+07	5.13E+06	0.00E+00	2.43E+06	1.28E+07	7.18E+05	5.97E+07	0.00E+00
2	3.07E+07	1.30E+04	5.13E+06	3.52E+07	8.09E+04	1.19E+07	6.24E+05	5.74E+07	1.14E+06
3	3.08E+07	1.30E+04	5.10E+06	3.37E+07	8.10E+04	1.17E+07	6.19E+05	5.64E+07	8.28E+05
4	3.08E+07	1.30E+04	5.08E+06	3.26E+07	8.20E+04	1.15E+07	6.17E+05	5.56E+07	6.32E+05
5	3.03E+07	2.43E+08	5.15E+06	1.56E+06	4.57E+06	1.69E+07	1.21E+06	6.96E+07	1.88E+08
6	2.90E+07	7.10E+08	4.77E+06	2.97E+03	4.05E+05	3.21E+07	4.51E+06	9.88E+07	6.08E+08
7	3.01E+07	2.34E+08	5.12E+06	1.52E+07	4.27E+06	2.53E+07	1.09E+06	9.03E+07	1.64E+08
8	3.05E+07	0.00E+00	5.42E+06	7.54E+07	9.42E+06	1.70E+07	7.54E+05	7.69E+07	7.18E+06
9	3.05E+07	0.00E+00	5.41E+06	6.62E+07	9.73E+06	1.57E+07	7.31E+05	7.23E+07	3.69E+06
10	3.05E+07	1.08E+07	5.42E+06	4.94E+07	3.31E+06	1.54E+07	7.20E+05	7.02E+07	6.47E+06
11	3.05E+07	1.03E+06	5.40E+06	5.08E+07	9.09E+04	1.47E+07	7.35E+05	6.79E+07	4.36E+06
12	3.06E+07	1.76E+07	5.37E+06	3.92E+07	8.36E+04	1.56E+07	7.02E+05	6.77E+07	8.72E+06
13	3.06E+07	3.57E+01	5.37E+06	4.66E+07	7.65E+04	1.42E+07	6.89E+05	6.54E+07	2.27E+06
14	3.06E+07	9.35E+05	5.34E+06	4.36E+07	1.28E+05	1.38E+07	6.82E+05	6.41E+07	1.77E+06
15	3.06E+07	7.56E+05	5.32E+06	4.22E+07	1.28E+05	1.36E+07	6.75E+05	6.31E+07	1.42E+06
16	3.06E+07	7.73E+06	5.30E+06	3.62E+07	1.30E+05	1.34E+07	6.76E+05	6.25E+07	3.19E+06
17	3.06E+07	2.09E+06	5.28E+06	4.32E+07	5.17E+06	1.30E+07	6.66E+05	6.16E+07	7.64E+05
18	3.06E+07	2.46E+06	5.27E+06	3.82E+07	4.99E+05	1.31E+07	6.61E+05	6.07E+07	1.60E+06
19	3.06E+07	8.96E+07	5.05E+06	1.88E+07	4.85E+06	1.53E+07	7.47E+05	6.58E+07	5.74E+07
20	3.07E+07	1.44E+05	5.17E+06	5.06E+07	1.06E+07	1.30E+07	6.57E+05	6.15E+07	7.21E+05
21	3.07E+07	1.26E+06	5.17E+06	4.77E+07	1.10E+07	1.27E+07	6.58E+05	6.01E+07	2.86E+05
22	3.07E+07	3.62E+05	5.16E+06	4.08E+07	3.76E+06	1.24E+07	6.48E+05	5.92E+07	9.71E+05

23	3.07E+07	0.00E+00	5.15E+06	3.84E+07	1.44E+05	1.22E+07	6.45E+05	5.84E+07	2.78E+06
24	3.07E+07	0.00E+00	5.14E+06	3.66E+07	1.32E+05	1.20E+07	6.41E+05	5.78E+07	1.86E+06
25	3.07E+07	1.11E+02	5.13E+06	3.52E+07	1.21E+05	1.19E+07	6.39E+05	5.71E+07	1.30E+06
26	3.07E+07	1.31E+03	5.11E+06	3.42E+07	1.33E+05	1.17E+07	6.36E+05	5.66E+07	9.52E+05
27	3.07E+07	1.46E+04	5.10E+06	3.33E+07	1.33E+05	1.16E+07	6.33E+05	5.61E+07	7.46E+05
28	3.07E+07	1.37E+03	5.09E+06	3.26E+07	1.35E+05	1.15E+07	6.31E+05	5.56E+07	5.86E+05
29	3.07E+07	5.34E+05	5.08E+06	3.63E+07	5.46E+06	1.14E+07	6.33E+05	5.51E+07	1.25E+05
30	3.07E+07	4.88E+07	5.18E+06	1.67E+07	5.25E+05	1.22E+07	6.63E+05	5.78E+07	3.01E+07
31	3.07E+07	4.50E+06	5.16E+06	3.48E+07	5.11E+06	1.14E+07	6.25E+05	5.59E+07	2.24E+06
32	3.07E+07	3.58E+07	5.11E+06	2.75E+07	1.12E+07	1.14E+07	8.47E+05	5.62E+07	1.94E+07
33	3.07E+07	6.24E+06	5.01E+06	4.10E+07	1.16E+07	1.12E+07	6.43E+05	5.54E+07	4.06E+06
34	3.07E+07	7.73E+07	5.00E+06	1.28E+07	3.97E+06	1.18E+07	6.63E+05	5.79E+07	5.15E+07
35	3.05E+07	4.67E+08	5.19E+06	1.93E+06	1.50E+05	2.00E+07	1.49E+06	8.04E+07	4.03E+08
36	3.07E+07	7.10E+06	5.40E+06	5.03E+07	1.38E+05	1.43E+07	6.44E+05	6.75E+07	1.11E+07
37	3.04E+07	9.13E+07	5.15E+06	1.75E+07	1.26E+05	1.74E+07	7.79E+05	6.93E+07	5.69E+07
38	3.02E+07	1.40E+08	5.23E+06	3.65E+06	1.33E+05	1.73E+07	1.24E+06	7.17E+07	8.91E+07
39	2.93E+07	4.93E+08	5.07E+06	7.78E+04	1.29E+05	2.02E+07	3.33E+06	8.90E+07	4.14E+08
40	3.02E+07	5.70E+07	5.24E+06	4.07E+07	1.35E+05	1.57E+07	1.01E+06	7.79E+07	3.85E+07
41	3.05E+07	6.71E+03	5.23E+06	6.04E+07	5.52E+06	1.42E+07	7.29E+05	7.19E+07	3.82E+06
42	3.05E+07	4.51E+06	5.22E+06	4.91E+07	5.29E+05	1.43E+07	7.12E+05	6.93E+07	4.45E+06
43	3.05E+07	5.16E+05	5.21E+06	5.24E+07	5.17E+06	1.35E+07	7.02E+05	6.72E+07	2.06E+06
44	3.05E+07	1.54E+07	5.18E+06	4.99E+07	1.14E+07	1.33E+07	7.30E+05	6.67E+07	8.91E+06
45	3.06E+07	1.34E+06	5.15E+06	5.45E+07	1.17E+07	1.29E+07	6.92E+05	6.47E+07	1.48E+06
46	3.06E+07	3.78E+04	5.14E+06	4.69E+07	4.01E+06	1.27E+07	6.81E+05	6.34E+07	1.92E+06
47	3.05E+07	1.76E+08	5.04E+06	1.18E+07	1.50E+05	1.41E+07	1.15E+06	7.13E+07	1.37E+08
48	3.06E+07	0.00E+00	5.10E+06	4.79E+07	1.38E+05	1.27E+07	6.84E+05	6.60E+07	4.12E+06
49	3.06E+07	1.22E+07	5.12E+06	3.70E+07	1.26E+05	1.31E+07	6.72E+05	6.50E+07	6.10E+06
50	3.06E+07	0.00E+00	5.10E+06	4.26E+07	1.33E+05	1.24E+07	6.65E+05	6.31E+07	2.01E+06
51	3.06E+07	4.41E+06	5.08E+06	3.73E+07	1.33E+05	1.23E+07	6.61E+05	6.23E+07	2.01E+06
52	3.06E+07	3.87E+06	5.09E+06	3.67E+07	1.35E+05	1.22E+07	6.59E+05	6.15E+07	1.81E+06
53	3.06E+07	6.73E+04	5.08E+06	4.50E+07	7.16E+06	1.19E+07	6.54E+05	6.05E+07	5.82E+05
54	3.07E+07	1.58E+05	5.05E+06	3.83E+07	6.42E+05	1.18E+07	6.51E+05	5.98E+07	1.36E+06
55	3.06E+07	1.32E+07	5.01E+06	3.54E+07	6.69E+06	1.18E+07	6.75E+05	5.99E+07	5.21E+06
56	3.07E+07	4.11E+05	5.03E+06	4.98E+07	1.47E+07	1.15E+07	6.46E+05	5.87E+07	3.21E+05
57	3.06E+07	8.66E+06	5.01E+06	4.63E+07	1.51E+07	1.15E+07	8.72E+05	5.82E+07	5.03E+06
58	3.07E+07	9.26E+07	5.24E+06	1.44E+07	5.13E+06	1.34E+07	6.66E+05	6.24E+07	6.12E+07
59	3.07E+07	5.47E+07	5.14E+06	2.42E+07	1.50E+05	1.19E+07	8.74E+05	6.14E+07	4.04E+07
60	3.05E+07	1.71E+08	4.97E+06	9.75E+06	1.38E+05	1.30E+07	1.23E+06	6.74E+07	1.35E+08
61	3.07E+07	1.05E+06	5.01E+06	4.21E+07	1.26E+05	1.18E+07	6.54E+05	6.25E+07	3.81E+06
62	3.07E+07	6.63E+06	4.99E+06	3.57E+07	1.33E+05	1.17E+07	6.41E+05	6.11E+07	4.51E+06
63	3.07E+07	0.00E+00	4.98E+06	3.81E+07	1.33E+05	1.14E+07	6.35E+05	5.98E+07	1.85E+06
64	3.07E+07	0.00E+00	4.98E+06	3.66E+07	1.35E+05	1.13E+07	6.33E+05	5.88E+07	1.44E+06
65	3.07E+07	2.20E+05	4.97E+06	4.01E+07	5.58E+06	1.12E+07	6.30E+05	5.81E+07	5.94E+05

66	3.07E+07	4.49E+06	4.95E+06	3.29E+07	5.33E+05	1.13E+07	6.29E+05	5.77E+07	2.92E+06
67	3.07E+07	2.01E+08	5.25E+06	1.57E+07	5.22E+06	2.14E+07	7.00E+05	7.16E+07	1.54E+08
68	3.07E+07	2.03E+05	5.54E+06	5.28E+07	1.15E+07	1.36E+07	6.28E+05	6.23E+07	1.37E+06
69	3.07E+07	8.62E+06	5.32E+06	4.59E+07	1.18E+07	1.27E+07	6.37E+05	6.07E+07	4.70E+06
70	3.07E+07	1.80E+06	5.35E+06	4.00E+07	4.05E+06	1.24E+07	6.47E+05	5.92E+07	1.60E+06
71	3.07E+07	1.17E+07	5.30E+06	3.11E+07	1.50E+05	1.27E+07	6.30E+05	5.90E+07	6.47E+06
72	3.07E+07	6.87E+06	5.26E+06	3.37E+07	1.38E+05	1.29E+07	6.20E+05	5.82E+07	4.73E+06
73	3.07E+07	1.08E+07	5.23E+06	2.83E+07	1.26E+05	1.26E+07	6.19E+05	5.79E+07	3.71E+06
74	3.07E+07	2.55E+04	5.21E+06	3.46E+07	1.24E+05	1.20E+07	6.17E+05	5.68E+07	1.13E+06
75	3.07E+07	1.05E+04	5.18E+06	3.36E+07	1.24E+05	1.17E+07	6.15E+05	5.62E+07	9.00E+05
76	3.08E+07	4.23E+04	5.16E+06	3.27E+07	1.26E+05	1.16E+07	6.14E+05	5.56E+07	7.24E+05
77	3.08E+07	1.50E+05	5.14E+06	3.73E+07	6.21E+06	1.14E+07	6.13E+05	5.51E+07	6.76E+04
78	3.08E+07	1.19E+04	5.12E+06	3.20E+07	5.66E+05	1.13E+07	6.11E+05	5.46E+07	9.04E+05
79	3.08E+07	3.25E+06	5.10E+06	3.36E+07	5.81E+06	1.12E+07	6.14E+05	5.43E+07	8.95E+05
80	3.08E+07	4.80E+04	5.08E+06	4.23E+07	1.28E+07	1.10E+07	6.09E+05	5.37E+07	3.75E+04
81	3.08E+07	0.00E+00	5.06E+06	4.21E+07	1.32E+07	1.09E+07	6.08E+05	5.32E+07	2.97E+04
82	3.08E+07	4.39E+05	5.05E+06	3.35E+07	4.50E+06	1.08E+07	6.06E+05	5.28E+07	1.02E+06
83	3.08E+07	3.93E+03	5.03E+06	3.13E+07	1.39E+05	1.07E+07	6.05E+05	5.24E+07	3.28E+06
84	3.08E+07	1.07E+06	5.02E+06	2.91E+07	1.28E+05	1.07E+07	6.04E+05	5.21E+07	2.49E+06
85	3.08E+07	2.55E+04	5.01E+06	2.88E+07	1.17E+05	1.06E+07	6.03E+05	5.17E+07	1.64E+06
86	3.08E+07	1.13E+05	4.99E+06	2.79E+07	1.40E+05	1.05E+07	6.02E+05	5.14E+07	1.24E+06
87	3.07E+07	4.47E+07	4.96E+06	1.37E+07	1.36E+05	1.09E+07	7.35E+05	5.36E+07	2.86E+07
88	3.08E+07	1.18E+04	4.98E+06	2.83E+07	1.42E+05	1.05E+07	6.04E+05	5.19E+07	9.59E+05
89	3.08E+07	1.32E+05	4.97E+06	3.30E+07	6.60E+06	1.04E+07	6.00E+05	5.13E+07	7.85E+03
90	3.08E+07	2.39E+07	4.92E+06	1.87E+07	6.11E+05	1.05E+07	6.07E+05	5.20E+07	1.47E+07
91	3.08E+07	3.39E+05	4.92E+06	3.22E+07	6.18E+06	1.03E+07	6.09E+05	5.11E+07	9.97E+04
92	3.08E+07	0.00E+00	4.91E+06	3.92E+07	1.36E+07	1.02E+07	5.97E+05	5.05E+07	4.57E+03
93	3.08E+07	3.65E+06	4.87E+06	3.60E+07	1.36E+07	1.02E+07	6.28E+05	5.03E+07	7.23E+05
94	3.08E+07	3.09E+07	5.24E+06	2.19E+07	4.61E+06	1.13E+07	6.00E+05	5.21E+07	2.02E+07
95	3.08E+07	4.49E+05	5.11E+06	2.88E+07	1.21E+05	1.04E+07	5.94E+05	5.06E+07	3.58E+06
96	2.90E+07	7.03E+08	5.07E+06	1.84E+05	1.11E+05	1.70E+07	4.74E+06	8.43E+07	6.31E+08
97	3.00E+07	7.26E+07	5.12E+06	3.16E+07	1.01E+05	1.21E+07	1.25E+06	6.86E+07	5.75E+07
98	3.05E+07	2.38E+04	5.08E+06	4.69E+07	1.18E+05	1.14E+07	7.13E+05	6.26E+07	7.78E+06
99	3.06E+07	1.89E+00	5.03E+06	4.14E+07	1.18E+05	1.12E+07	6.92E+05	6.02E+07	4.84E+06
100	3.06E+07	4.37E+04	5.00E+06	3.80E+07	1.20E+05	1.10E+07	6.83E+05	5.85E+07	3.35E+06
101	3.06E+07	2.08E+05	4.99E+06	4.18E+07	6.98E+06	1.09E+07	6.75E+05	5.73E+07	1.82E+06
102	3.06E+07	6.86E+04	4.97E+06	3.50E+07	6.13E+05	1.07E+07	6.68E+05	5.63E+07	2.36E+06
103	3.06E+07	1.29E+06	4.95E+06	3.78E+07	6.52E+06	1.06E+07	6.63E+05	5.55E+07	1.30E+06
104	3.06E+07	2.88E+03	4.93E+06	4.55E+07	1.44E+07	1.05E+07	6.58E+05	5.47E+07	8.33E+05
105	3.07E+07	1.64E+05	4.92E+06	4.48E+07	1.49E+07	1.04E+07	6.53E+05	5.39E+07	6.79E+05
106	3.01E+07	1.36E+08	4.57E+06	9.73E+06	4.94E+06	1.07E+07	1.38E+06	6.12E+07	1.03E+08
107	3.02E+07	8.28E+07	4.62E+06	1.52E+07	1.33E+05	1.04E+07	1.35E+06	5.95E+07	6.15E+07
108	3.06E+07	0.00E+00	4.76E+06	3.71E+07	1.22E+05	1.03E+07	6.87E+05	5.65E+07	4.83E+06

109	3.06E+07	2.32E+05	4.78E+06	3.39E+07	1.12E+05	1.02E+07	6.69E+05	5.52E+07	3.37E+06
110	3.06E+07	0.00E+00	4.78E+06	3.24E+07	1.17E+05	1.01E+07	6.64E+05	5.43E+07	2.55E+06
111	3.06E+07	2.01E+06	4.77E+06	3.00E+07	1.17E+05	1.01E+07	6.76E+05	5.38E+07	2.72E+06
112	3.06E+07	1.34E+06	4.75E+06	2.92E+07	1.18E+05	1.00E+07	6.56E+05	5.32E+07	1.95E+06
113	3.06E+07	3.49E+06	4.75E+06	3.42E+07	7.67E+06	1.01E+07	6.52E+05	5.29E+07	1.84E+06
114	3.07E+07	1.24E+05	4.73E+06	2.96E+07	6.59E+05	9.95E+06	6.49E+05	5.22E+07	1.64E+06
115	3.07E+07	2.07E+04	4.71E+06	3.44E+07	7.16E+06	9.88E+06	6.46E+05	5.17E+07	4.17E+05
116	3.07E+07	3.24E+04	4.70E+06	4.20E+07	1.54E+07	9.82E+06	6.44E+05	5.12E+07	3.50E+05
117	3.07E+07	4.46E+06	4.69E+06	3.86E+07	1.57E+07	9.79E+06	6.93E+05	5.09E+07	1.39E+06
118	3.07E+07	1.80E+05	4.69E+06	3.18E+07	5.29E+06	9.74E+06	6.41E+05	5.04E+07	1.29E+06
119	3.07E+07	0.00E+00	4.67E+06	2.92E+07	1.21E+05	9.68E+06	6.38E+05	5.00E+07	4.09E+06
120	3.07E+07	0.00E+00	4.66E+06	2.76E+07	1.11E+05	9.64E+06	6.35E+05	4.97E+07	2.91E+06
121	3.07E+07	0.00E+00	4.64E+06	2.65E+07	1.01E+05	9.60E+06	6.33E+05	4.94E+07	2.16E+06
122	3.07E+07	0.00E+00	4.63E+06	2.57E+07	1.68E+05	9.55E+06	6.30E+05	4.91E+07	1.67E+06
123	3.07E+07	0.00E+00	4.61E+06	2.51E+07	1.68E+05	9.52E+06	6.28E+05	4.88E+07	1.37E+06
124	3.07E+07	2.55E+03	4.58E+06	2.46E+07	1.70E+05	9.48E+06	6.26E+05	4.85E+07	1.13E+06
125	3.07E+07	1.43E+07	4.61E+06	2.95E+07	1.13E+07	9.89E+06	6.49E+05	4.88E+07	8.45E+06
126	3.07E+07	5.10E+04	4.59E+06	2.56E+07	8.58E+05	9.55E+06	6.23E+05	4.82E+07	1.79E+06
127	3.07E+07	2.30E+07	4.41E+06	2.78E+07	1.02E+07	9.60E+06	6.41E+05	4.95E+07	1.60E+07
128	3.08E+07	1.01E+04	4.53E+06	4.56E+07	2.27E+07	9.46E+06	6.20E+05	4.79E+07	2.52E+05
129	3.08E+07	7.21E+04	4.54E+06	4.45E+07	2.24E+07	9.42E+06	6.22E+05	4.73E+07	1.36E+05
130	3.08E+07	1.58E+06	4.52E+06	2.98E+07	7.45E+06	9.42E+06	6.17E+05	4.71E+07	2.14E+06
131	3.08E+07	1.09E+06	4.49E+06	2.66E+07	8.06E+04	9.37E+06	6.16E+05	4.68E+07	6.09E+06
132	3.08E+07	6.18E+03	4.48E+06	2.55E+07	7.41E+04	9.33E+06	6.14E+05	4.65E+07	4.26E+06
133	3.08E+07	4.10E+04	4.46E+06	2.42E+07	6.78E+04	9.29E+06	6.13E+05	4.63E+07	3.21E+06
134	3.08E+07	1.77E+07	4.68E+06	1.79E+07	9.25E+04	9.59E+06	6.53E+05	4.71E+07	1.36E+07
135	3.07E+07	1.01E+07	4.60E+06	1.84E+07	8.94E+04	9.43E+06	7.16E+05	4.69E+07	6.70E+06
136	3.08E+07	1.56E+04	4.53E+06	2.27E+07	4.72E+04	9.31E+06	6.12E+05	4.63E+07	1.76E+06
137	3.07E+07	1.03E+06	4.50E+06	2.98E+07	9.66E+06	9.27E+06	6.26E+05	4.60E+07	6.27E+05
138	3.07E+07	1.86E+07	4.45E+06	1.69E+07	7.19E+05	9.29E+06	7.27E+05	4.65E+07	1.34E+07
139	3.07E+07	2.04E+07	4.49E+06	2.57E+07	8.98E+06	9.73E+06	9.36E+05	4.68E+07	1.48E+07
140	3.08E+07	7.43E+05	4.45E+06	3.96E+07	1.95E+07	9.32E+06	6.14E+05	4.59E+07	2.81E+05
141	3.07E+07	2.70E+07	4.21E+06	3.16E+07	1.91E+07	9.28E+06	6.63E+05	4.70E+07	1.75E+07
142	3.08E+07	1.01E+07	4.31E+06	2.46E+07	6.41E+06	9.29E+06	6.06E+05	4.64E+07	7.14E+06
143	3.08E+07	2.63E+06	4.36E+06	2.42E+07	5.23E+04	9.31E+06	6.05E+05	4.56E+07	6.32E+06
144	3.08E+07	5.05E+07	4.68E+06	1.45E+07	4.81E+04	1.10E+07	6.18E+05	4.82E+07	4.05E+07
145	3.08E+07	1.31E+07	4.62E+06	1.91E+07	4.40E+04	1.01E+07	6.05E+05	4.69E+07	9.96E+06
146	3.08E+07	1.73E+06	4.54E+06	2.27E+07	2.24E+05	9.76E+06	6.01E+05	4.60E+07	3.20E+06
147	3.08E+07	2.14E+07	4.48E+06	1.83E+07	2.25E+05	1.09E+07	5.99E+05	4.70E+07	1.64E+07
148	3.05E+07	1.38E+08	4.26E+06	4.21E+06	2.27E+05	1.10E+07	9.52E+05	5.36E+07	1.11E+08
149	3.08E+07	1.65E+05	4.40E+06	3.62E+07	1.01E+07	9.91E+06	6.14E+05	4.88E+07	2.18E+06
150	3.05E+07	1.97E+08	4.33E+06	4.23E+06	7.26E+05	1.12E+07	2.18E+06	5.52E+07	1.67E+08
151	3.07E+07	3.69E+05	4.41E+06	3.89E+07	9.40E+06	1.01E+07	6.50E+05	5.10E+07	3.34E+06

152	3.08E+07	0.00E+00	4.43E+06	4.69E+07	2.07E+07	9.89E+06	6.15E+05	4.93E+07	1.65E+06
153	3.05E+07	1.41E+07	4.30E+06	4.15E+07	2.09E+07	9.80E+06	7.32E+05	4.90E+07	9.96E+06
154	3.07E+07	4.39E+06	4.38E+06	3.04E+07	6.99E+06	9.94E+06	6.31E+05	4.82E+07	4.14E+06
155	3.08E+07	0.00E+00	4.34E+06	2.88E+07	2.66E+04	9.70E+06	6.12E+05	4.73E+07	6.20E+06
156	3.08E+07	0.00E+00	4.32E+06	2.66E+07	2.44E+04	9.62E+06	6.09E+05	4.68E+07	4.63E+06
157	3.08E+07	0.00E+00	4.30E+06	2.51E+07	2.23E+04	9.56E+06	6.07E+05	4.64E+07	3.54E+06
158	3.08E+07	1.91E+04	4.27E+06	2.40E+07	1.54E+05	9.51E+06	6.06E+05	4.61E+07	2.80E+06
159	3.08E+07	0.00E+00	4.25E+06	2.32E+07	1.54E+05	9.46E+06	6.04E+05	4.58E+07	2.31E+06
160	3.08E+07	2.87E+05	4.23E+06	2.23E+07	1.56E+05	9.42E+06	6.03E+05	4.55E+07	2.00E+06
161	3.07E+07	6.98E+06	4.14E+06	3.04E+07	1.27E+07	9.39E+06	6.42E+05	4.56E+07	3.95E+06
162	3.08E+07	1.08E+05	4.19E+06	2.31E+07	9.12E+05	9.33E+06	6.02E+05	4.50E+07	2.28E+06
163	3.08E+07	1.11E+06	4.20E+06	3.09E+07	1.18E+07	9.33E+06	6.00E+05	4.47E+07	5.26E+05
164	3.08E+07	4.57E+03	4.20E+06	4.52E+07	2.60E+07	9.27E+06	5.99E+05	4.43E+07	7.95E+04
165	3.08E+07	1.84E+05	4.20E+06	4.39E+07	2.51E+07	9.22E+06	6.03E+05	4.40E+07	1.83E+05
166	3.08E+07	9.17E+06	4.32E+06	2.56E+07	8.18E+06	9.58E+06	5.97E+05	4.44E+07	7.10E+06
167	3.08E+07	8.07E+06	4.21E+06	2.38E+07	3.36E+04	9.90E+06	5.96E+05	4.43E+07	1.20E+07
168	3.08E+07	0.00E+00	4.17E+06	2.39E+07	3.10E+04	9.36E+06	5.94E+05	4.37E+07	5.24E+06
169	3.08E+07	0.00E+00	4.15E+06	2.24E+07	2.83E+04	9.27E+06	5.94E+05	4.35E+07	4.05E+06
170	3.08E+07	5.64E+04	4.14E+06	2.15E+07	1.82E+05	9.23E+06	5.93E+05	4.33E+07	3.25E+06
171	3.08E+07	1.15E+06	4.13E+06	2.01E+07	1.82E+05	9.20E+06	5.97E+05	4.31E+07	3.08E+06
172	3.08E+07	7.39E+03	4.12E+06	2.02E+07	1.85E+05	9.15E+06	5.91E+05	4.29E+07	2.29E+06
173	3.08E+07	0.00E+00	4.12E+06	2.96E+07	1.21E+07	9.11E+06	5.90E+05	4.27E+07	1.34E+05
174	3.08E+07	0.00E+00	4.09E+06	2.08E+07	1.03E+06	9.08E+06	5.89E+05	4.25E+07	2.45E+06
175	3.08E+07	8.02E+06	4.08E+06	2.53E+07	1.13E+07	9.14E+06	5.94E+05	4.26E+07	4.65E+06
176	3.08E+07	1.81E+05	4.09E+06	4.10E+07	2.41E+07	9.05E+06	5.88E+05	4.22E+07	1.34E+05
177	3.08E+07	1.65E+07	4.37E+06	3.71E+07	2.35E+07	9.72E+06	5.86E+05	4.32E+07	1.17E+07
178	3.08E+07	1.44E+07	4.31E+06	1.98E+07	7.92E+06	9.43E+06	5.96E+05	4.31E+07	8.27E+06
179	3.08E+07	3.96E+07	4.51E+06	1.38E+07	2.05E+05	1.01E+07	6.42E+05	4.46E+07	3.31E+07
180	3.09E+07	4.20E+04	4.42E+06	2.38E+07	1.88E+05	9.41E+06	5.86E+05	4.32E+07	5.76E+06
181	3.08E+07	8.71E+07	5.10E+06	7.58E+06	1.72E+05	1.10E+07	7.11E+05	4.77E+07	7.10E+07
182	3.09E+07	0.00E+00	4.87E+06	2.38E+07	1.15E+04	9.72E+06	5.89E+05	4.48E+07	4.49E+06
183	3.09E+07	4.55E+03	4.67E+06	2.17E+07	1.11E+04	9.55E+06	5.84E+05	4.40E+07	3.19E+06
184	3.09E+07	0.00E+00	4.54E+06	2.06E+07	1.16E+04	9.46E+06	5.83E+05	4.35E+07	2.55E+06
185	3.09E+07	8.48E+05	4.48E+06	2.95E+07	1.23E+07	9.42E+06	5.82E+05	4.31E+07	4.46E+05
186	3.09E+07	1.59E+06	4.41E+06	1.95E+07	8.61E+05	9.38E+06	5.81E+05	4.29E+07	2.78E+06
187	3.09E+07	2.59E+05	4.35E+06	2.83E+07	1.14E+07	9.30E+06	5.81E+05	4.25E+07	1.56E+05
188	3.09E+07	5.35E+04	4.31E+06	4.19E+07	2.52E+07	9.25E+06	5.79E+05	4.21E+07	1.22E+05
189	3.09E+07	2.42E+04	4.28E+06	4.12E+07	2.48E+07	9.20E+06	5.79E+05	4.17E+07	1.81E+05
190	3.09E+07	3.57E+05	4.24E+06	2.57E+07	8.02E+06	9.16E+06	5.77E+05	4.15E+07	1.94E+06
191	3.09E+07	2.26E+07	4.41E+06	1.58E+07	1.29E+04	9.51E+06	5.83E+05	4.24E+07	2.12E+07
192	3.09E+07	9.13E+07	4.64E+06	1.02E+07	1.19E+04	1.25E+07	6.13E+05	4.72E+07	7.69E+07
193	3.09E+07	8.63E+06	4.71E+06	2.06E+07	1.09E+04	1.01E+07	6.12E+05	4.44E+07	9.79E+06
194	3.03E+07	3.81E+08	5.20E+06	1.27E+06	1.85E+05	1.87E+07	1.38E+06	6.48E+07	3.32E+08

195	3.06E+07	2.58E+07	5.14E+06	2.88E+07	1.85E+05	1.22E+07	7.98E+05	5.34E+07	2.39E+07
196	3.00E+07	5.89E+08	5.11E+06	6.07E+04	3.44E+04	2.46E+07	2.48E+06	7.99E+07	5.17E+08
197	3.05E+07	6.49E+07	5.19E+06	3.81E+07	9.69E+06	1.48E+07	1.29E+06	6.52E+07	4.78E+07
198	3.06E+07	6.02E+06	5.13E+06	4.32E+07	7.07E+05	1.31E+07	6.70E+05	5.94E+07	1.12E+07
199	3.07E+07	1.43E+07	5.10E+06	3.79E+07	9.01E+06	1.27E+07	6.54E+05	5.72E+07	8.49E+06
200	3.08E+07	7.53E+04	5.07E+06	5.30E+07	1.94E+07	1.22E+07	6.30E+05	5.49E+07	1.79E+06
201	3.08E+07	0.00E+00	5.05E+06	5.08E+07	1.97E+07	1.19E+07	6.24E+05	5.33E+07	1.14E+06
202	3.07E+07	4.03E+07	5.00E+06	2.25E+07	6.58E+06	1.23E+07	8.36E+05	5.42E+07	2.46E+07
203	3.07E+07	6.24E+06	4.96E+06	3.11E+07	3.81E+04	1.18E+07	6.61E+05	5.28E+07	7.86E+06
204	3.08E+07	8.79E+05	4.97E+06	3.20E+07	3.50E+04	1.15E+07	6.16E+05	5.17E+07	4.76E+06
205	3.08E+07	7.15E+05	4.95E+06	3.00E+07	3.21E+04	1.13E+07	6.12E+05	5.08E+07	3.71E+06
206	3.08E+07	7.83E+04	4.93E+06	2.91E+07	1.23E+05	1.11E+07	6.09E+05	5.02E+07	2.89E+06
207	3.08E+07	4.97E+05	4.90E+06	2.76E+07	1.23E+05	1.10E+07	6.06E+05	4.97E+07	2.45E+06
208	3.08E+07	2.22E+07	4.89E+06	1.98E+07	1.24E+05	1.12E+07	6.13E+05	5.05E+07	1.52E+07
209	3.08E+07	5.49E+05	4.89E+06	3.58E+07	1.11E+07	1.08E+07	6.04E+05	4.92E+07	3.55E+05
210	3.08E+07	2.44E+06	4.86E+06	2.56E+07	9.06E+05	1.07E+07	6.26E+05	4.87E+07	2.79E+06
211	3.08E+07	9.99E+05	4.86E+06	3.34E+07	1.04E+07	1.06E+07	5.99E+05	4.82E+07	3.43E+05
212	3.08E+07	0.00E+00	4.88E+06	4.58E+07	2.28E+07	1.05E+07	5.97E+05	4.76E+07	8.26E+04
213	3.08E+07	1.63E+07	4.79E+06	3.72E+07	2.27E+07	1.05E+07	7.09E+05	4.79E+07	7.31E+06
214	3.08E+07	4.79E+07	4.77E+06	1.66E+07	7.61E+06	1.10E+07	6.75E+05	4.97E+07	3.11E+07
215	3.08E+07	3.21E+07	4.80E+06	1.70E+07	1.38E+05	1.14E+07	6.44E+05	4.94E+07	2.32E+07
216	3.03E+07	2.85E+08	4.44E+06	9.82E+05	1.27E+05	1.58E+07	1.14E+06	6.29E+07	2.41E+08
217	3.08E+07	3.27E+05	4.69E+06	3.76E+07	1.16E+05	1.17E+07	6.18E+05	5.39E+07	7.13E+06
218	3.07E+07	5.61E+07	4.67E+06	1.49E+07	1.22E+05	1.16E+07	8.60E+05	5.39E+07	4.00E+07
219	3.01E+07	6.90E+08	4.85E+06	9.98E+04	1.23E+05	2.12E+07	2.76E+06	8.30E+07	6.18E+08
220	3.07E+07	9.77E+06	4.90E+06	4.99E+07	1.24E+05	1.35E+07	6.78E+05	6.65E+07	1.45E+07
221	3.07E+07	0.00E+00	4.85E+06	5.17E+07	8.25E+06	1.24E+07	6.24E+05	6.14E+07	4.66E+06
222	3.07E+07	7.30E+07	4.62E+06	2.10E+07	7.06E+05	1.47E+07	7.04E+05	6.44E+07	4.88E+07
223	3.04E+07	6.42E+07	4.54E+06	2.36E+07	7.71E+06	1.37E+07	9.33E+05	6.30E+07	3.73E+07
224	3.06E+07	1.36E+08	5.21E+06	2.68E+07	1.66E+07	1.66E+07	7.82E+05	6.66E+07	9.81E+07
225	3.06E+07	1.36E+08	5.02E+06	2.65E+07	1.68E+07	1.39E+07	1.00E+06	6.59E+07	1.01E+08
226	3.07E+07	1.16E+05	4.88E+06	4.96E+07	5.66E+06	1.28E+07	6.33E+05	6.14E+07	4.83E+06
227	3.07E+07	5.18E+04	4.84E+06	4.34E+07	1.37E+05	1.24E+07	6.22E+05	5.93E+07	6.57E+06
228	3.07E+07	2.14E+06	4.82E+06	3.87E+07	1.26E+05	1.22E+07	6.41E+05	5.80E+07	5.39E+06
229	3.07E+07	5.97E+02	4.80E+06	3.76E+07	1.16E+05	1.19E+07	6.16E+05	5.68E+07	3.70E+06
230	3.07E+07	0.00E+00	4.79E+06	3.57E+07	6.47E+04	1.17E+07	6.14E+05	5.59E+07	2.99E+06
231	3.08E+07	0.00E+00	4.78E+06	3.43E+07	6.25E+04	1.16E+07	6.11E+05	5.51E+07	2.48E+06
232	3.08E+07	4.27E+05	4.76E+06	3.27E+07	6.55E+04	1.14E+07	6.10E+05	5.44E+07	2.14E+06
233	3.07E+07	2.08E+07	4.74E+06	3.18E+07	1.20E+07	1.15E+07	6.13E+05	5.48E+07	9.07E+06
234	3.08E+07	7.37E+06	4.72E+06	2.93E+07	9.02E+05	1.13E+07	6.08E+05	5.41E+07	5.16E+06
235	3.08E+07	2.53E+05	4.73E+06	4.05E+07	1.12E+07	1.11E+07	6.06E+05	5.30E+07	4.66E+05
236	3.08E+07	0.00E+00	4.73E+06	5.26E+07	2.41E+07	1.10E+07	6.05E+05	5.21E+07	3.98E+05
237	3.08E+07	2.62E+05	4.73E+06	5.12E+07	2.38E+07	1.09E+07	6.03E+05	5.14E+07	3.99E+05

238	3.08E+07	9.98E+06	4.78E+06	3.28E+07	7.90E+06	1.13E+07	6.06E+05	5.16E+07	7.03E+06
239	3.08E+07	1.21E+06	4.71E+06	3.21E+07	7.26E+04	1.08E+07	6.01E+05	5.07E+07	6.68E+06
240	3.08E+07	0.00E+00	4.68E+06	3.08E+07	6.68E+04	1.07E+07	5.99E+05	5.02E+07	4.73E+06
241	3.08E+07	0.00E+00	4.66E+06	2.91E+07	6.11E+04	1.06E+07	5.98E+05	4.98E+07	3.55E+06
242	3.08E+07	8.05E+03	4.64E+06	2.79E+07	8.47E+04	1.05E+07	5.97E+05	4.94E+07	2.77E+06
243	3.08E+07	6.17E+05	4.62E+06	2.65E+07	8.47E+04	1.04E+07	5.95E+05	4.92E+07	2.35E+06
244	3.08E+07	8.97E+02	4.61E+06	2.62E+07	8.58E+04	1.03E+07	5.95E+05	4.88E+07	1.88E+06
245	3.08E+07	1.83E+05	4.62E+06	3.55E+07	1.17E+07	1.03E+07	5.94E+05	4.84E+07	2.43E+05
246	3.00E+07	1.52E+08	4.45E+06	4.84E+06	8.99E+05	1.21E+07	1.28E+06	5.61E+07	1.21E+08
247	3.03E+07	2.49E+07	4.54E+06	3.42E+07	1.09E+07	1.07E+07	7.78E+05	5.23E+07	1.94E+07
248	3.07E+07	3.16E+05	4.56E+06	5.04E+07	2.38E+07	1.05E+07	6.35E+05	5.02E+07	9.45E+05
249	3.06E+07	1.63E+07	4.48E+06	4.55E+07	2.32E+07	1.04E+07	6.75E+05	5.00E+07	1.27E+07
250	3.08E+07	2.08E+03	4.55E+06	3.49E+07	7.78E+06	1.03E+07	6.31E+05	4.89E+07	2.66E+06
251	3.08E+07	2.67E+04	4.54E+06	3.07E+07	9.51E+04	1.02E+07	6.28E+05	4.83E+07	6.82E+06
252	3.08E+07	1.84E+06	4.51E+06	2.73E+07	8.75E+04	1.01E+07	6.25E+05	4.80E+07	5.55E+06
253	3.08E+07	0.00E+00	4.49E+06	2.69E+07	8.00E+04	1.00E+07	6.22E+05	4.76E+07	3.84E+06
254	3.08E+07	0.00E+00	4.48E+06	2.57E+07	7.40E+04	9.97E+06	6.19E+05	4.73E+07	3.04E+06
255	3.08E+07	2.49E+07	4.50E+06	1.69E+07	7.41E+04	1.05E+07	6.40E+05	4.82E+07	1.76E+07
256	3.08E+07	2.99E+07	4.70E+06	1.62E+07	7.50E+04	1.10E+07	6.24E+05	4.92E+07	2.07E+07
257	3.08E+07	1.13E+06	4.62E+06	3.55E+07	1.31E+07	1.02E+07	6.12E+05	4.77E+07	5.01E+05
258	2.99E+07	3.31E+08	4.25E+06	6.25E+05	9.85E+05	1.25E+07	1.64E+06	6.51E+07	2.86E+08
259	3.05E+07	5.66E+07	4.47E+06	3.23E+07	1.22E+07	1.21E+07	7.79E+05	5.78E+07	4.10E+07
260	3.07E+07	8.98E+00	4.54E+06	5.81E+07	2.66E+07	1.08E+07	6.57E+05	5.32E+07	2.12E+06
261	3.07E+07	2.00E+03	4.48E+06	5.36E+07	2.52E+07	1.06E+07	6.49E+05	5.14E+07	1.05E+06
262	3.07E+07	3.89E+06	4.45E+06	3.57E+07	8.32E+06	1.05E+07	6.89E+05	5.06E+07	4.63E+06
263	3.07E+07	0.00E+00	4.46E+06	3.30E+07	8.32E+04	1.03E+07	6.39E+05	4.98E+07	7.34E+06
264	3.07E+07	1.42E+07	4.45E+06	2.43E+07	7.65E+04	1.03E+07	6.73E+05	4.97E+07	1.30E+07
265	3.08E+07	0.00E+00	4.44E+06	2.89E+07	7.00E+04	1.02E+07	6.32E+05	4.89E+07	4.31E+06
266	3.08E+07	5.05E+06	4.43E+06	2.39E+07	1.88E+05	1.02E+07	6.28E+05	4.87E+07	4.54E+06
267	3.07E+07	1.04E+08	4.38E+06	6.37E+06	1.88E+05	1.10E+07	7.09E+05	5.34E+07	8.00E+07
268	3.01E+07	2.57E+08	4.24E+06	9.49E+05	1.91E+05	1.23E+07	1.41E+06	6.33E+07	2.15E+08
269	3.07E+07	2.62E+04	4.36E+06	4.64E+07	9.54E+06	1.06E+07	6.66E+05	5.51E+07	5.58E+06
270	3.07E+07	8.34E+05	4.34E+06	3.30E+07	8.67E+05	1.04E+07	6.70E+05	5.29E+07	4.06E+06
271	3.07E+07	5.68E+07	4.65E+06	3.12E+07	8.92E+06	1.39E+07	6.65E+05	5.59E+07	4.39E+07
272	3.07E+07	5.35E+05	4.58E+06	4.85E+07	1.93E+07	1.11E+07	6.46E+05	5.23E+07	1.00E+06
273	3.08E+07	2.32E+04	4.51E+06	4.65E+07	1.89E+07	1.08E+07	6.38E+05	5.10E+07	5.63E+05
274	3.08E+07	1.28E+04	4.49E+06	3.44E+07	6.19E+06	1.06E+07	6.34E+05	5.02E+07	2.06E+06
275	3.07E+07	7.50E+05	4.47E+06	3.07E+07	5.74E+04	1.05E+07	6.74E+05	4.97E+07	5.83E+06
276	3.08E+07	1.45E+06	4.43E+06	2.82E+07	5.28E+04	1.04E+07	6.30E+05	4.93E+07	4.42E+06
277	3.08E+07	7.00E+06	4.46E+06	2.45E+07	4.83E+04	1.07E+07	6.27E+05	4.93E+07	6.14E+06
278	3.08E+07	1.66E+07	4.52E+06	2.03E+07	1.51E+05	1.08E+07	6.27E+05	4.95E+07	1.11E+07
279	3.08E+07	3.55E+07	4.61E+06	1.49E+07	1.46E+05	1.16E+07	6.33E+05	5.09E+07	2.25E+07
280	3.08E+07	4.58E+04	4.51E+06	2.71E+07	1.54E+05	1.06E+07	6.19E+05	4.90E+07	2.10E+06

281	3.07E+07	3.04E+06	4.45E+06	3.11E+07	8.45E+06	1.04E+07	6.81E+05	4.85E+07	1.33E+06
282	3.05E+07	2.79E+08	4.54E+06	1.19E+06	7.51E+05	1.35E+07	1.15E+06	6.31E+07	2.37E+08
283	3.07E+07	3.24E+06	4.60E+06	3.99E+07	7.46E+06	1.10E+07	6.36E+05	5.47E+07	4.69E+06
284	3.08E+07	0.00E+00	4.49E+06	4.50E+07	1.59E+07	1.07E+07	6.23E+05	5.21E+07	8.87E+05
285	3.08E+07	1.80E+03	4.48E+06	4.30E+07	1.58E+07	1.06E+07	6.19E+05	5.09E+07	3.87E+05
286	3.08E+07	0.00E+00	4.49E+06	3.28E+07	5.29E+06	1.05E+07	6.16E+05	5.01E+07	1.62E+06
287	3.08E+07	1.94E+04	4.48E+06	2.97E+07	4.96E+04	1.03E+07	6.14E+05	4.95E+07	4.55E+06
288	3.08E+07	0.00E+00	4.47E+06	2.80E+07	4.56E+04	1.03E+07	6.11E+05	4.90E+07	3.42E+06
289	3.08E+07	1.61E+06	4.45E+06	2.56E+07	4.17E+04	1.02E+07	6.26E+05	4.86E+07	3.02E+06
290	3.08E+07	0.00E+00	4.44E+06	2.58E+07	5.07E+04	1.01E+07	6.08E+05	4.81E+07	2.18E+06
291	3.08E+07	0.00E+00	4.43E+06	2.51E+07	5.08E+04	1.00E+07	6.05E+05	4.78E+07	1.84E+06
292	3.08E+07	9.75E+05	4.43E+06	2.36E+07	5.14E+04	9.97E+06	6.07E+05	4.75E+07	1.74E+06
293	3.08E+07	2.39E+04	4.41E+06	2.86E+07	5.81E+06	9.89E+06	6.02E+05	4.71E+07	4.67E+05
294	3.08E+07	1.88E+06	4.41E+06	2.29E+07	4.58E+05	9.88E+06	6.06E+05	4.69E+07	2.18E+06
295	3.08E+07	6.98E+06	4.41E+06	2.45E+07	5.22E+06	1.00E+07	6.86E+05	4.69E+07	3.83E+06
296	3.08E+07	2.10E+05	4.38E+06	3.31E+07	1.16E+07	9.79E+06	6.00E+05	4.63E+07	2.30E+05
297	3.08E+07	2.09E+05	4.36E+06	3.25E+07	1.15E+07	9.72E+06	5.97E+05	4.59E+07	1.98E+05
298	3.08E+07	2.89E+06	4.34E+06	2.39E+07	3.81E+06	9.68E+06	6.06E+05	4.57E+07	2.22E+06
299	3.08E+07	4.62E+07	4.35E+06	1.18E+07	5.70E+04	1.06E+07	6.86E+05	4.85E+07	3.33E+07
300	3.08E+07	2.37E+07	4.30E+06	1.58E+07	5.24E+04	1.02E+07	7.47E+05	4.80E+07	1.56E+07
301	3.08E+07	0.00E+00	4.35E+06	2.40E+07	4.79E+04	9.82E+06	6.01E+05	4.65E+07	2.20E+06
302	3.08E+07	5.12E+07	4.69E+06	1.38E+07	5.11E+04	1.06E+07	6.81E+05	4.87E+07	4.03E+07
303	3.08E+07	7.26E+07	4.97E+06	8.37E+06	5.11E+04	1.15E+07	8.51E+05	5.12E+07	5.30E+07
304	3.08E+07	1.65E+05	4.90E+06	2.56E+07	5.18E+04	1.03E+07	6.00E+05	4.85E+07	2.26E+06
305	3.08E+07	0.00E+00	4.69E+06	2.96E+07	6.73E+06	1.01E+07	5.93E+05	4.73E+07	5.43E+05
306	2.97E+07	6.17E+08	4.74E+06	1.94E+04	5.22E+05	2.17E+07	3.14E+06	8.19E+07	5.44E+08
307	3.05E+07	1.33E+07	4.82E+06	5.10E+07	6.27E+06	1.28E+07	1.08E+06	6.27E+07	1.68E+07
308	3.07E+07	6.08E+05	4.77E+06	5.07E+07	1.30E+07	1.18E+07	6.50E+05	5.75E+07	3.74E+06
309	3.07E+07	0.00E+00	4.76E+06	4.61E+07	1.24E+07	1.15E+07	6.35E+05	5.52E+07	1.90E+06
310	3.07E+07	0.00E+00	4.72E+06	3.66E+07	4.18E+06	1.13E+07	6.28E+05	5.37E+07	2.31E+06
311	3.07E+07	1.40E+02	4.71E+06	3.31E+07	5.74E+04	1.11E+07	6.23E+05	5.27E+07	4.16E+06
312	3.07E+07	2.30E+06	4.69E+06	2.96E+07	5.28E+04	1.10E+07	6.20E+05	5.20E+07	3.64E+06
313	3.08E+07	1.09E+06	4.66E+06	2.87E+07	4.83E+04	1.08E+07	6.19E+05	5.13E+07	2.43E+06
314	3.08E+07	1.18E+07	4.66E+06	2.28E+07	9.79E+04	1.12E+07	6.33E+05	5.13E+07	6.81E+06
315	3.07E+07	8.47E+07	4.71E+06	9.90E+06	9.80E+04	1.29E+07	7.67E+05	5.55E+07	6.07E+07
316	3.08E+07	3.92E+06	4.69E+06	2.76E+07	9.92E+04	1.11E+07	6.31E+05	5.22E+07	2.91E+06
317	3.08E+07	1.27E+07	4.62E+06	2.72E+07	7.06E+06	1.10E+07	6.09E+05	5.18E+07	4.85E+06
318	3.08E+07	2.59E+07	4.56E+06	1.80E+07	5.96E+05	1.10E+07	6.08E+05	5.24E+07	1.47E+07
319	3.05E+07	1.27E+08	4.24E+06	1.06E+07	6.33E+06	1.14E+07	7.21E+05	5.78E+07	9.58E+07
320	3.08E+07	0.00E+00	4.45E+06	4.38E+07	1.40E+07	1.06E+07	6.12E+05	5.28E+07	1.01E+06
321	3.08E+07	5.16E+04	4.48E+06	4.14E+07	1.42E+07	1.05E+07	6.09E+05	5.13E+07	2.45E+05
322	3.08E+07	2.62E+04	4.49E+06	3.22E+07	4.77E+06	1.04E+07	6.06E+05	5.05E+07	1.28E+06
323	3.06E+07	2.23E+08	5.15E+06	6.87E+06	1.10E+05	1.56E+07	1.15E+06	6.17E+07	1.87E+08

324	3.08E+07	3.12E+02	5.08E+06	3.70E+07	1.01E+05	1.17E+07	6.18E+05	5.52E+07	5.52E+06
325	3.08E+07	0.00E+00	4.95E+06	3.23E+07	9.25E+04	1.12E+07	6.06E+05	5.32E+07	3.04E+06
326	3.08E+07	2.58E+05	4.87E+06	2.99E+07	1.01E+05	1.10E+07	6.04E+05	5.21E+07	2.14E+06
327	3.08E+07	4.92E+05	4.82E+06	2.85E+07	9.72E+04	1.08E+07	6.01E+05	5.13E+07	1.73E+06
328	3.08E+07	5.00E+05	4.79E+06	2.76E+07	1.02E+05	1.07E+07	6.03E+05	5.07E+07	1.64E+06
329	3.04E+07	5.06E+07	4.46E+06	2.12E+07	8.97E+06	1.09E+07	7.60E+05	5.32E+07	3.29E+07
330	3.08E+07	0.00E+00	4.62E+06	2.89E+07	7.12E+05	1.06E+07	6.14E+05	5.07E+07	1.70E+06
331	3.08E+07	1.62E+05	4.64E+06	3.32E+07	7.66E+06	1.05E+07	6.10E+05	4.99E+07	2.29E+05
332	3.08E+07	1.83E+03	4.63E+06	4.13E+07	1.66E+07	1.04E+07	6.08E+05	4.91E+07	1.17E+05
333	3.08E+07	0.00E+00	4.61E+06	4.05E+07	1.64E+07	1.03E+07	6.05E+05	4.86E+07	1.40E+05
334	3.08E+07	0.00E+00	4.60E+06	3.04E+07	5.54E+06	1.02E+07	6.03E+05	4.81E+07	1.43E+06
335	3.08E+07	6.59E+06	4.61E+06	2.52E+07	1.13E+05	1.04E+07	6.02E+05	4.83E+07	7.79E+06
336	3.08E+07	1.26E+07	4.63E+06	2.25E+07	1.04E+05	1.10E+07	5.99E+05	4.86E+07	1.03E+07
337	3.04E+07	1.26E+08	4.60E+06	8.14E+06	9.51E+04	1.41E+07	1.02E+06	5.55E+07	9.80E+07
338	3.03E+07	3.58E+08	5.02E+06	1.63E+06	1.19E+05	2.63E+07	1.01E+06	7.21E+07	2.96E+08
339	2.94E+07	5.38E+08	4.96E+06	5.47E+05	1.19E+05	2.64E+07	2.66E+06	8.53E+07	4.59E+08
340	3.04E+07	1.37E+08	5.10E+06	1.94E+07	1.20E+05	2.44E+07	7.96E+05	7.66E+07	9.02E+07
341	3.06E+07	2.42E+07	5.24E+06	4.85E+07	6.09E+06	1.87E+07	7.07E+05	6.83E+07	1.47E+07
342	3.06E+07	1.86E+06	5.24E+06	4.83E+07	5.52E+05	1.57E+07	7.19E+05	6.38E+07	5.30E+06
343	3.07E+07	6.02E+07	5.30E+06	2.85E+07	5.70E+06	1.87E+07	6.88E+05	6.58E+07	3.38E+07
344	3.07E+07	0.00E+00	5.35E+06	5.51E+07	1.21E+07	1.52E+07	6.73E+05	6.15E+07	1.66E+06
345	3.06E+07	4.88E+06	5.23E+06	5.05E+07	1.25E+07	1.45E+07	6.97E+05	5.99E+07	3.60E+06
346	3.06E+07	1.43E+07	5.23E+06	3.51E+07	4.26E+06	1.42E+07	8.27E+05	5.91E+07	6.77E+06
347	3.04E+07	7.87E+07	5.13E+06	1.33E+07	1.33E+05	1.72E+07	1.11E+06	6.27E+07	4.64E+07
348	3.06E+07	2.22E+07	5.22E+06	2.72E+07	1.23E+05	1.47E+07	7.11E+05	6.04E+07	9.23E+06
349	3.07E+07	4.03E+05	5.21E+06	3.89E+07	1.12E+05	1.38E+07	6.72E+05	5.82E+07	2.45E+06
350	3.07E+07	0.00E+00	5.18E+06	3.71E+07	1.06E+05	1.34E+07	6.64E+05	5.69E+07	1.86E+06
351	3.07E+07	3.23E+03	5.16E+06	3.56E+07	1.06E+05	1.31E+07	6.58E+05	5.61E+07	1.51E+06
352	3.07E+07	2.75E+05	5.15E+06	3.41E+07	1.08E+05	1.28E+07	6.54E+05	5.53E+07	1.30E+06
353	3.07E+07	5.13E+05	5.16E+06	3.70E+07	5.08E+06	1.26E+07	6.49E+05	5.46E+07	5.37E+05
354	3.07E+07	3.13E+07	5.18E+06	2.23E+07	4.69E+05	1.33E+07	6.65E+05	5.57E+07	1.93E+07
355	3.07E+07	1.20E+06	5.16E+06	3.55E+07	4.76E+06	1.25E+07	6.51E+05	5.43E+07	4.32E+05
356	3.08E+07	1.59E+04	5.15E+06	4.05E+07	1.01E+07	1.22E+07	6.39E+05	5.33E+07	2.39E+05
357	3.07E+07	9.32E+06	5.01E+06	3.63E+07	9.90E+06	1.20E+07	8.01E+05	5.32E+07	5.35E+06
358	3.05E+07	1.94E+08	4.86E+06	7.78E+06	3.38E+06	1.39E+07	1.25E+06	6.19E+07	1.57E+08
359	2.93E+07	6.92E+08	4.99E+06	6.24E+03	1.19E+05	2.38E+07	3.35E+06	9.13E+07	6.08E+08
360	2.96E+07	3.61E+08	5.03E+06	5.20E+06	1.10E+05	2.42E+07	2.49E+06	9.06E+07	2.83E+08
361	3.04E+07	4.74E+07	5.20E+06	4.82E+07	1.00E+05	1.79E+07	8.29E+05	7.80E+07	3.45E+07
362	3.04E+07	1.44E+08	5.22E+06	1.97E+07	1.00E+05	2.32E+07	1.01E+06	8.09E+07	9.40E+07
363	3.03E+07	2.21E+08	5.09E+06	1.68E+07	1.01E+05	2.85E+07	1.33E+06	8.66E+07	1.57E+08
364	3.01E+07	9.37E+07	5.24E+06	3.90E+07	1.02E+05	1.88E+07	1.72E+06	7.98E+07	6.76E+07
365	3.05E+07	6.60E+02	5.31E+06	6.51E+07	4.80E+06	1.69E+07	8.13E+05	7.39E+07	4.45E+06
366	3.03E+07	1.57E+08	5.14E+06	1.22E+07	4.43E+05	2.32E+07	1.59E+06	8.12E+07	9.79E+07

367	3.05E+07	1.47E+07	5.34E+06	5.66E+07	4.49E+06	1.74E+07	8.02E+05	7.40E+07	1.04E+07
368	3.05E+07	1.08E+06	5.31E+06	6.35E+07	9.88E+06	1.62E+07	7.69E+05	7.08E+07	2.70E+06
369	3.05E+07	1.27E+06	5.29E+06	6.03E+07	1.02E+07	1.56E+07	7.52E+05	6.87E+07	2.15E+06
370	3.05E+07	1.46E+06	5.28E+06	5.20E+07	3.48E+06	1.51E+07	7.51E+05	6.71E+07	2.75E+06
371	3.06E+07	3.57E+05	5.27E+06	4.89E+07	1.13E+05	1.47E+07	7.29E+05	6.58E+07	3.74E+06
372	3.06E+07	0.00E+00	5.26E+06	4.66E+07	1.04E+05	1.43E+07	7.20E+05	6.46E+07	2.70E+06
373	3.06E+07	2.78E+07	5.21E+06	3.13E+07	9.49E+04	1.56E+07	7.38E+05	6.52E+07	1.31E+07
374	3.04E+07	2.12E+08	5.10E+06	5.56E+06	9.99E+04	2.31E+07	1.17E+06	7.78E+07	1.51E+08
375	3.06E+07	0.00E+00	5.24E+06	5.27E+07	9.65E+04	1.58E+07	7.16E+05	6.87E+07	3.19E+06
376	2.99E+07	2.60E+08	5.14E+06	7.07E+06	1.01E+05	1.79E+07	1.85E+06	8.04E+07	2.02E+08
377	3.05E+07	6.80E+07	5.15E+06	2.97E+07	6.14E+06	1.95E+07	7.61E+05	7.59E+07	3.10E+07
378	3.05E+07	0.00E+00	5.20E+06	5.41E+07	5.35E+05	1.56E+07	7.26E+05	7.01E+07	2.81E+06
379	3.05E+07	1.81E+04	5.18E+06	5.48E+07	5.73E+06	1.49E+07	7.17E+05	6.78E+07	1.43E+06
380	3.06E+07	1.22E+05	5.17E+06	5.88E+07	1.23E+07	1.44E+07	7.17E+05	6.60E+07	1.12E+06
381	3.06E+07	1.72E+04	5.17E+06	5.69E+07	1.23E+07	1.41E+07	7.04E+05	6.46E+07	9.23E+05
382	3.06E+07	3.76E+07	5.10E+06	2.91E+07	4.19E+06	1.48E+07	7.09E+05	6.60E+07	1.67E+07
383	3.06E+07	9.89E+05	5.14E+06	4.51E+07	1.12E+05	1.38E+07	6.94E+05	6.37E+07	3.54E+06
384	3.06E+07	2.43E+05	5.14E+06	4.32E+07	1.03E+05	1.35E+07	6.88E+05	6.25E+07	2.41E+06
385	3.06E+07	2.17E+04	5.13E+06	4.15E+07	9.44E+04	1.32E+07	6.84E+05	6.16E+07	1.73E+06
386	3.06E+07	3.90E+05	5.12E+06	3.97E+07	8.13E+04	1.30E+07	6.80E+05	6.08E+07	1.35E+06
387	3.06E+07	4.51E+07	5.05E+06	2.63E+07	8.14E+04	1.63E+07	6.91E+05	6.31E+07	2.69E+07
388	3.06E+07	2.31E+07	5.02E+06	2.65E+07	8.24E+04	1.44E+07	6.85E+05	6.24E+07	7.70E+06
389	3.06E+07	0.00E+00	5.07E+06	4.34E+07	4.75E+06	1.32E+07	6.71E+05	6.02E+07	3.19E+05
390	3.04E+07	4.39E+07	4.92E+06	2.53E+07	4.18E+05	1.37E+07	7.71E+05	6.18E+07	2.78E+07
391	2.99E+07	4.40E+08	5.05E+06	6.59E+05	4.44E+06	2.37E+07	2.13E+06	8.34E+07	3.62E+08
392	3.06E+07	3.16E+05	5.22E+06	6.30E+07	9.79E+06	1.54E+07	7.29E+05	6.99E+07	3.48E+06
393	3.06E+07	2.04E+05	5.16E+06	5.67E+07	1.01E+07	1.43E+07	6.97E+05	6.60E+07	1.60E+06
394	3.06E+07	2.86E+07	5.12E+06	3.38E+07	3.43E+06	1.49E+07	6.97E+05	6.57E+07	1.34E+07
395	3.06E+07	1.55E+05	5.12E+06	4.54E+07	9.13E+04	1.38E+07	6.84E+05	6.35E+07	3.23E+06
396	3.06E+07	0.00E+00	5.11E+06	4.29E+07	8.40E+04	1.35E+07	6.79E+05	6.22E+07	2.20E+06
397	3.06E+07	0.00E+00	5.10E+06	4.10E+07	7.68E+04	1.32E+07	6.75E+05	6.12E+07	1.59E+06
398	3.06E+07	1.11E+06	5.08E+06	3.87E+07	8.17E+04	1.30E+07	6.72E+05	6.04E+07	1.40E+06
399	3.06E+07	5.53E+07	5.15E+06	1.84E+07	8.18E+04	1.42E+07	6.81E+05	6.30E+07	3.15E+07
400	3.06E+07	2.22E+08	5.35E+06	9.18E+06	8.28E+04	2.24E+07	7.76E+05	7.50E+07	1.69E+08
401	3.07E+07	4.87E+07	5.25E+06	3.55E+07	5.63E+06	1.89E+07	6.66E+05	6.98E+07	2.53E+07
402	3.06E+07	7.50E+07	5.37E+06	1.98E+07	4.79E+05	1.97E+07	6.86E+05	6.98E+07	4.01E+07
403	3.07E+07	1.00E+06	5.37E+06	5.00E+07	5.25E+06	1.53E+07	6.60E+05	6.53E+07	6.13E+05
404	3.07E+07	3.98E+05	5.28E+06	5.40E+07	1.16E+07	1.46E+07	6.57E+05	6.33E+07	3.36E+05
405	3.07E+07	1.22E+06	5.24E+06	5.18E+07	1.20E+07	1.41E+07	6.56E+05	6.20E+07	2.68E+05
406	3.07E+07	4.82E+06	5.20E+06	4.15E+07	4.06E+06	1.38E+07	6.80E+05	6.12E+07	2.52E+06
407	3.07E+07	2.55E+04	5.20E+06	4.13E+07	9.18E+04	1.34E+07	6.51E+05	6.01E+07	2.90E+06
408	3.07E+07	2.23E+06	5.18E+06	3.75E+07	8.44E+04	1.32E+07	6.55E+05	5.95E+07	2.20E+06
409	3.07E+07	5.85E+04	5.17E+06	3.77E+07	7.72E+04	1.29E+07	6.46E+05	5.87E+07	1.28E+06

410	3.07E+07	1.09E+07	5.15E+06	3.06E+07	8.98E+04	1.35E+07	6.44E+05	5.89E+07	4.24E+06
411	3.07E+07	3.04E+03	5.15E+06	3.61E+07	8.99E+04	1.27E+07	6.42E+05	5.78E+07	7.32E+05
412	3.07E+07	2.22E+06	5.12E+06	3.34E+07	9.10E+04	1.26E+07	6.41E+05	5.73E+07	8.64E+05
413	3.07E+07	2.20E+05	5.11E+06	3.92E+07	5.62E+06	1.23E+07	6.39E+05	5.65E+07	1.12E+05
414	3.07E+07	2.40E+07	5.34E+06	2.62E+07	4.88E+05	1.33E+07	6.49E+05	5.81E+07	1.37E+07
415	3.07E+07	0.00E+00	5.27E+06	3.86E+07	5.25E+06	1.23E+07	6.36E+05	5.64E+07	7.97E+04
416	3.08E+07	9.08E+04	5.20E+06	4.38E+07	1.16E+07	1.21E+07	6.34E+05	5.55E+07	5.59E+04
417	3.08E+07	1.07E+07	5.15E+06	3.67E+07	1.16E+07	1.20E+07	6.33E+05	5.52E+07	3.82E+06
418	3.08E+07	1.84E+08	5.40E+06	1.56E+07	3.94E+06	2.11E+07	6.44E+05	6.72E+07	1.43E+08
419	3.08E+07	1.10E+06	5.51E+06	4.11E+07	1.01E+05	1.42E+07	6.30E+05	5.98E+07	3.91E+06
420	3.07E+07	4.92E+07	5.19E+06	1.70E+07	9.28E+04	1.57E+07	6.89E+05	6.10E+07	2.48E+07
421	2.98E+07	4.49E+08	4.99E+06	2.96E+05	8.49E+04	2.55E+07	1.83E+06	8.29E+07	3.73E+08
422	3.04E+07	4.32E+07	5.32E+06	3.59E+07	5.70E+04	1.73E+07	8.06E+05	7.03E+07	2.64E+07
423	3.07E+07	1.75E+05	5.39E+06	4.81E+07	5.51E+04	1.52E+07	6.71E+05	6.55E+07	2.90E+06
424	3.07E+07	2.37E+05	5.36E+06	4.38E+07	5.78E+04	1.46E+07	6.67E+05	6.33E+07	1.55E+06
425	3.07E+07	3.45E+05	5.33E+06	4.45E+07	3.61E+06	1.41E+07	6.62E+05	6.18E+07	6.91E+05
426	3.07E+07	3.07E+05	5.31E+06	4.00E+07	3.13E+05	1.38E+07	6.58E+05	6.06E+07	9.84E+05
427	3.07E+07	1.65E+07	5.29E+06	3.13E+07	3.37E+06	1.42E+07	6.60E+05	6.08E+07	4.75E+06
428	3.07E+07	9.32E+06	5.27E+06	3.86E+07	7.45E+06	1.35E+07	7.05E+05	5.97E+07	2.46E+06
429	3.07E+07	2.15E+07	5.24E+06	3.16E+07	7.36E+06	1.33E+07	7.59E+05	5.96E+07	7.94E+06
430	3.07E+07	5.43E+06	5.24E+06	3.55E+07	2.50E+06	1.29E+07	7.16E+05	5.86E+07	2.15E+06
431	3.07E+07	0.00E+00	5.24E+06	3.69E+07	6.41E+04	1.27E+07	6.48E+05	5.76E+07	1.88E+06
432	3.06E+07	1.47E+08	5.22E+06	8.11E+06	5.89E+04	2.08E+07	8.13E+05	6.72E+07	1.02E+08
433	3.00E+07	5.45E+08	4.87E+06	1.78E+05	5.39E+04	3.01E+07	1.97E+06	9.20E+07	4.55E+08
434	2.98E+07	4.73E+08	5.04E+06	7.37E+05	2.08E+05	2.83E+07	2.49E+06	9.75E+07	3.80E+08
435	2.98E+07	2.70E+08	5.05E+06	1.36E+07	2.08E+05	2.49E+07	1.76E+06	9.41E+07	1.97E+08
436	3.00E+07	1.28E+08	5.17E+06	1.59E+07	2.11E+05	2.15E+07	1.31E+06	8.75E+07	6.87E+07
437	3.00E+07	5.45E+07	5.20E+06	5.82E+07	5.56E+06	1.76E+07	1.39E+06	8.25E+07	4.08E+07
438	2.90E+07	4.42E+08	5.02E+06	3.68E+05	6.14E+05	2.24E+07	3.36E+06	1.01E+08	3.48E+08
439	3.03E+07	1.91E+06	5.24E+06	8.21E+07	5.24E+06	1.76E+07	8.78E+05	8.60E+07	9.88E+06
440	3.04E+07	8.43E+05	5.27E+06	7.91E+07	1.14E+07	1.65E+07	8.17E+05	8.06E+07	6.36E+06
441	3.04E+07	7.88E+05	5.27E+06	7.41E+07	1.18E+07	1.58E+07	8.13E+05	7.74E+07	4.85E+06
442	3.04E+07	6.17E+05	5.27E+06	6.39E+07	4.08E+06	1.54E+07	8.04E+05	7.51E+07	4.86E+06
443	3.04E+07	7.05E+04	5.27E+06	5.89E+07	2.34E+05	1.49E+07	7.75E+05	7.32E+07	5.62E+06
444	3.04E+07	3.30E+05	5.26E+06	5.54E+07	2.15E+05	1.46E+07	7.64E+05	7.16E+07	4.21E+06
445	3.05E+07	2.13E+05	5.25E+06	5.28E+07	1.97E+05	1.43E+07	7.56E+05	7.02E+07	3.29E+06
446	3.05E+07	0.00E+00	5.24E+06	5.08E+07	1.20E+05	1.40E+07	7.48E+05	6.89E+07	2.73E+06
447	3.05E+07	4.98E+06	5.23E+06	4.56E+07	1.20E+05	1.40E+07	7.41E+05	6.82E+07	3.26E+06
448	3.05E+07	6.82E+07	5.31E+06	2.77E+07	1.22E+05	1.71E+07	7.46E+05	7.20E+07	4.17E+07
449	3.05E+07	2.30E+07	5.37E+06	4.44E+07	7.12E+06	1.45E+07	7.33E+05	6.93E+07	1.16E+07
450	3.05E+07	3.07E+07	5.29E+06	3.31E+07	6.25E+05	1.49E+07	7.32E+05	6.91E+07	1.42E+07
451	3.05E+07	1.42E+05	5.28E+06	5.32E+07	6.65E+06	1.38E+07	7.20E+05	6.68E+07	1.25E+06
452	3.06E+07	5.22E+05	5.26E+06	5.88E+07	1.45E+07	1.35E+07	7.16E+05	6.54E+07	1.07E+06

453	3.06E+07	1.77E+04	5.25E+06	5.79E+07	1.47E+07	1.32E+07	7.11E+05	6.42E+07	9.30E+05
454	3.06E+07	1.14E+05	5.23E+06	4.83E+07	5.00E+06	1.30E+07	7.07E+05	6.33E+07	2.24E+06
455	3.06E+07	2.23E+07	5.17E+06	3.65E+07	1.35E+05	1.29E+07	7.07E+05	6.40E+07	1.68E+07
456	3.05E+07	2.32E+08	4.97E+06	7.88E+06	1.24E+05	1.50E+07	1.00E+06	7.55E+07	1.84E+08
457	3.06E+07	0.00E+00	5.10E+06	4.97E+07	1.13E+05	1.30E+07	7.05E+05	6.79E+07	3.65E+06
458	3.06E+07	1.86E+06	5.09E+06	4.41E+07	1.00E+05	1.27E+07	6.97E+05	6.57E+07	2.40E+06
459	3.06E+07	0.00E+00	5.09E+06	4.34E+07	1.01E+05	1.25E+07	6.90E+05	6.44E+07	1.37E+06
460	3.06E+07	4.18E+07	5.11E+06	2.62E+07	1.02E+05	1.29E+07	6.88E+05	6.60E+07	2.40E+07
461	3.06E+07	3.17E+06	5.15E+06	4.49E+07	5.62E+06	1.25E+07	6.84E+05	6.40E+07	1.03E+06
462	3.06E+07	8.96E+07	4.99E+06	2.46E+07	4.99E+05	1.81E+07	6.93E+05	6.86E+07	6.19E+07
463	2.99E+07	5.99E+08	4.98E+06	2.02E+06	5.25E+06	2.05E+07	2.22E+06	9.38E+07	5.14E+08
464	3.05E+07	4.35E+05	5.13E+06	7.45E+07	1.16E+07	1.46E+07	7.42E+05	7.76E+07	6.15E+06
465	3.05E+07	1.94E+08	4.96E+06	1.55E+07	1.20E+07	1.78E+07	7.88E+05	8.45E+07	1.30E+08
466	3.05E+07	1.78E+08	4.98E+06	1.62E+07	4.06E+06	1.66E+07	9.43E+05	8.61E+07	1.22E+08
467	3.05E+07	6.86E+06	5.05E+06	5.90E+07	1.13E+05	1.45E+07	7.37E+05	7.83E+07	7.76E+06
468	3.06E+07	0.00E+00	5.06E+06	5.76E+07	1.04E+05	1.39E+07	6.94E+05	7.48E+07	3.70E+06
469	3.06E+07	1.06E+06	5.05E+06	5.30E+07	9.49E+04	1.36E+07	6.89E+05	7.27E+07	2.65E+06
470	3.06E+07	1.57E+05	5.04E+06	5.13E+07	2.07E+05	1.33E+07	6.85E+05	7.09E+07	1.93E+06
471	3.06E+07	0.00E+00	5.03E+06	4.94E+07	2.00E+05	1.30E+07	6.80E+05	6.95E+07	1.51E+06
472	3.06E+07	3.45E+04	5.02E+06	4.76E+07	2.09E+05	1.28E+07	6.78E+05	6.83E+07	1.20E+06
473	3.06E+07	2.52E+04	5.00E+06	5.09E+07	5.35E+06	1.26E+07	6.75E+05	6.72E+07	7.34E+05
474	3.06E+07	1.27E+05	5.00E+06	4.54E+07	5.98E+05	1.24E+07	6.72E+05	6.62E+07	1.22E+06
475	3.06E+07	2.41E+07	4.98E+06	3.73E+07	5.03E+06	1.24E+07	6.73E+05	6.62E+07	1.26E+07
476	3.06E+07	6.83E+06	5.01E+06	4.81E+07	1.07E+07	1.23E+07	7.07E+05	6.53E+07	1.48E+06
477	3.03E+07	9.10E+07	4.95E+06	2.63E+07	1.11E+07	1.29E+07	1.51E+06	6.87E+07	5.84E+07
478	2.99E+07	2.17E+08	4.66E+06	1.17E+07	3.84E+06	1.42E+07	1.95E+06	7.80E+07	1.65E+08
479	3.05E+07	1.73E+05	4.83E+06	5.32E+07	2.32E+05	1.24E+07	7.41E+05	7.00E+07	5.25E+06
480	3.05E+07	3.29E+07	4.83E+06	3.55E+07	2.13E+05	1.45E+07	7.16E+05	6.97E+07	1.86E+07
481	3.04E+07	2.81E+07	4.80E+06	3.26E+07	1.95E+05	1.26E+07	7.82E+05	6.84E+07	1.38E+07
482	3.05E+07	3.93E+03	4.86E+06	4.57E+07	2.52E+05	1.22E+07	6.98E+05	6.62E+07	1.69E+06
483	3.02E+07	1.78E+08	4.79E+06	3.77E+06	2.52E+05	1.51E+07	1.52E+06	7.43E+07	1.26E+08
484	3.05E+07	0.00E+00	4.90E+06	4.86E+07	2.55E+05	1.26E+07	7.20E+05	6.85E+07	1.95E+06
485	2.97E+07	4.57E+08	4.65E+06	2.73E+06	5.22E+06	1.50E+07	3.30E+06	8.67E+07	3.84E+08
486	3.01E+07	1.79E+08	4.69E+06	2.31E+07	6.39E+05	1.42E+07	1.50E+06	8.41E+07	1.37E+08
487	3.04E+07	3.91E+07	4.75E+06	5.24E+07	4.93E+06	1.28E+07	7.89E+05	7.83E+07	2.98E+07
488	3.04E+07	4.06E+05	4.76E+06	6.67E+07	1.05E+07	1.23E+07	7.60E+05	7.46E+07	4.19E+06
489	3.04E+07	7.18E+06	4.77E+06	5.87E+07	1.08E+07	1.22E+07	7.51E+05	7.28E+07	4.52E+06
490	3.01E+07	6.30E+07	4.50E+06	4.14E+07	3.73E+06	1.21E+07	1.11E+06	7.50E+07	4.71E+07
491	3.02E+07	2.67E+07	4.65E+06	4.45E+07	1.67E+05	1.22E+07	8.19E+05	7.26E+07	2.02E+07
492	3.04E+07	2.42E+04	4.74E+06	5.10E+07	1.53E+05	1.18E+07	7.53E+05	6.98E+07	3.68E+06
493	2.98E+07	2.51E+08	4.88E+06	5.07E+06	1.40E+05	1.51E+07	1.33E+06	8.29E+07	1.91E+08
494	2.97E+07	2.68E+08	5.05E+06	3.93E+06	2.32E+05	2.00E+07	1.51E+06	8.89E+07	1.96E+08
495	3.02E+07	3.61E+07	5.23E+06	4.75E+07	2.32E+05	1.67E+07	9.44E+05	8.06E+07	2.08E+07

496	2.90E+07	6.36E+08	4.91E+06	7.77E+03	2.35E+05	2.69E+07	3.73E+06	1.08E+08	5.31E+08
497	3.01E+07	2.29E+06	5.24E+06	8.76E+07	8.84E+06	1.69E+07	9.46E+05	8.99E+07	8.73E+06
498	3.02E+07	2.51E+05	5.22E+06	7.11E+07	8.67E+05	1.53E+07	8.85E+05	8.41E+07	5.74E+06
499	3.03E+07	5.44E+04	5.16E+06	7.27E+07	8.29E+06	1.47E+07	8.54E+05	8.08E+07	3.62E+06
500	3.03E+07	1.39E+05	5.13E+06	7.88E+07	1.82E+07	1.42E+07	8.38E+05	7.82E+07	2.95E+06
501	3.03E+07	4.86E+02	5.10E+06	7.66E+07	1.88E+07	1.39E+07	8.25E+05	7.61E+07	2.47E+06
502	3.03E+07	0.00E+00	5.08E+06	6.36E+07	6.29E+06	1.35E+07	8.14E+05	7.44E+07	3.86E+06
503	3.00E+07	9.80E+07	4.81E+06	3.10E+07	1.33E+05	1.39E+07	1.29E+06	8.04E+07	6.82E+07
504	2.99E+07	1.09E+08	4.86E+06	2.34E+07	1.22E+05	1.46E+07	1.24E+06	8.10E+07	7.01E+07
505	3.02E+07	4.69E+07	4.97E+06	3.25E+07	1.12E+05	1.45E+07	8.68E+05	7.89E+07	2.04E+07
506	3.02E+07	1.02E+08	5.05E+06	2.22E+07	1.50E+05	1.57E+07	9.32E+05	8.07E+07	6.17E+07
507	3.02E+07	7.12E+07	5.17E+06	3.73E+07	1.50E+05	1.53E+07	9.66E+05	8.06E+07	4.68E+07
508	3.02E+07	1.75E+08	5.17E+06	1.03E+07	1.52E+05	1.67E+07	1.02E+06	8.61E+07	1.16E+08
509	2.95E+07	1.49E+08	5.02E+06	2.70E+07	7.99E+06	1.67E+07	2.50E+06	8.72E+07	9.64E+07
510	3.01E+07	4.32E+06	5.06E+06	6.12E+07	7.17E+05	1.43E+07	1.05E+06	8.03E+07	4.52E+06
511	3.02E+07	2.34E+06	5.04E+06	6.41E+07	7.46E+06	1.38E+07	9.07E+05	7.74E+07	2.17E+06
512	3.03E+07	1.57E+06	5.00E+06	7.05E+07	1.61E+07	1.34E+07	8.63E+05	7.53E+07	1.60E+06
513	3.03E+07	5.97E+05	4.98E+06	6.94E+07	1.62E+07	1.31E+07	8.44E+05	7.37E+07	1.35E+06
514	3.03E+07	7.94E+03	4.96E+06	5.90E+07	5.53E+06	1.29E+07	8.29E+05	7.23E+07	2.69E+06
515	3.03E+07	8.38E+05	4.95E+06	5.37E+07	1.68E+05	1.27E+07	8.16E+05	7.12E+07	4.89E+06
516	3.03E+07	3.35E+05	4.94E+06	5.14E+07	1.55E+05	1.25E+07	8.05E+05	7.02E+07	3.32E+06
517	3.03E+07	8.55E+07	4.90E+06	2.79E+07	1.42E+05	1.32E+07	8.22E+05	7.40E+07	6.06E+07
518	3.03E+07	3.70E+07	5.05E+06	3.12E+07	1.07E+05	1.41E+07	8.34E+05	7.32E+07	1.53E+07
519	3.03E+07	6.39E+07	5.01E+06	3.26E+07	1.03E+05	1.32E+07	9.48E+05	7.35E+07	4.41E+07
520	2.89E+07	5.16E+08	4.54E+06	1.44E+06	1.08E+05	1.70E+07	4.17E+06	9.57E+07	4.33E+08
521	2.99E+07	1.11E+08	4.73E+06	3.62E+07	7.59E+06	1.40E+07	1.62E+06	8.69E+07	7.18E+07
522	3.01E+07	1.55E+07	4.78E+06	5.90E+07	6.42E+05	1.33E+07	1.01E+06	8.12E+07	1.33E+07
523	3.02E+07	3.12E+07	4.77E+06	4.95E+07	7.08E+06	1.34E+07	9.32E+05	7.97E+07	1.46E+07
524	3.02E+07	3.04E+05	4.79E+06	7.20E+07	1.50E+07	1.27E+07	8.74E+05	7.63E+07	2.37E+06
525	3.02E+07	0.00E+00	4.79E+06	6.99E+07	1.55E+07	1.25E+07	8.56E+05	7.43E+07	1.85E+06
526	3.03E+07	8.82E+04	4.77E+06	5.90E+07	5.25E+06	1.23E+07	8.41E+05	7.28E+07	2.99E+06
527	3.02E+07	2.32E+08	5.18E+06	1.60E+07	1.20E+05	1.98E+07	1.20E+06	8.78E+07	1.74E+08
528	3.03E+07	1.49E+08	5.12E+06	2.60E+07	1.10E+05	2.57E+07	8.61E+05	8.84E+07	9.57E+07
529	3.03E+07	1.16E+07	5.36E+06	5.69E+07	1.01E+05	1.71E+07	8.26E+05	8.01E+07	6.05E+06
530	3.00E+07	4.52E+08	4.81E+06	3.67E+06	9.08E+04	3.52E+07	1.57E+06	1.04E+08	3.50E+08
531	2.93E+07	4.40E+08	4.97E+06	1.87E+06	9.09E+04	3.24E+07	2.40E+06	1.11E+08	3.30E+08
532	3.01E+07	4.67E+07	5.29E+06	5.89E+07	9.20E+04	2.08E+07	1.11E+06	9.58E+07	2.31E+07
533	3.02E+07	0.00E+00	5.35E+06	8.50E+07	8.53E+06	1.82E+07	8.91E+05	8.92E+07	3.69E+06
534	2.99E+07	5.01E+07	5.29E+06	5.01E+07	6.90E+05	1.79E+07	1.45E+06	8.87E+07	2.65E+07
535	3.00E+07	3.95E+06	5.31E+06	7.57E+07	7.95E+06	1.68E+07	1.06E+06	8.48E+07	4.43E+06
536	3.02E+07	0.00E+00	5.33E+06	8.27E+07	1.69E+07	1.62E+07	8.89E+05	8.21E+07	2.17E+06
537	3.02E+07	9.98E+04	5.33E+06	7.91E+07	1.63E+07	1.57E+07	8.68E+05	8.00E+07	1.92E+06
538	3.02E+07	4.25E+06	5.27E+06	6.46E+07	5.52E+06	1.53E+07	8.85E+05	7.87E+07	3.91E+06

539	3.03E+07	3.59E+03	5.26E+06	6.25E+07	1.02E+05	1.49E+07	8.43E+05	7.69E+07	5.26E+06
540	3.03E+07	1.75E+04	5.24E+06	5.93E+07	9.38E+04	1.46E+07	8.31E+05	7.56E+07	3.71E+06
541	3.03E+07	3.99E+04	5.23E+06	5.68E+07	8.58E+04	1.42E+07	8.21E+05	7.44E+07	2.77E+06
542	3.03E+07	1.05E+05	5.21E+06	5.47E+07	8.03E+04	1.40E+07	8.12E+05	7.33E+07	2.19E+06
543	3.03E+07	1.48E+07	5.19E+06	4.58E+07	8.04E+04	1.40E+07	8.32E+05	7.30E+07	8.12E+06
544	3.03E+07	5.96E+05	5.18E+06	5.17E+07	8.14E+04	1.36E+07	7.97E+05	7.18E+07	1.57E+06
545	3.03E+07	3.21E+07	5.13E+06	4.47E+07	6.66E+06	1.58E+07	7.92E+05	7.28E+07	1.61E+07
546	3.03E+07	3.62E+06	5.14E+06	4.94E+07	5.49E+05	1.38E+07	7.85E+05	7.10E+07	2.43E+06
547	3.03E+07	2.42E+06	5.11E+06	5.37E+07	6.22E+06	1.34E+07	8.41E+05	6.98E+07	1.40E+06
548	3.04E+07	1.07E+05	5.12E+06	6.06E+07	1.30E+07	1.31E+07	7.75E+05	6.87E+07	6.22E+05
549	3.04E+07	2.64E+05	5.11E+06	5.96E+07	1.34E+07	1.29E+07	7.68E+05	6.78E+07	5.35E+05
550	3.04E+07	1.08E+06	5.07E+06	5.06E+07	4.52E+06	1.27E+07	7.62E+05	6.71E+07	2.03E+06
551	3.00E+07	1.52E+08	5.15E+06	1.30E+07	9.02E+04	1.46E+07	1.71E+06	7.62E+07	1.07E+08
552	3.03E+07	3.21E+07	5.25E+06	2.99E+07	8.30E+04	1.37E+07	8.74E+05	7.23E+07	1.05E+07
553	3.03E+07	2.02E+07	5.20E+06	3.72E+07	7.59E+04	1.33E+07	9.26E+05	7.05E+07	8.16E+06
554	3.03E+07	4.00E+02	5.15E+06	4.82E+07	9.54E+04	1.27E+07	7.84E+05	6.86E+07	1.61E+06
555	3.03E+07	0.00E+00	5.11E+06	4.66E+07	9.55E+04	1.25E+07	7.72E+05	6.74E+07	1.26E+06
556	3.03E+07	7.13E+03	5.08E+06	4.52E+07	9.67E+04	1.23E+07	7.66E+05	6.65E+07	1.01E+06
557	3.04E+07	4.88E+05	5.06E+06	4.90E+07	5.89E+06	1.21E+07	7.59E+05	6.57E+07	4.41E+05
558	3.04E+07	1.56E+06	5.04E+06	4.27E+07	5.13E+05	1.20E+07	7.54E+05	6.50E+07	1.47E+06
559	3.04E+07	1.14E+07	5.02E+06	4.14E+07	5.50E+06	1.21E+07	7.48E+05	6.48E+07	5.11E+06
560	3.04E+07	1.74E+04	5.02E+06	5.23E+07	1.12E+07	1.18E+07	7.44E+05	6.37E+07	3.19E+05
561	3.04E+07	3.53E+05	5.01E+06	5.12E+07	1.13E+07	1.16E+07	7.40E+05	6.30E+07	3.33E+05
562	3.04E+07	1.53E+04	4.99E+06	4.45E+07	3.83E+06	1.15E+07	7.35E+05	6.24E+07	1.42E+06
563	3.04E+07	2.69E+05	4.97E+06	4.15E+07	1.07E+05	1.14E+07	7.32E+05	6.18E+07	3.09E+06
564	3.04E+07	0.00E+00	4.96E+06	4.01E+07	9.86E+04	1.13E+07	7.27E+05	6.13E+07	2.07E+06
565	3.04E+07	5.62E+02	4.95E+06	3.89E+07	9.02E+04	1.12E+07	7.24E+05	6.08E+07	1.46E+06
566	3.04E+07	1.25E+07	4.91E+06	3.20E+07	9.32E+04	1.12E+07	7.75E+05	6.09E+07	6.88E+06
567	3.04E+07	2.24E+07	4.87E+06	2.64E+07	9.01E+04	1.12E+07	7.74E+05	6.16E+07	1.05E+07
568	2.99E+07	2.37E+08	4.62E+06	2.29E+06	9.45E+04	1.36E+07	1.88E+06	7.33E+07	1.85E+08
569	3.04E+07	8.37E+04	4.78E+06	4.98E+07	5.42E+06	1.15E+07	7.68E+05	6.59E+07	1.39E+06
570	3.04E+07	8.62E+04	4.81E+06	4.22E+07	4.77E+05	1.13E+07	7.41E+05	6.37E+07	1.27E+06
571	3.04E+07	3.80E+07	4.72E+06	3.43E+07	4.63E+06	1.15E+07	8.06E+05	6.61E+07	2.45E+07
572	3.04E+07	9.05E+06	4.75E+06	4.39E+07	9.90E+06	1.14E+07	7.64E+05	6.36E+07	2.42E+06
573	3.04E+07	1.09E+06	4.80E+06	4.79E+07	9.96E+06	1.11E+07	7.44E+05	6.20E+07	4.28E+05
574	3.04E+07	1.97E+04	4.78E+06	4.20E+07	3.34E+06	1.09E+07	7.20E+05	6.10E+07	1.23E+06
575	3.04E+07	1.07E+07	4.87E+06	3.40E+07	1.05E+05	1.13E+07	7.42E+05	6.11E+07	6.80E+06
576	2.95E+07	4.94E+08	5.05E+06	6.16E+05	9.63E+04	2.36E+07	3.08E+06	9.00E+07	4.13E+08
577	3.03E+07	6.36E+06	5.21E+06	5.48E+07	8.81E+04	1.44E+07	8.10E+05	7.37E+07	7.76E+06
578	3.02E+07	1.70E+08	5.12E+06	4.86E+06	7.19E+04	1.59E+07	1.50E+06	7.69E+07	1.16E+08
579	3.02E+07	1.06E+08	5.20E+06	8.75E+06	7.20E+04	1.59E+07	1.03E+06	7.71E+07	5.62E+07
580	3.03E+07	0.00E+00	5.15E+06	5.23E+07	7.29E+04	1.33E+07	7.70E+05	7.15E+07	2.17E+06
581	3.03E+07	0.00E+00	5.09E+06	5.34E+07	5.04E+06	1.29E+07	7.56E+05	6.91E+07	1.10E+06

582	3.04E+07	6.98E+04	5.05E+06	4.73E+07	4.28E+05	1.26E+07	7.49E+05	6.75E+07	1.52E+06
583	3.03E+07	2.55E+07	4.99E+06	3.82E+07	4.70E+06	1.24E+07	8.80E+05	6.74E+07	1.35E+07
584	3.04E+07	1.02E+05	5.00E+06	5.41E+07	1.04E+07	1.21E+07	7.44E+05	6.57E+07	6.18E+05
585	3.03E+07	5.07E+07	4.92E+06	3.35E+07	1.07E+07	1.24E+07	1.02E+06	6.81E+07	2.71E+07
586	3.03E+07	1.23E+07	4.94E+06	4.23E+07	3.63E+06	1.20E+07	8.95E+05	6.61E+07	7.31E+06
587	3.04E+07	1.68E+07	4.93E+06	3.63E+07	8.08E+04	1.19E+07	7.36E+05	6.56E+07	1.00E+07
588	3.04E+07	0.00E+00	4.92E+06	4.33E+07	7.43E+04	1.16E+07	7.26E+05	6.39E+07	2.32E+06
589	3.04E+07	0.00E+00	4.91E+06	4.15E+07	6.80E+04	1.14E+07	7.22E+05	6.29E+07	1.62E+06
590	3.04E+07	0.00E+00	4.90E+06	4.02E+07	1.07E+05	1.13E+07	7.18E+05	6.21E+07	1.19E+06
591	3.04E+07	0.00E+00	4.88E+06	3.92E+07	1.07E+05	1.12E+07	7.14E+05	6.15E+07	9.28E+05
592	3.04E+07	6.84E+05	4.87E+06	3.77E+07	1.08E+05	1.11E+07	7.11E+05	6.09E+07	8.06E+05
593	3.04E+07	1.24E+06	4.85E+06	4.26E+07	6.42E+06	1.10E+07	7.07E+05	6.04E+07	5.52E+05
594	3.04E+07	1.99E+06	4.85E+06	3.64E+07	5.62E+05	1.10E+07	7.10E+05	5.99E+07	1.49E+06
595	3.04E+07	4.84E+06	4.81E+06	3.84E+07	6.00E+06	1.09E+07	7.10E+05	5.96E+07	1.30E+06
596	3.04E+07	6.73E+04	4.80E+06	4.80E+07	1.29E+07	1.08E+07	6.99E+05	5.88E+07	1.56E+05
597	3.05E+07	1.84E+06	4.79E+06	4.61E+07	1.30E+07	1.07E+07	7.01E+05	5.83E+07	5.51E+05
598	3.05E+07	2.86E+06	4.88E+06	3.84E+07	4.42E+06	1.07E+07	6.95E+05	5.80E+07	2.74E+06
599	3.05E+07	3.56E+06	4.82E+06	3.47E+07	1.20E+05	1.07E+07	6.92E+05	5.76E+07	4.36E+06
600	3.05E+07	1.10E+05	4.79E+06	3.54E+07	1.11E+05	1.05E+07	6.89E+05	5.70E+07	2.40E+06
601	3.03E+07	1.94E+07	4.72E+06	2.64E+07	1.01E+05	1.09E+07	8.06E+05	5.78E+07	1.12E+07
602	3.03E+07	5.88E+07	5.01E+06	2.01E+07	9.63E+04	1.34E+07	9.32E+05	6.08E+07	3.90E+07
603	3.03E+07	6.13E+07	5.21E+06	1.48E+07	9.64E+04	1.23E+07	1.03E+06	6.15E+07	3.66E+07
604	3.00E+07	4.03E+08	4.93E+06	1.14E+06	9.76E+04	1.62E+07	1.89E+06	8.07E+07	3.40E+08
605	3.02E+07	1.31E+08	4.91E+06	2.08E+07	4.21E+06	1.33E+07	1.44E+06	7.46E+07	9.37E+07
606	3.01E+07	3.54E+08	5.04E+06	4.83E+06	3.98E+05	2.01E+07	1.53E+06	8.83E+07	2.83E+08
607	3.01E+07	7.22E+08	4.81E+06	1.21E+07	3.94E+06	4.35E+07	2.14E+06	1.23E+08	5.97E+08
608	3.02E+07	5.41E+07	5.47E+06	7.18E+07	8.67E+06	2.11E+07	1.05E+06	9.58E+07	3.50E+07
609	3.03E+07	1.44E+08	5.43E+06	3.01E+07	8.69E+06	2.15E+07	9.75E+05	9.40E+07	8.51E+07
610	3.03E+07	8.62E+06	5.50E+06	7.11E+07	2.97E+06	1.75E+07	7.78E+05	8.63E+07	7.91E+06
611	3.03E+07	3.61E+06	5.52E+06	6.59E+07	1.08E+05	1.65E+07	7.55E+05	8.24E+07	5.51E+06
612	3.03E+07	0.00E+00	5.50E+06	6.34E+07	9.95E+04	1.58E+07	7.47E+05	7.93E+07	3.21E+06
613	3.03E+07	2.82E+06	5.48E+06	5.74E+07	9.10E+04	1.54E+07	7.47E+05	7.72E+07	2.62E+06
614	3.04E+07	2.15E+06	5.47E+06	5.50E+07	1.20E+05	1.49E+07	7.37E+05	7.54E+07	1.88E+06
615	3.03E+07	4.77E+07	5.42E+06	3.22E+07	1.16E+05	1.55E+07	7.85E+05	7.76E+07	2.17E+07
616	3.04E+07	9.13E+07	5.44E+06	2.08E+07	1.22E+05	1.61E+07	8.19E+05	7.90E+07	5.19E+07
617	3.04E+07	1.27E+08	5.51E+06	1.79E+07	5.32E+06	1.82E+07	7.38E+05	8.27E+07	7.36E+07
618	3.04E+07	4.98E+06	5.49E+06	5.48E+07	5.00E+05	1.50E+07	7.20E+05	7.70E+07	2.46E+06
619	3.04E+07	7.46E+07	5.34E+06	3.55E+07	4.98E+06	1.52E+07	7.23E+05	7.94E+07	4.54E+07
620	3.04E+07	1.99E+05	5.41E+06	6.54E+07	1.09E+07	1.42E+07	7.14E+05	7.47E+07	8.11E+05
621	3.04E+07	2.48E+07	5.44E+06	4.84E+07	1.05E+07	1.49E+07	7.10E+05	7.41E+07	8.85E+06
622	3.02E+07	9.81E+07	5.06E+06	4.07E+07	3.58E+06	1.42E+07	1.03E+06	7.89E+07	7.64E+07
623	3.03E+07	7.09E+07	5.09E+06	3.23E+07	1.35E+05	1.40E+07	9.00E+05	7.73E+07	4.63E+07
624	3.04E+07	0.00E+00	5.17E+06	5.46E+07	1.24E+05	1.34E+07	7.18E+05	7.31E+07	2.87E+06

625	3.04E+07	0.00E+00	5.18E+06	5.12E+07	1.14E+05	1.31E+07	7.09E+05	7.12E+07	1.69E+06
626	3.04E+07	5.91E+03	5.17E+06	4.91E+07	1.16E+05	1.29E+07	7.05E+05	6.98E+07	1.18E+06
627	3.04E+07	1.23E+05	5.16E+06	4.75E+07	1.16E+05	1.27E+07	7.00E+05	6.88E+07	9.05E+05
628	3.04E+07	1.57E+06	5.14E+06	4.51E+07	1.17E+05	1.26E+07	6.98E+05	6.78E+07	1.00E+06
629	3.04E+07	9.59E+06	5.14E+06	4.60E+07	5.72E+06	1.30E+07	7.27E+05	6.76E+07	4.18E+06
630	3.04E+07	9.34E+07	5.09E+06	3.31E+07	5.23E+05	2.01E+07	6.93E+05	7.33E+07	6.74E+07
631	3.04E+07	3.15E+03	5.22E+06	5.32E+07	5.35E+06	1.41E+07	6.89E+05	6.82E+07	5.06E+05
632	3.04E+07	4.02E+06	5.15E+06	5.44E+07	1.18E+07	1.35E+07	6.92E+05	6.70E+07	1.11E+06
633	3.05E+07	2.48E+07	5.09E+06	4.45E+07	1.18E+07	1.34E+07	6.89E+05	6.79E+07	1.11E+07
634	3.05E+07	4.90E+06	5.10E+06	4.55E+07	3.97E+06	1.29E+07	7.00E+05	6.60E+07	2.34E+06
635	3.04E+07	6.76E+07	5.06E+06	2.15E+07	1.30E+05	1.52E+07	7.03E+05	7.02E+07	3.84E+07
636	3.05E+07	0.00E+00	5.11E+06	4.64E+07	1.20E+05	1.31E+07	6.78E+05	6.61E+07	2.07E+06
637	3.05E+07	1.56E+04	5.07E+06	4.40E+07	1.09E+05	1.27E+07	6.76E+05	6.47E+07	1.40E+06
638	3.05E+07	2.09E+06	5.05E+06	4.11E+07	7.51E+04	1.27E+07	6.73E+05	6.40E+07	1.27E+06
639	3.05E+07	2.39E+08	5.16E+06	8.25E+06	7.52E+04	2.50E+07	9.49E+05	8.02E+07	1.77E+08
640	3.05E+07	2.52E+06	5.48E+06	4.84E+07	7.61E+04	1.51E+07	6.79E+05	6.97E+07	1.45E+06
641	3.05E+07	3.75E+06	5.33E+06	5.19E+07	8.74E+06	1.40E+07	6.70E+05	6.72E+07	9.27E+05
642	3.05E+07	3.52E+06	5.29E+06	4.47E+07	6.87E+05	1.35E+07	7.83E+05	6.58E+07	3.21E+06
643	3.05E+07	1.63E+07	5.20E+06	4.45E+07	8.14E+06	1.41E+07	6.74E+05	6.60E+07	7.49E+06
644	3.05E+07	3.74E+07	5.30E+06	4.53E+07	1.73E+07	1.41E+07	7.02E+05	6.61E+07	2.03E+07
645	3.05E+07	1.41E+04	5.21E+06	5.90E+07	1.67E+07	1.32E+07	6.68E+05	6.40E+07	1.76E+05
646	3.05E+07	6.12E+06	5.17E+06	4.47E+07	5.63E+06	1.32E+07	6.64E+05	6.35E+07	3.58E+06
647	3.05E+07	1.45E+06	5.17E+06	4.34E+07	8.43E+04	1.28E+07	6.62E+05	6.24E+07	4.68E+06
648	3.05E+07	1.56E+07	5.09E+06	3.33E+07	7.76E+04	1.27E+07	7.02E+05	6.24E+07	8.67E+06
649	3.05E+07	0.00E+00	5.11E+06	4.09E+07	7.10E+04	1.24E+07	6.59E+05	6.13E+07	2.17E+06
650	3.05E+07	0.00E+00	5.09E+06	3.94E+07	1.12E+05	1.22E+07	6.57E+05	6.06E+07	1.56E+06
651	3.06E+07	6.76E+04	5.08E+06	3.83E+07	1.12E+05	1.20E+07	6.55E+05	6.00E+07	1.21E+06
652	3.06E+07	4.07E+02	5.07E+06	3.74E+07	1.14E+05	1.18E+07	6.54E+05	5.94E+07	9.36E+05
653	3.06E+07	0.00E+00	5.05E+06	4.67E+07	1.10E+07	1.17E+07	6.52E+05	5.89E+07	8.23E+04
654	3.06E+07	1.61E+07	5.03E+06	3.08E+07	8.84E+05	1.20E+07	6.53E+05	5.92E+07	9.79E+06
655	3.06E+07	1.81E+04	5.03E+06	4.52E+07	1.02E+07	1.16E+07	6.49E+05	5.82E+07	6.01E+04
656	3.06E+07	0.00E+00	5.00E+06	5.66E+07	2.25E+07	1.15E+07	6.47E+05	5.75E+07	4.03E+04
657	3.06E+07	5.29E+04	4.99E+06	5.43E+07	2.07E+07	1.13E+07	6.46E+05	5.69E+07	2.73E+05
658	3.06E+07	0.00E+00	4.98E+06	4.20E+07	6.93E+06	1.12E+07	6.44E+05	5.64E+07	2.32E+06
659	3.06E+07	1.51E+06	4.97E+06	3.70E+07	1.26E+05	1.12E+07	6.43E+05	5.61E+07	6.04E+06
660	3.06E+07	4.26E+07	4.92E+06	2.36E+07	1.16E+05	1.12E+07	7.12E+05	5.76E+07	3.21E+07
661	3.05E+07	1.23E+08	4.71E+06	8.51E+06	1.06E+05	1.18E+07	8.86E+05	6.30E+07	9.11E+07
662	3.06E+07	5.10E+06	4.87E+06	3.49E+07	9.24E+04	1.13E+07	6.48E+05	5.92E+07	4.12E+06
663	3.03E+07	8.83E+07	4.55E+06	2.47E+07	8.93E+04	1.15E+07	1.09E+06	6.34E+07	7.18E+07
664	3.05E+07	5.80E+07	4.92E+06	2.17E+07	9.36E+04	1.31E+07	6.99E+05	6.27E+07	3.84E+07
665	3.04E+07	2.86E+07	4.92E+06	3.79E+07	1.17E+07	1.18E+07	8.27E+05	6.08E+07	1.68E+07
666	3.05E+07	1.57E+06	4.87E+06	3.76E+07	9.07E+05	1.15E+07	6.67E+05	5.90E+07	2.50E+06
667	3.06E+07	1.09E+06	4.86E+06	4.46E+07	1.08E+07	1.12E+07	6.60E+05	5.79E+07	4.27E+05

668	3.06E+07	1.65E+04	4.86E+06	5.63E+07	2.29E+07	1.11E+07	6.56E+05	5.70E+07	9.46E+04
669	3.06E+07	2.82E+03	4.85E+06	5.47E+07	2.22E+07	1.10E+07	6.53E+05	5.62E+07	1.14E+05
670	3.06E+07	1.24E+06	4.84E+06	4.04E+07	7.38E+06	1.09E+07	6.49E+05	5.57E+07	2.55E+06
671	3.06E+07	3.43E+04	4.83E+06	3.72E+07	1.04E+05	1.08E+07	6.47E+05	5.51E+07	6.01E+06
672	3.06E+07	0.00E+00	4.81E+06	3.49E+07	9.54E+04	1.07E+07	6.44E+05	5.46E+07	4.28E+06
673	3.06E+07	0.00E+00	4.80E+06	3.32E+07	8.73E+04	1.06E+07	6.42E+05	5.42E+07	3.14E+06
674	3.06E+07	8.05E+06	4.78E+06	2.94E+07	9.71E+04	1.05E+07	6.40E+05	5.40E+07	7.59E+06
675	3.06E+07	5.62E+07	4.73E+06	1.94E+07	9.72E+04	1.08E+07	7.13E+05	5.62E+07	4.32E+07
676	3.05E+07	6.74E+07	4.62E+06	1.88E+07	9.85E+04	1.07E+07	8.81E+05	5.74E+07	5.22E+07
677	3.06E+07	1.10E+08	5.22E+06	2.37E+07	1.11E+07	1.23E+07	7.98E+05	6.07E+07	8.45E+07
678	3.06E+07	5.36E+05	5.02E+06	3.69E+07	8.72E+05	1.09E+07	6.46E+05	5.73E+07	3.45E+06
679	3.06E+07	2.76E+06	4.91E+06	4.07E+07	1.03E+07	1.08E+07	6.39E+05	5.60E+07	1.17E+06
680	3.06E+07	2.62E+07	4.81E+06	3.92E+07	2.13E+07	1.09E+07	6.47E+05	5.66E+07	1.14E+07
681	3.06E+07	2.34E+06	4.83E+06	5.02E+07	2.08E+07	1.06E+07	6.58E+05	5.51E+07	7.54E+05
682	3.06E+07	9.27E+05	4.83E+06	3.87E+07	6.98E+06	1.05E+07	6.59E+05	5.42E+07	2.70E+06
683	3.06E+07	1.75E+05	4.81E+06	3.53E+07	1.09E+05	1.04E+07	6.30E+05	5.36E+07	6.09E+06
684	3.06E+07	3.33E+06	4.78E+06	3.16E+07	1.00E+05	1.04E+07	6.32E+05	5.34E+07	5.85E+06
685	3.06E+07	9.80E+05	4.76E+06	3.10E+07	9.18E+04	1.03E+07	6.27E+05	5.29E+07	3.46E+06

Appendix C: Regression plots for the time steps analyzed for transient model evaluation.

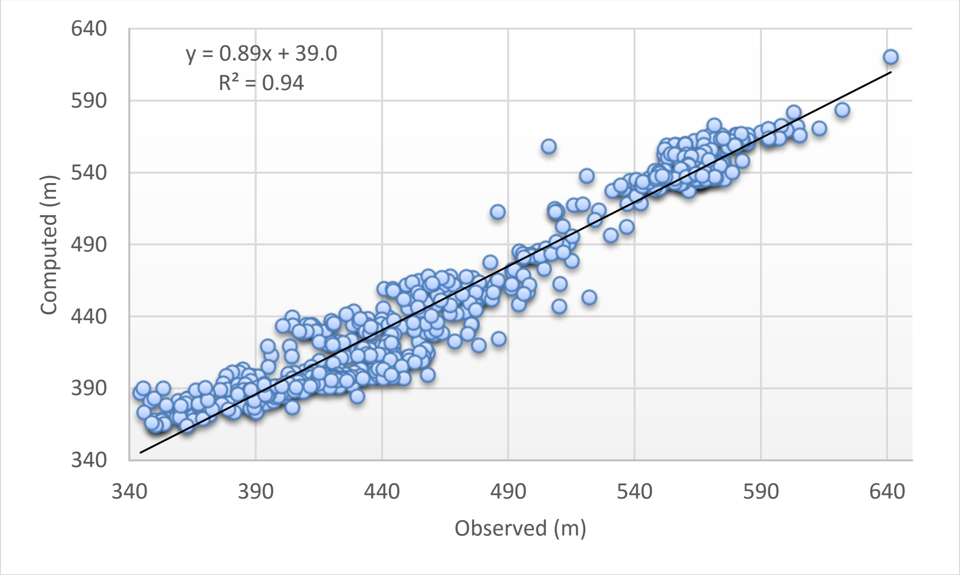


Figure 1. Observed versus computed head observations and corresponding equations for the time step 3/1/1980 of the transient simulation.

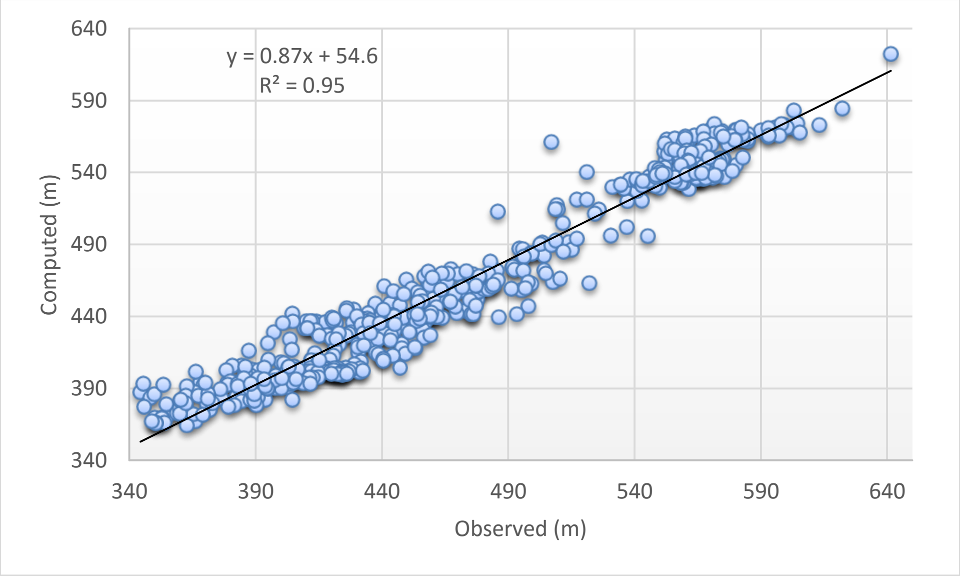


Figure 15. Observed verses computed head observations with corresponding equations for the time step 6/1/1990 of the transient simulation.

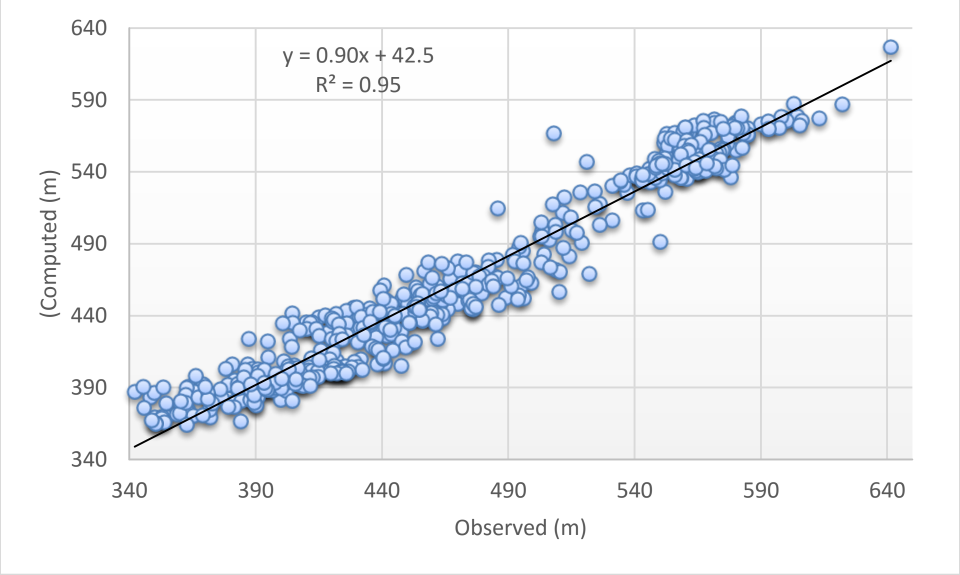


Figure 16. Observed versus computed head observations with the corresponding equations for time step 9/1/2000 of the transient simulation.

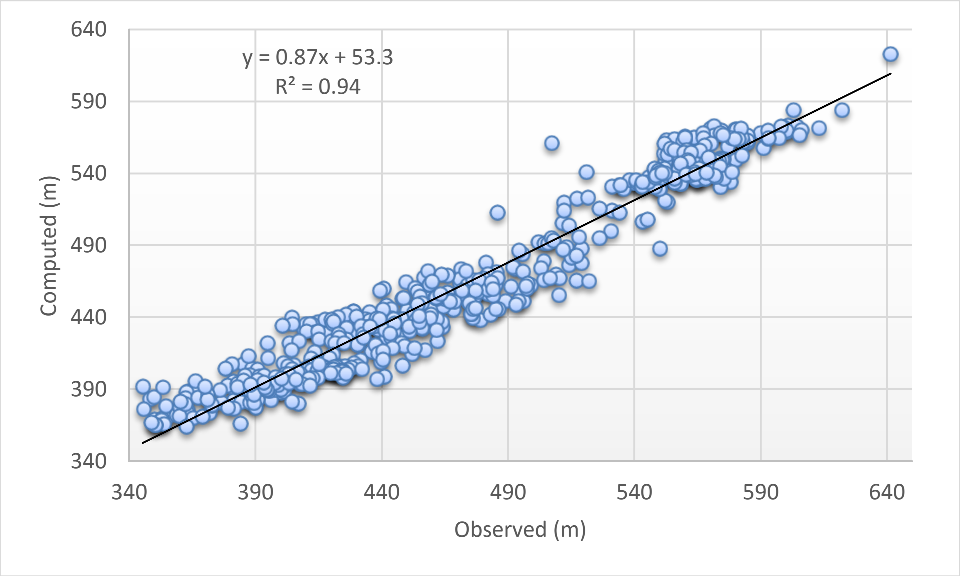


Figure 4.Observed versus computed head observations with the corresponding equations for time step 12/1/2010 of the transient simulation.

Appendix D: Simulated baseflow plots for each of the groundwater use baseflow analysis scenarios.

Current Conditions Simulation

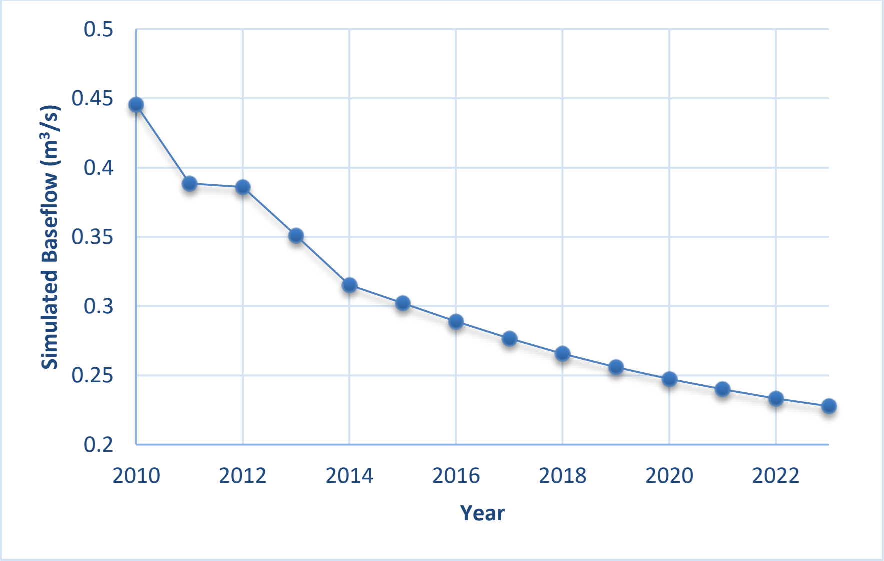


Figure 1. Simulated average annual baseflow for the USGS gage 07325800 on Cobb Creek near Eakly, OK for the entire model period, 1956 – 2023, (top) and for the simulation period, 2013 – 2023, (bottom) for the first groundwater use scenario which extended 2013 groundwater use through the simulation period.

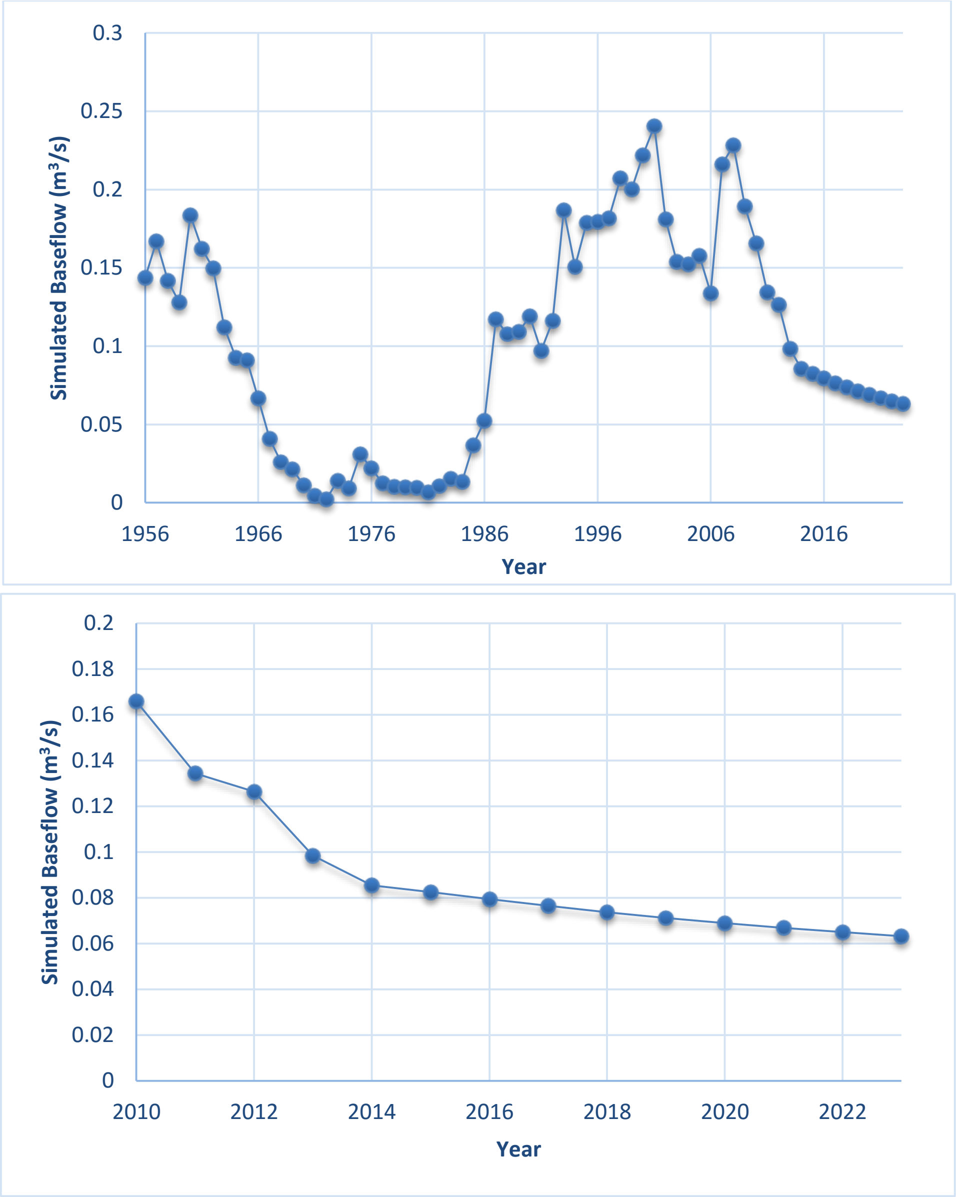


Figure 2. Simulated average annual baseflow for the USGS gage 07325850 on Lake Creek near Eakly, OK for the entire model period, 1956 – 2023, (top) and for the simulation period, 2013 – 2023, (bottom) for the first groundwater use scenario which extended 2013 groundwater use through the simulation period.

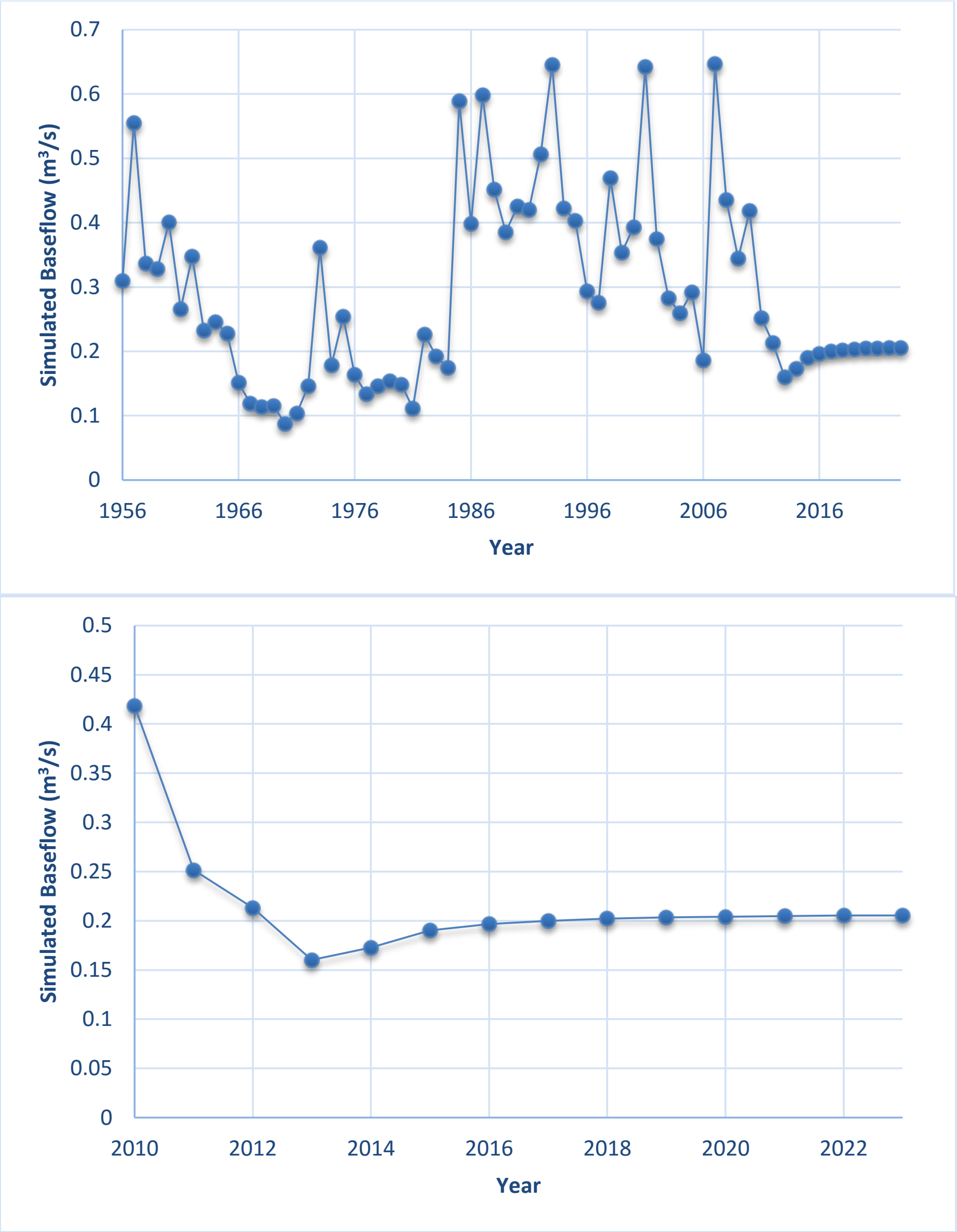
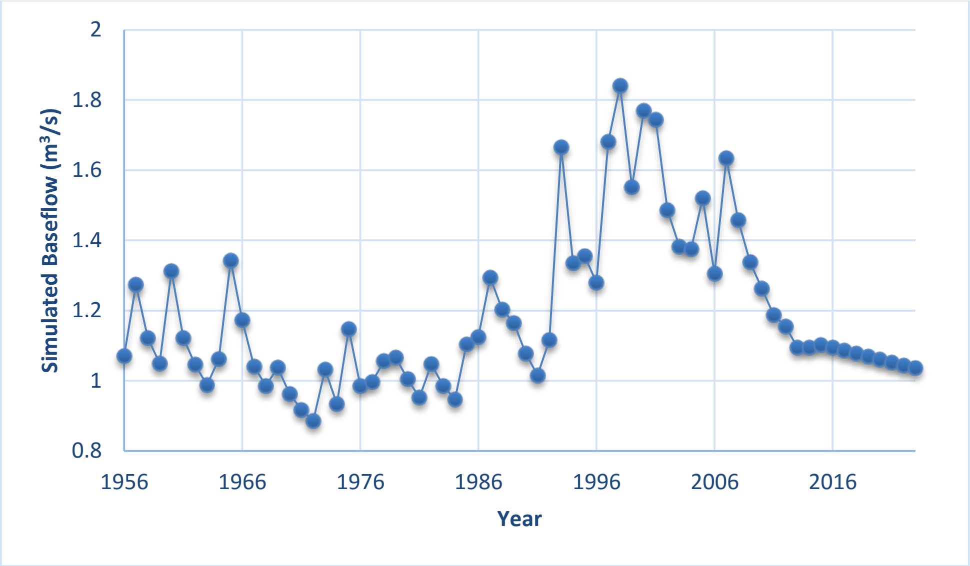


Figure 3. Simulated average annual baseflow for the USGS gage 07327447 on Little Washita River near Cement, OK for the entire model period, 1956 – 2023, (top) and for the simulation period, 2013 – 2023, (bottom) for the first groundwater use scenario which extended 2013 groundwater use through the simulation period.



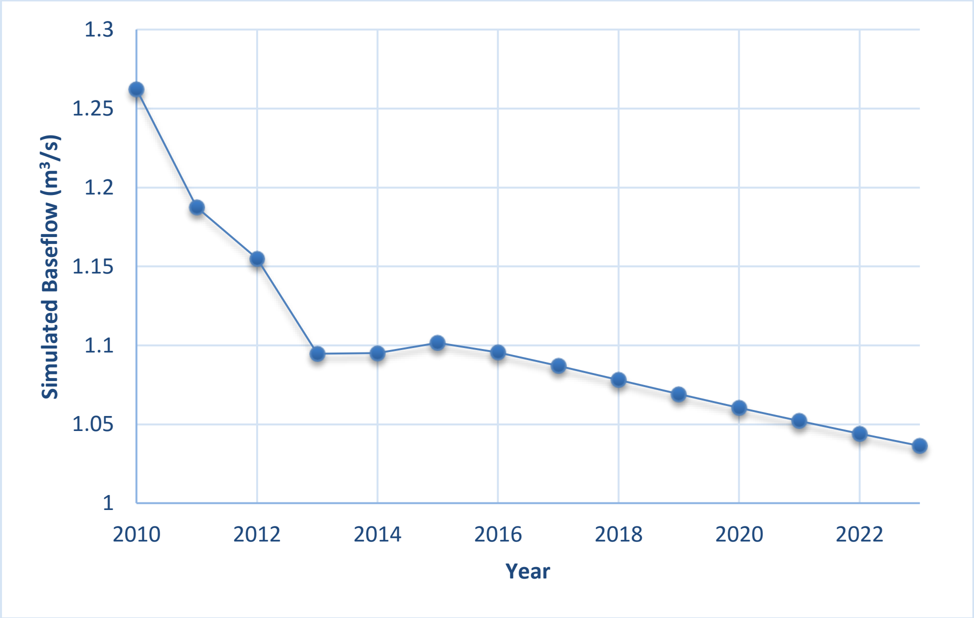


Figure 4. Simulated average annual baseflow for the USGS gage 07325000 on the Washita River near Clinton OK for the entire model period, 1956 – 2023, (top) and for the simulation period, 2013 – 2023, (bottom) for the first groundwater use scenario which extended 2013 groundwater use through the simulation period.

MAY Simulation

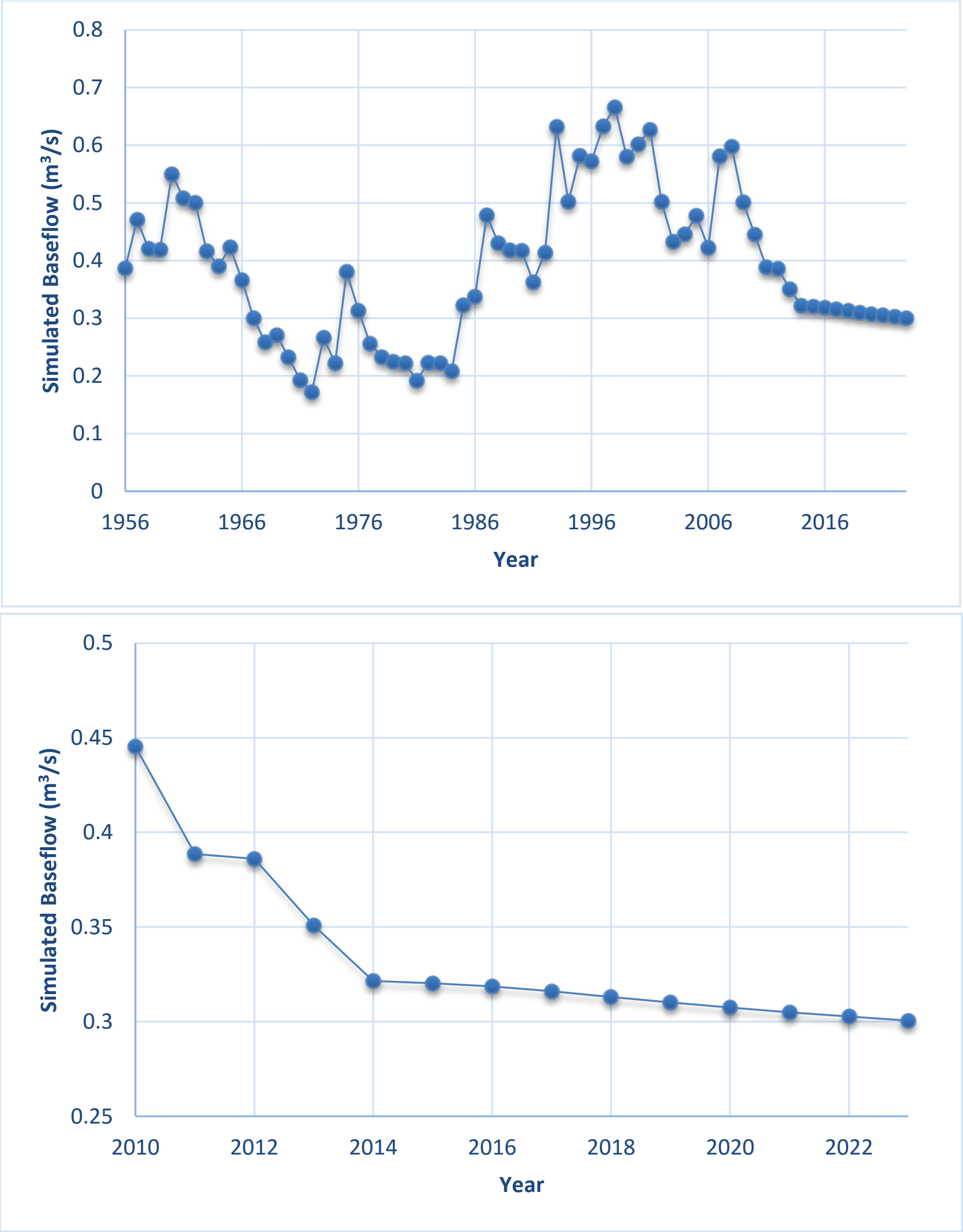


Figure 5. Simulated average annual baseflow for the USGS gage 07325800 on Cobb Creek near Eakly, OK for the entire model period, 1956 – 2023, (top) and for the simulation period, 2013 – 2023, (bottom) for the second groundwater use scenario which simulated each well pumping at a rate of 6093 m^3/ha per year.

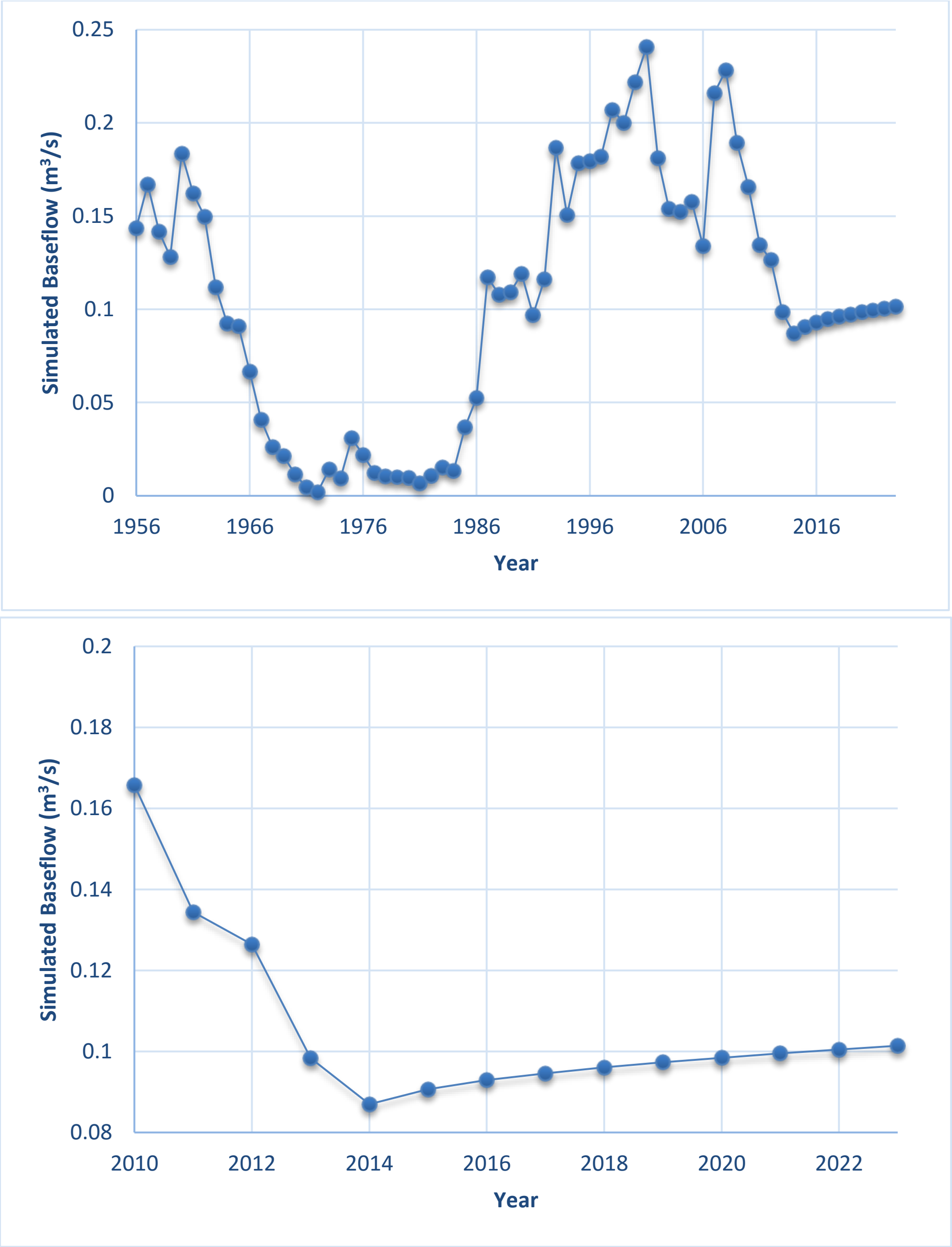


Figure 6. Simulated average annual baseflow for the USGS gage 07325850 on Lake Creek near Eakly, OK for the entire model period, 1956 – 2023, (top) and for the simulation period, 2013 – 2023, (bottom) for the second groundwater use scenario which simulated each well pumping at a rate of 6093 m^3/ha per year.

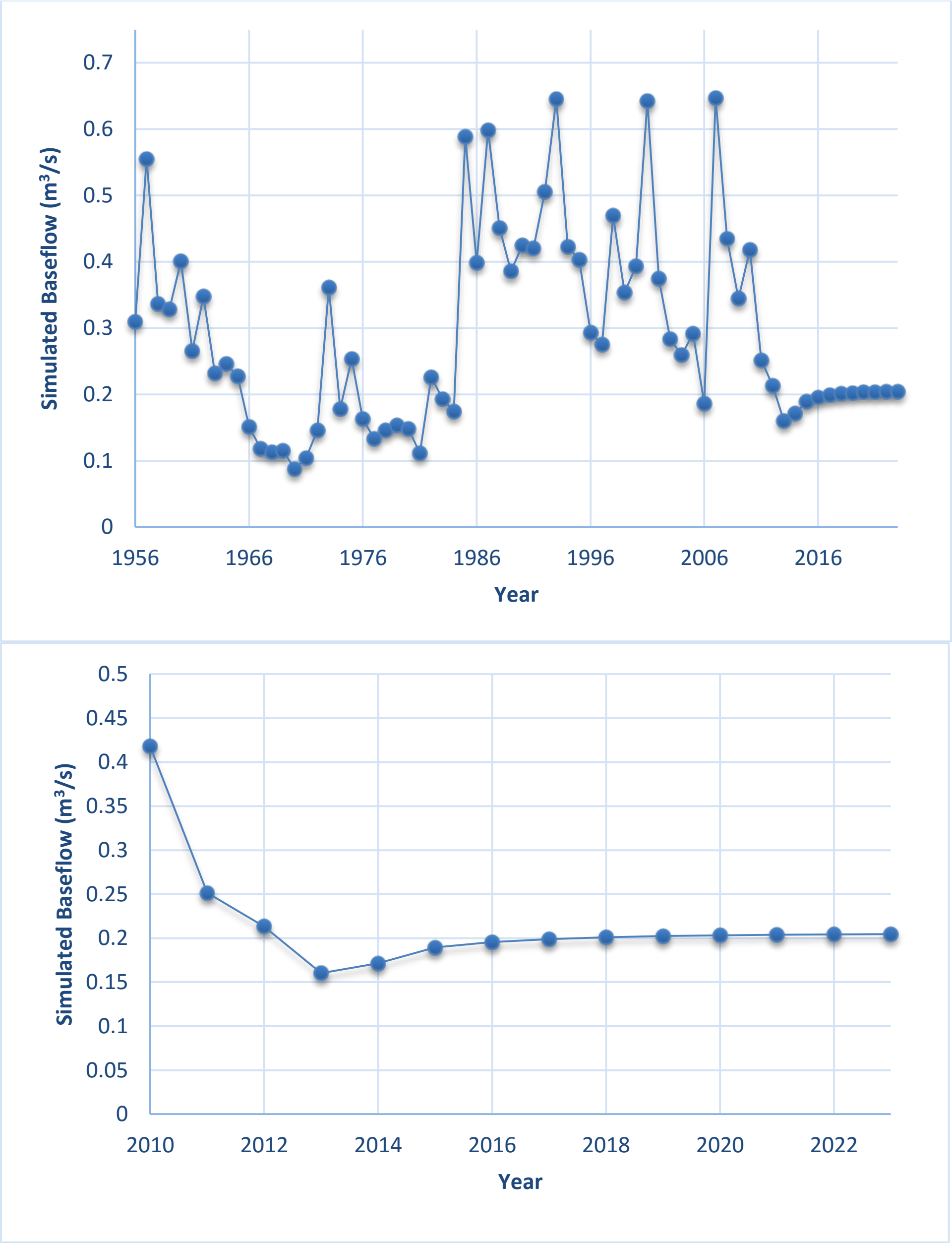


Figure 7. Simulated average annual baseflow for the USGS gage 07327447 on Little Washita River near Cement, OK for the entire model period, 1956 – 2023, (top) and for the simulation period, 2013 – 2023, (bottom) for the second groundwater use scenario which simulated each well pumping at a rate of 6093 m^3/ha per year.

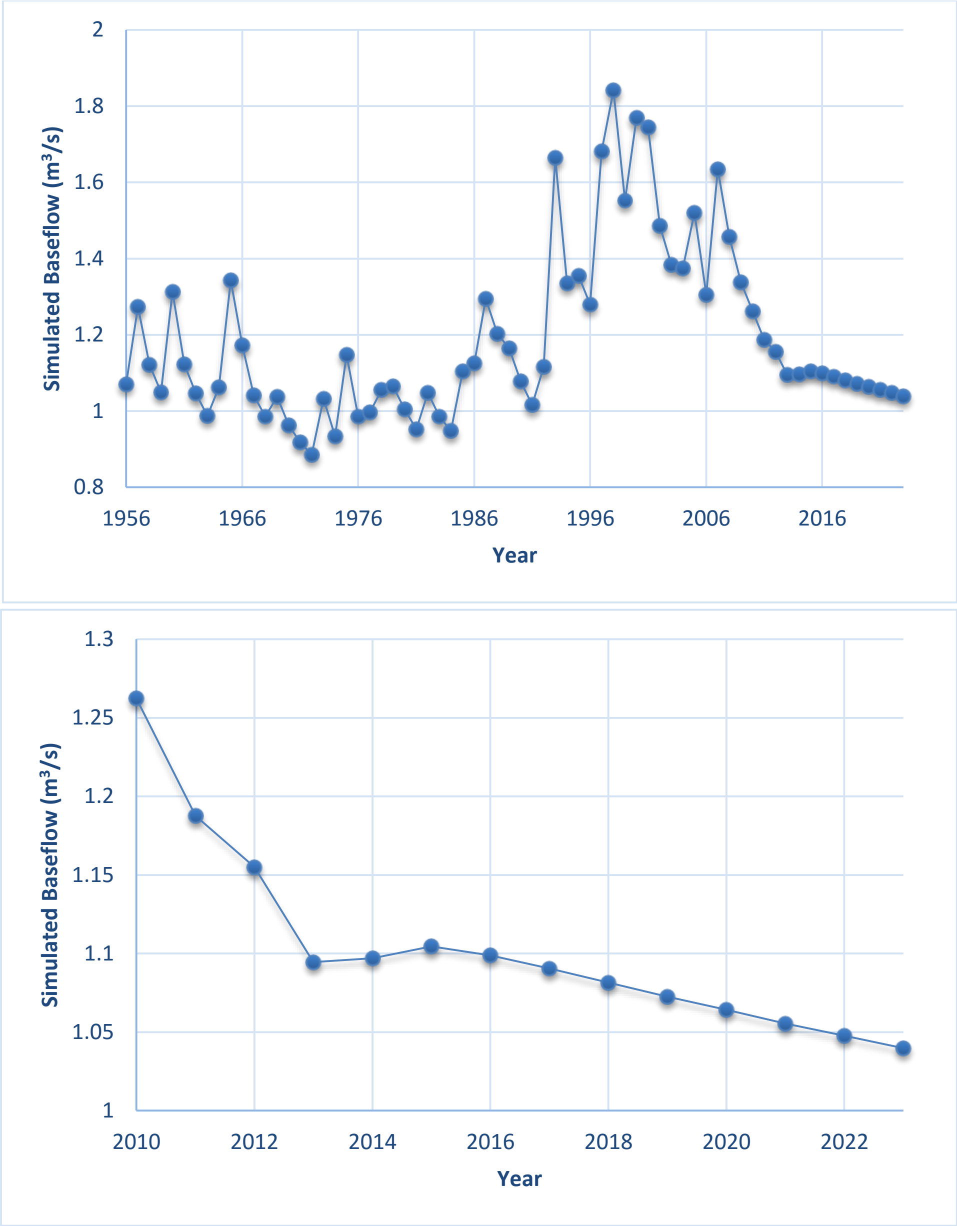
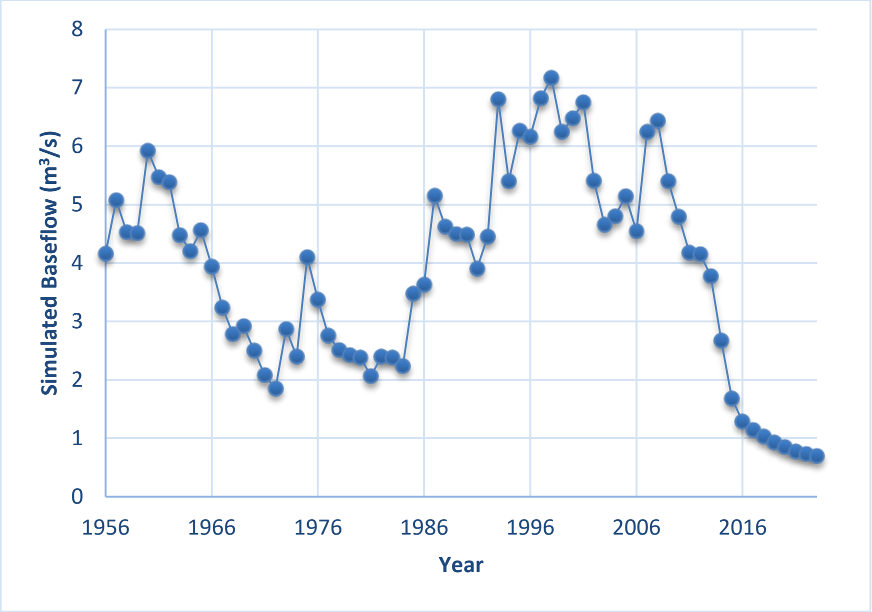


Figure 8. Simulated average annual baseflow for the USGS gage 07325000 on the Washita River near Clinton OK for the entire model period, 1956 – 2023, (top) and for the simulation period, 2013 – 2023, (bottom) for the second groundwater use scenario which simulated each well pumping at a rate of 6093 m^3/ha per year.

Maximum Irrigation Use Simulation



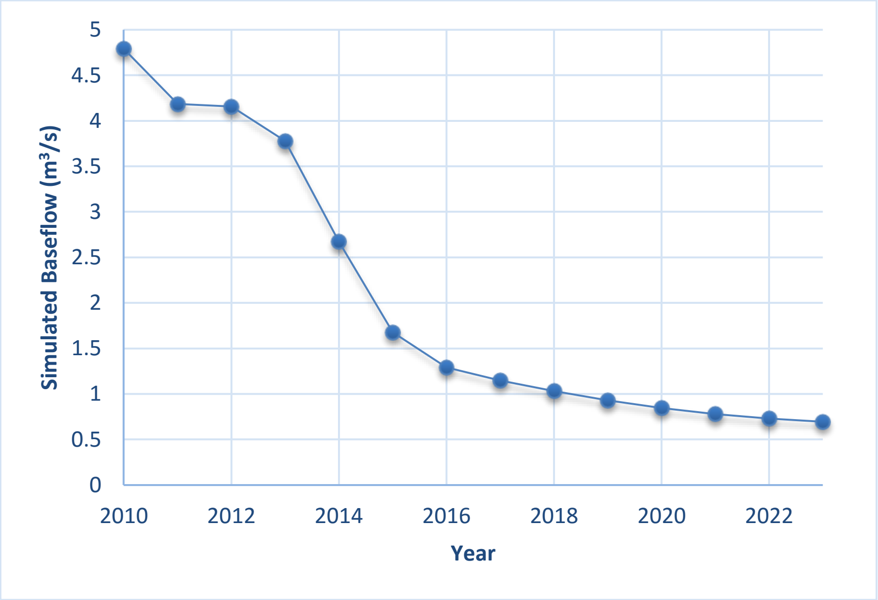


Figure 9. Simulated average annual baseflow for the USGS gage 07325800 on Cobb Creek near Eakly, OK for the entire model period, 1956 – 2023, (top) and for the simulation period, 2013 – 2023, (bottom) for the third groundwater use scenario which simulated each well pumping at a rate of approximately 5.5 mm/day for irrigation.

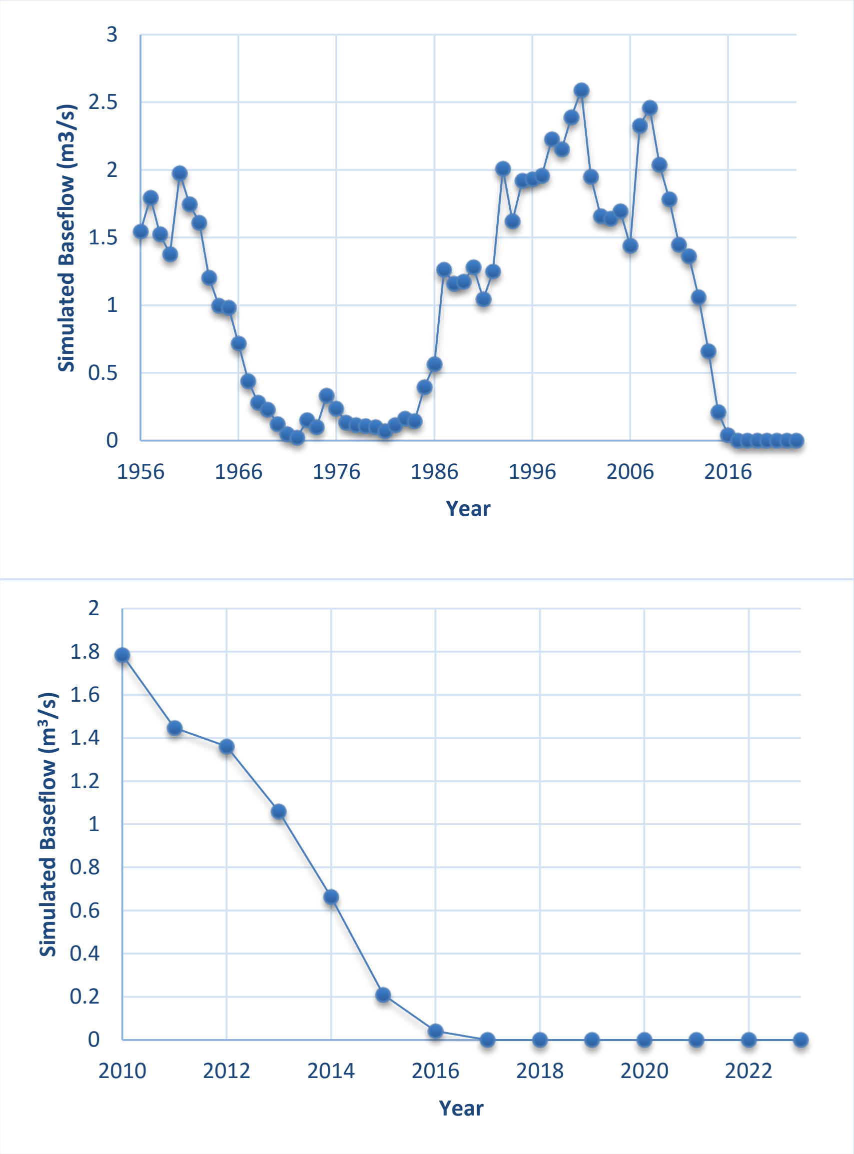


Figure 10. Simulated average annual baseflow for the USGS gage 07325850 on Lake Creek near Eakly, OK for the entire model period, 1956 – 2023, (top) and for the simulation period, 2013 – 2023, (bottom) for the third groundwater use scenario which simulated each well pumping at a rate of approximately 5.5 mm/day for irrigation.

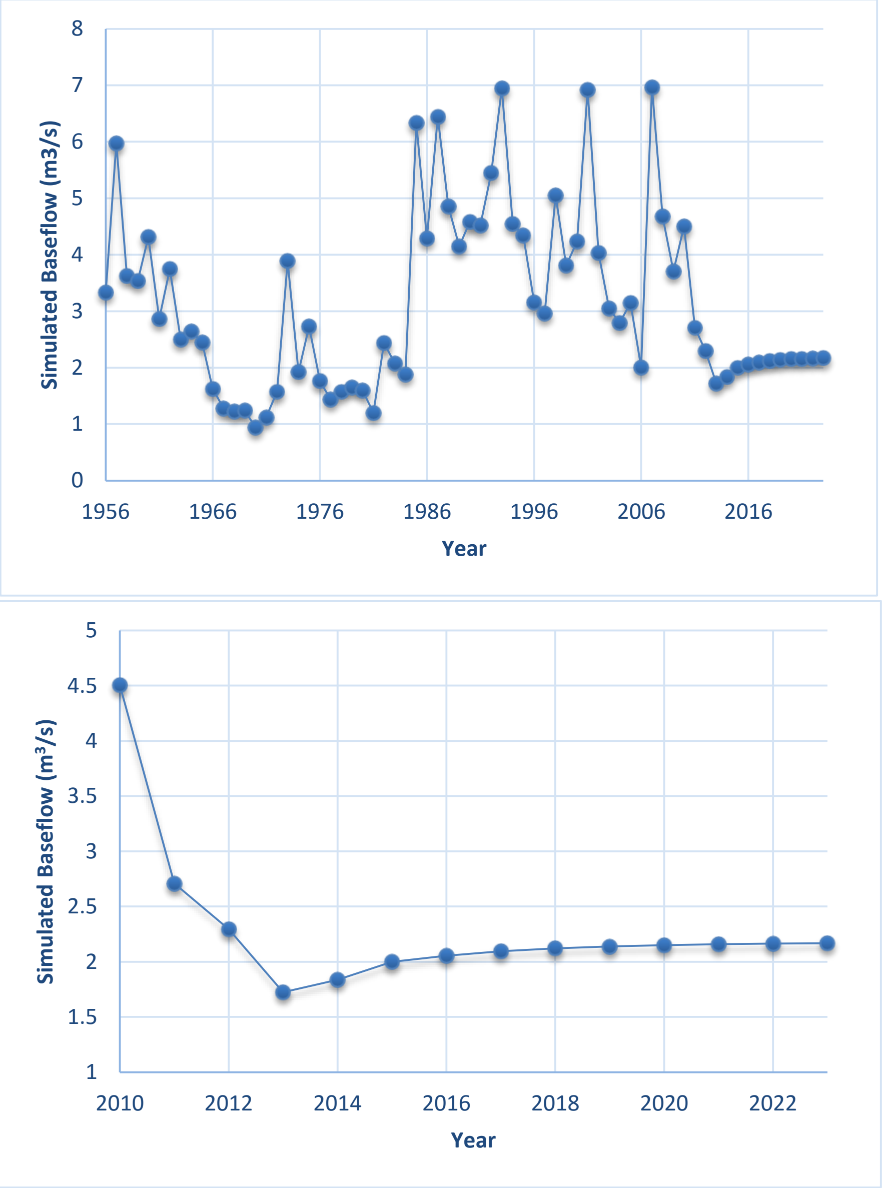


Figure 11. Simulated average annual baseflow for the USGS gage 07327447 on Little Washita River near Cement, OK for the entire model period, 1956 – 2023, (top) and for the simulation period, 2013 – 2023, (bottom) for the third groundwater use scenario which simulated each well pumping at a rate of approximately 5.5 mm/day for irrigation.

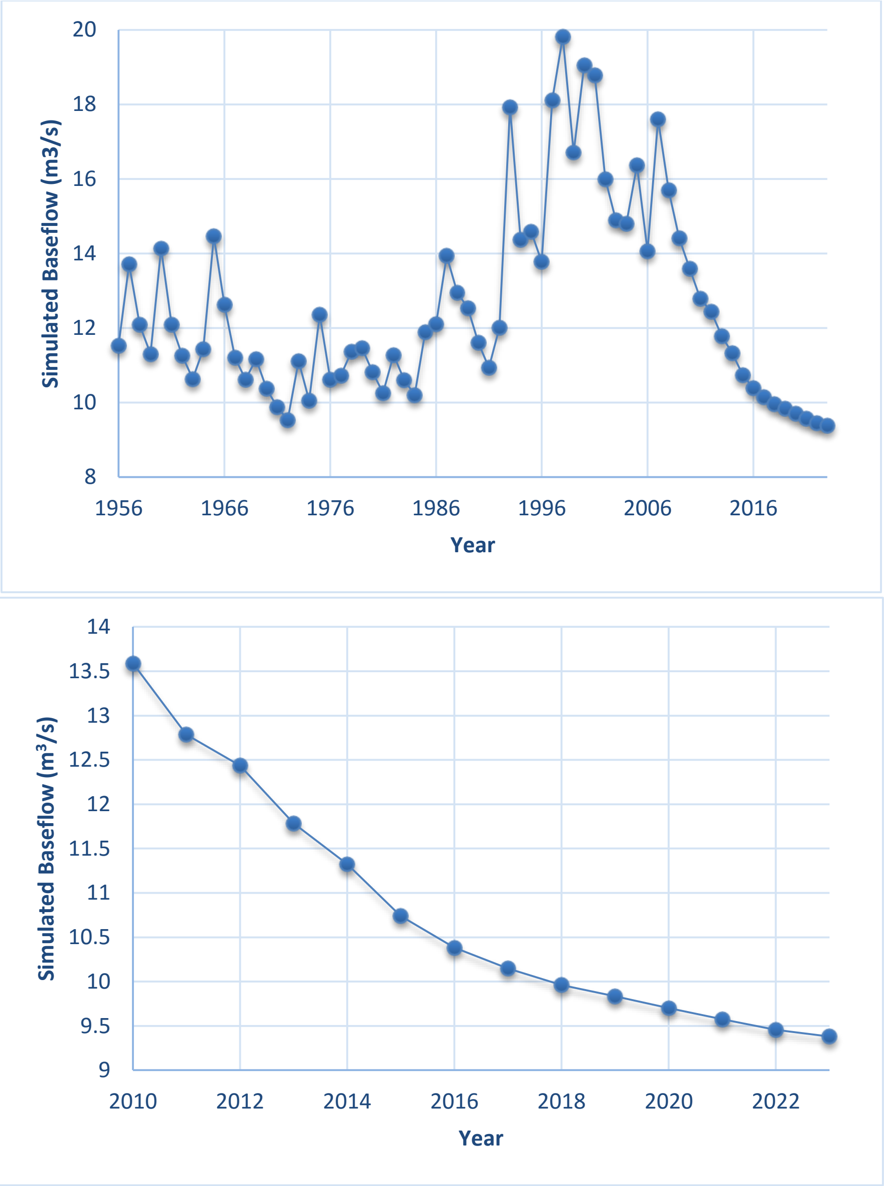
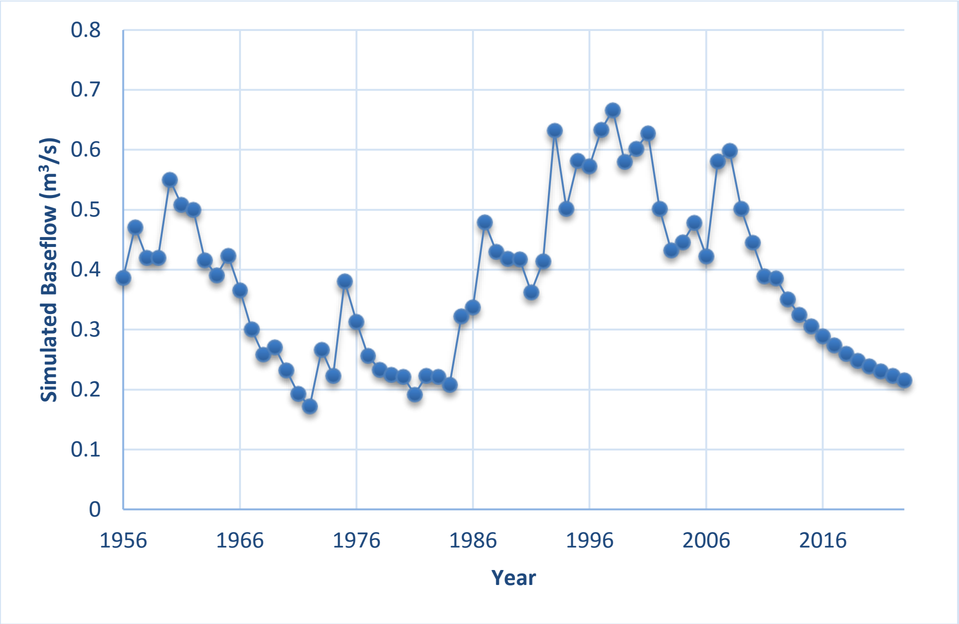


Figure 12. Simulated average annual baseflow for the USGS gage 07325000 on the Washita River near Clinton OK for the entire model period, 1956 – 2023, (top) and for the simulation period, 2013 – 2023, (bottom) for the third groundwater use scenario which simulated each well pumping at a rate of approximately 5.5 mm/day for irrigation.

Appendix E: Simulated baseflow plots for each of the recharge baseflow analysis scenarios.



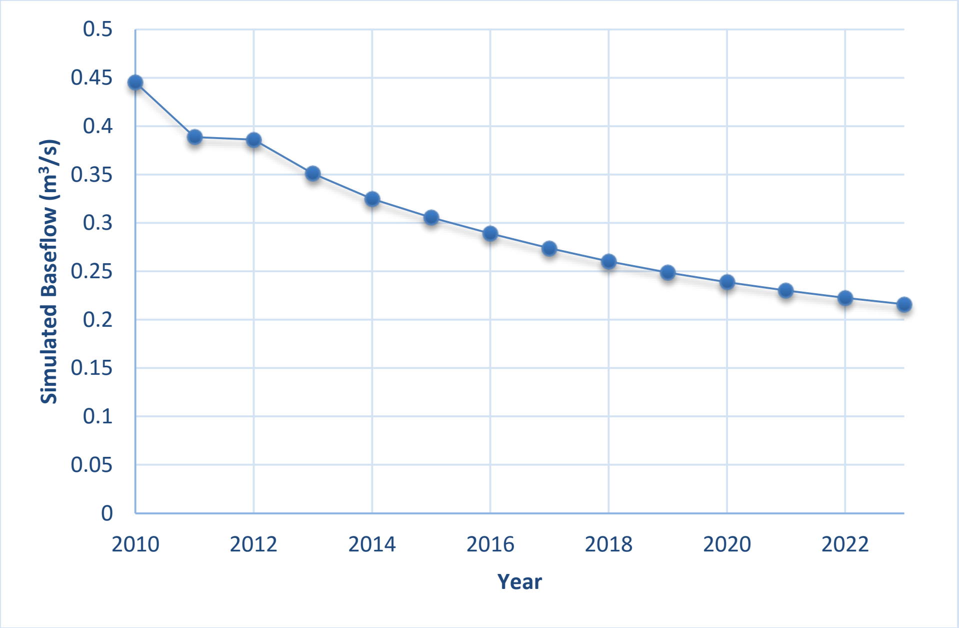


Figure 1. Simulated average annual baseflow for the USGS gage 07325800 on Cobb Creek near Eakly, OK for the entire model period, 1956 – 2023, (top) and for the simulation period, 2013 – 2023, (bottom) for the scenario which extended both the current groundwater use and the recharge rate for the simulation period.

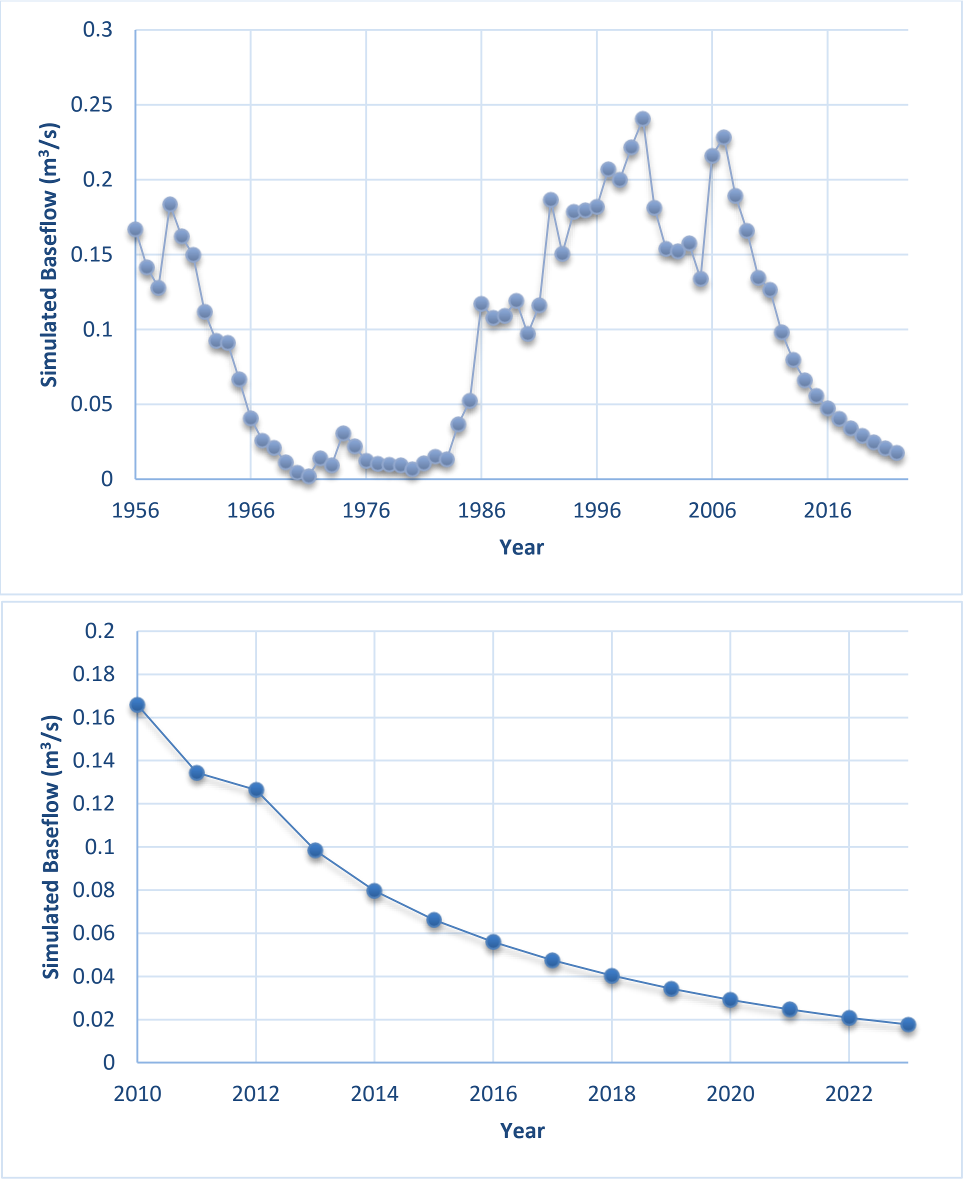


Figure 2. Simulated average annual baseflow for the USGS gage 07325850 on Lake Creek near Eakly, OK for the entire model period, 1956 – 2023, (top) and for the simulation period, 2013 – 2023, (bottom) for the scenario which extended both the current groundwater use and the recharge rate for the simulation period.

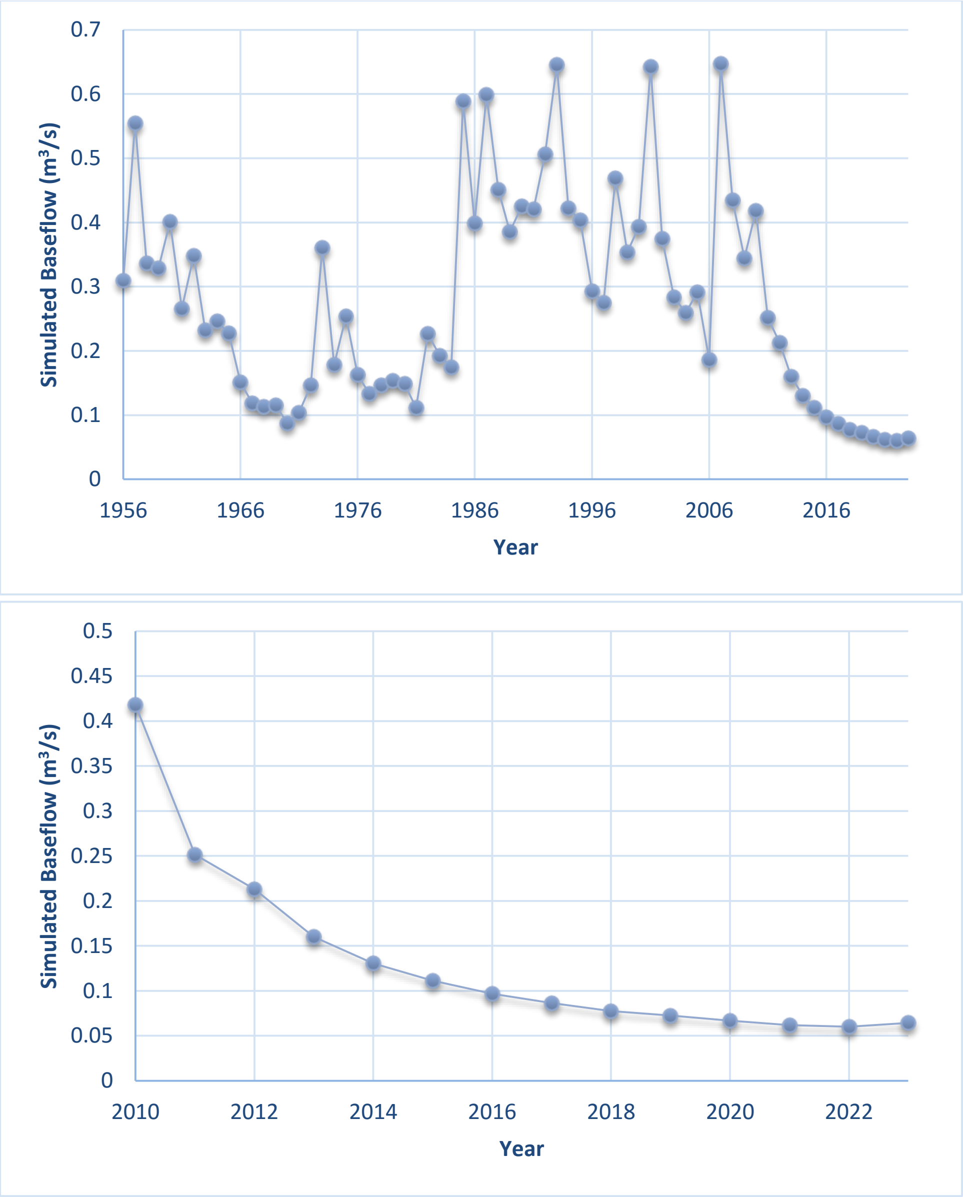


Figure 3. Simulated average annual baseflow for the USGS gage 07327447 on Little Washita River near Cement, OK for the entire model period, 1956 – 2023, (top) and for the simulation period, 2013 – 2023, (bottom) for the scenario which extended both the current groundwater use and the recharge rate for the simulation period.

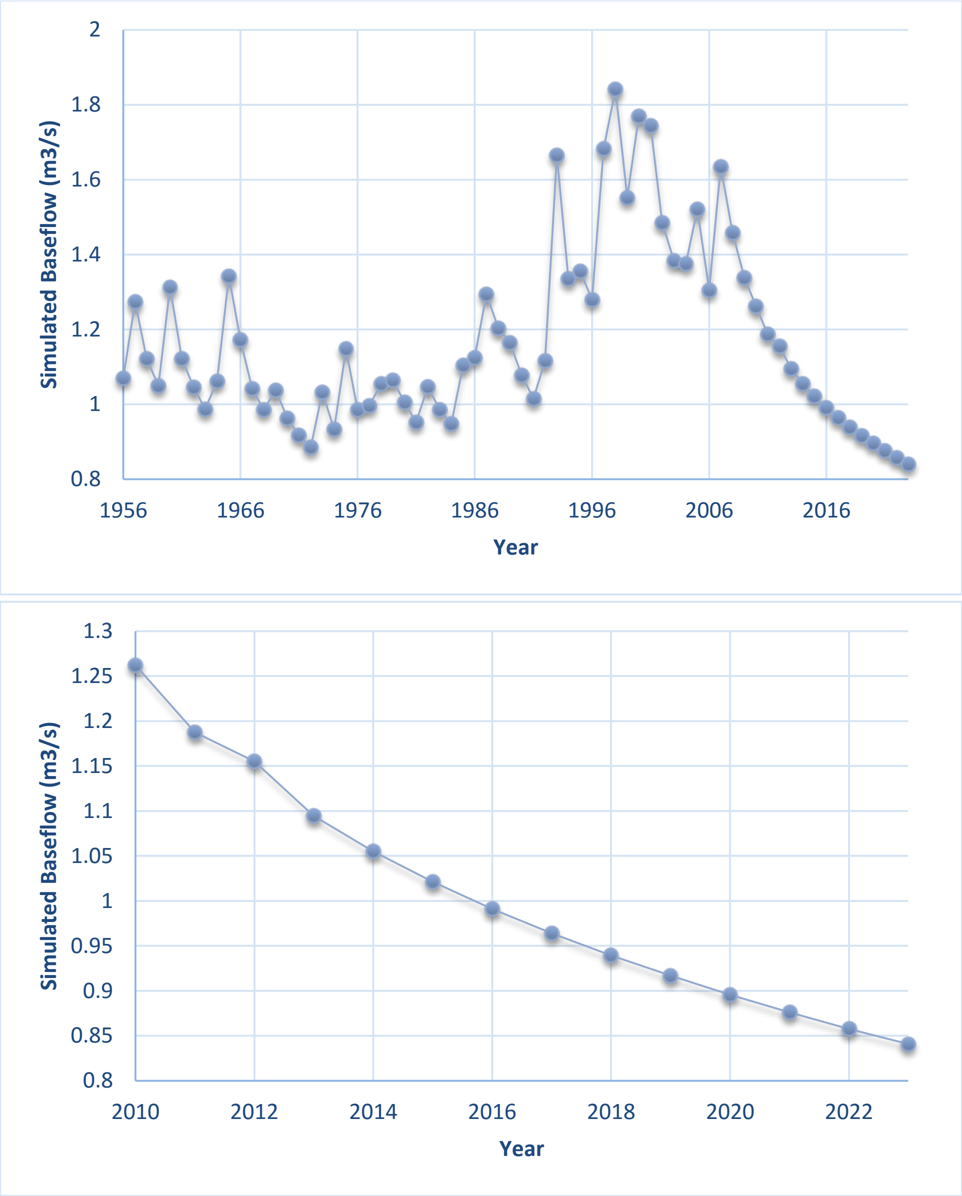


Figure 4. Simulated average annual baseflow for the USGS gage 07325000 on the Washita River near Clinton OK for the entire model period, 1956 – 2023, (top) and for the simulation period, 2013 – 2023, (bottom) for the scenario which extended both the current groundwater use and the recharge rate for the simulation period.

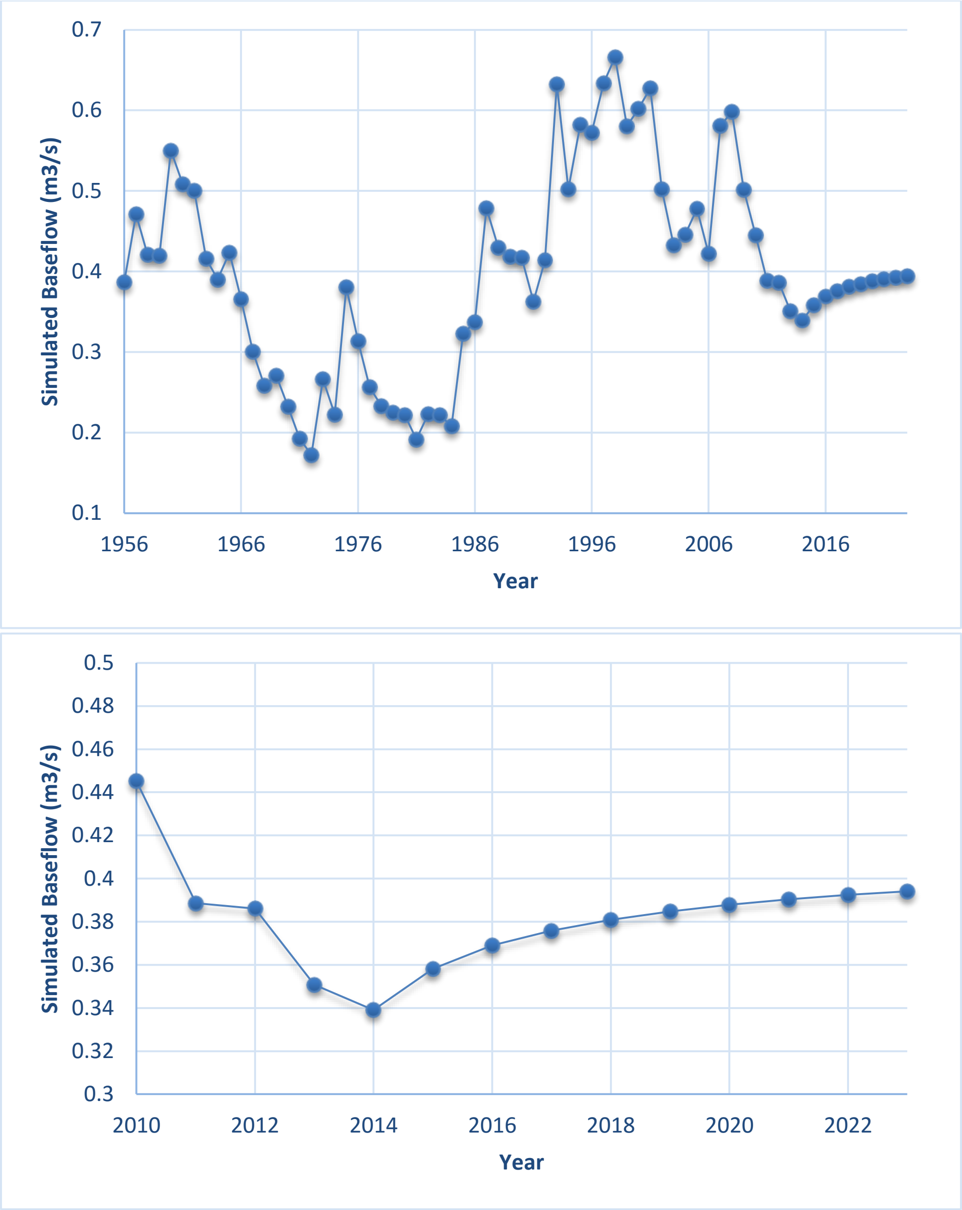


Figure 5. Simulated average annual baseflow for the USGS gage 07325800 on Cobb Creek near Eakly, OK for the entire model period, 1956 – 2023, (top) and for the simulation period, 2013 – 2023, (bottom) for the scenario which extended the 2013 groundwater use and increased the recharge rate to an average of 0.05 m/yr for the model area.

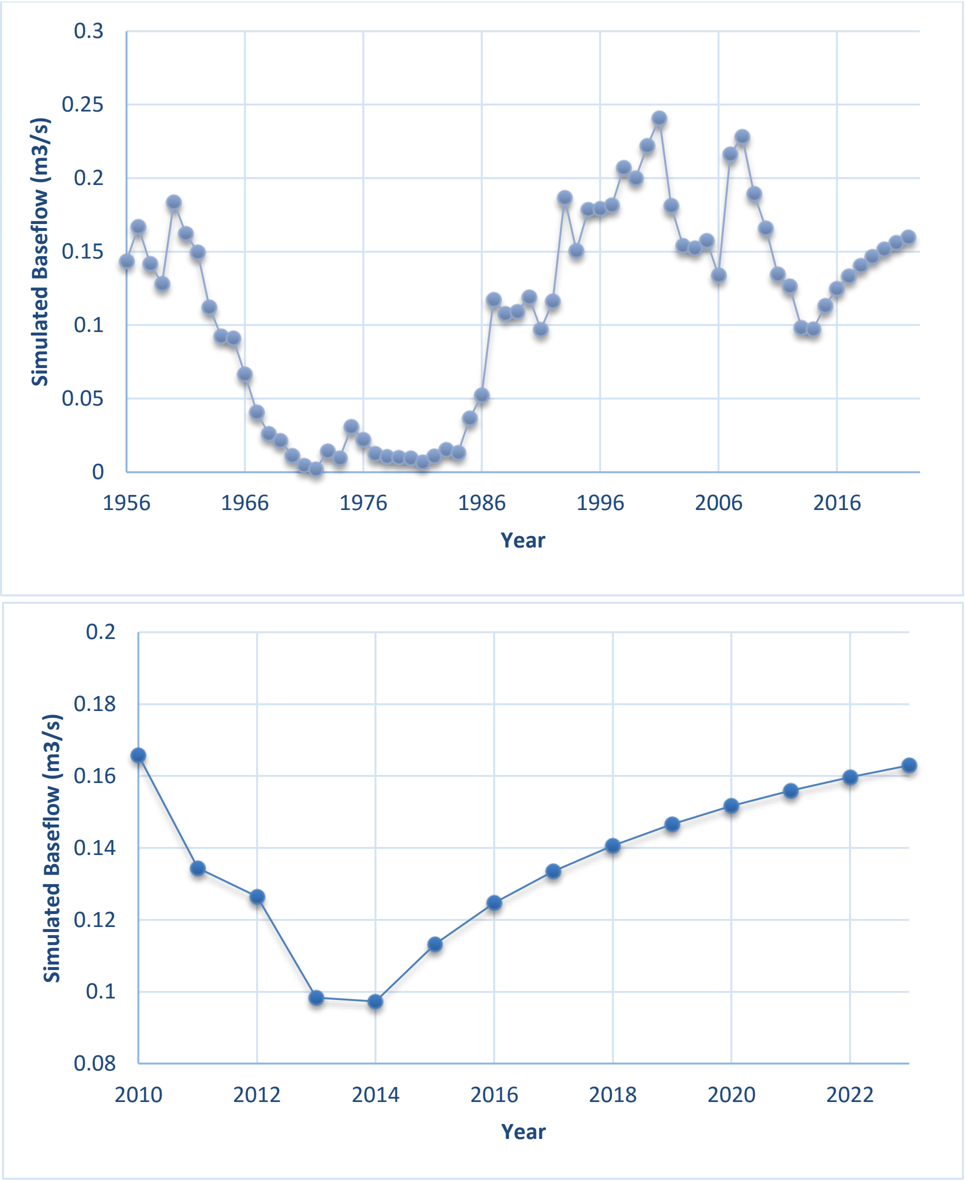


Figure 6. Simulated average annual baseflow for the USGS gage 07325850 on Lake Creek near Eakly, OK for the entire model period, 1956 – 2023, (top) and for the simulation period, 2013 – 2023, (bottom) for the scenario which extended the 2013 groundwater use and increased the recharge rate to an average of of 0.05 m/yr for the model area.

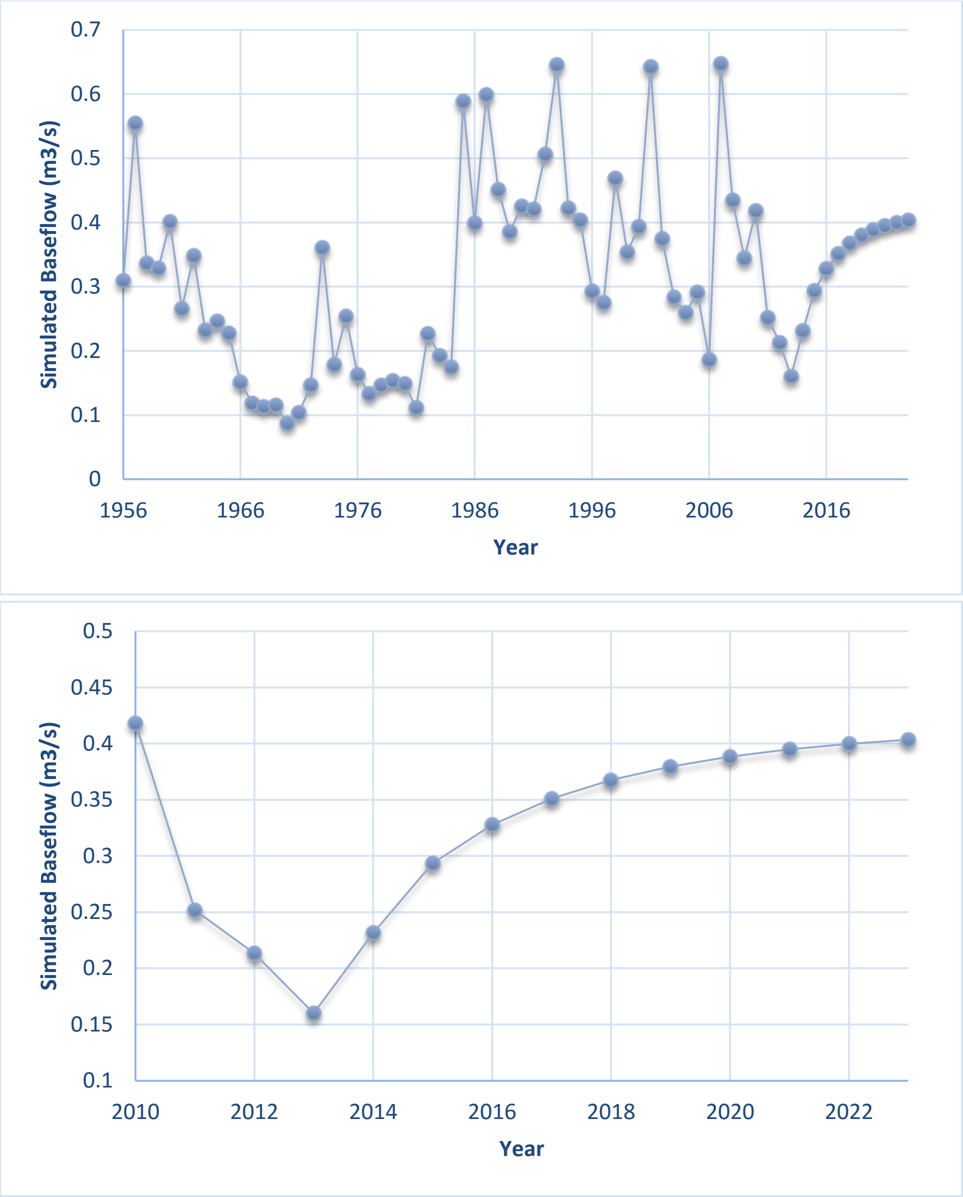


Figure 7. Simulated average annual baseflow for the USGS gage 07327447 on Little Washita River near Cement, OK for the entire model period, 1956 – 2023, (top) and for the simulation period, 2013 – 2023, (bottom) for the scenario which extended the 2013 groundwater use and increased the recharge rate to an average of of 0.05 m/yr for the model area.

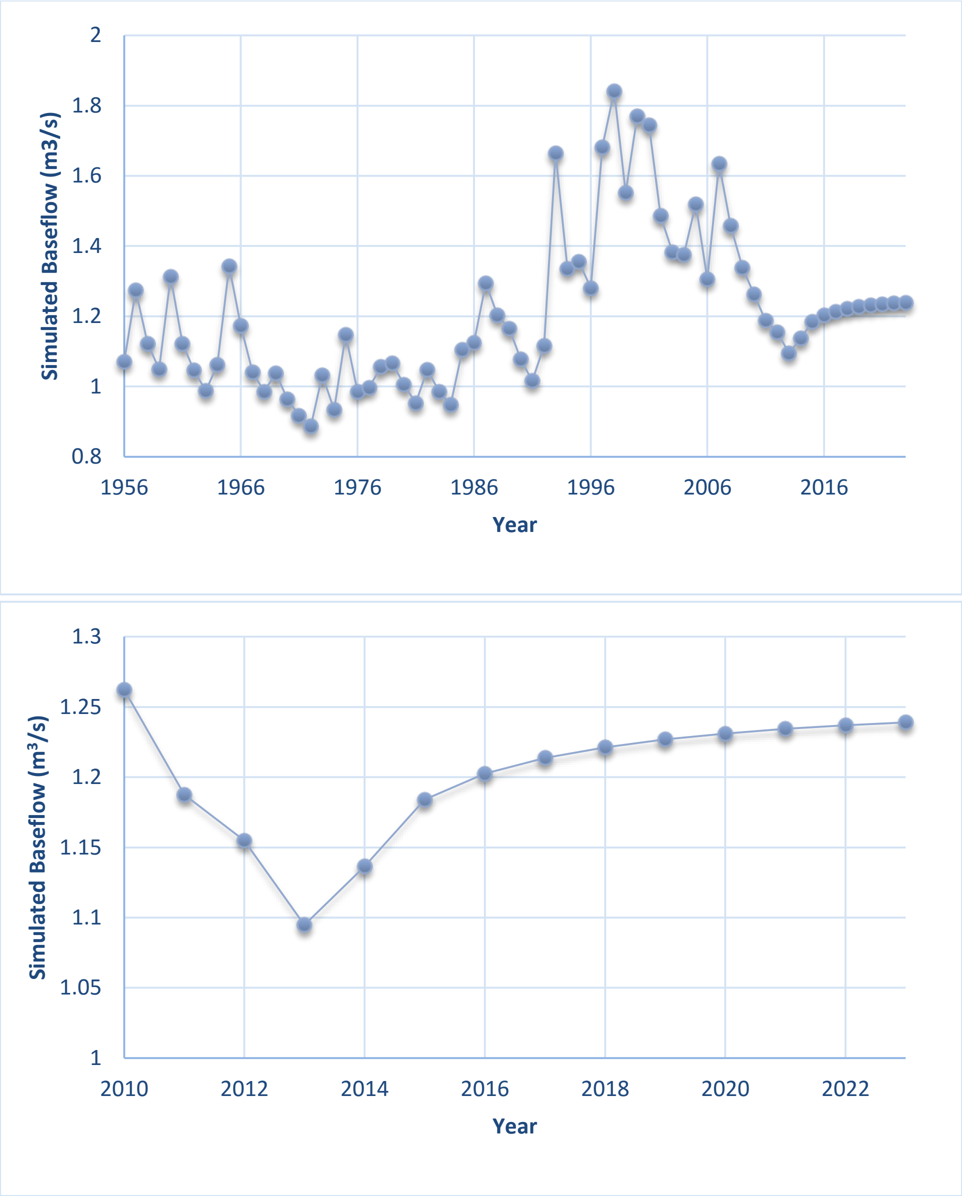


Figure 8. Simulated average annual baseflow for the USGS gage 07325000 on the Washita River near Clinton OK for the entire model period, 1956 – 2023, (top) and for the simulation period, 2013 – 2023, (bottom) for the scenario which extended the 2013 groundwater use and increased the recharge rate to an average of of 0.05 m/yr for the model area.

VITA

Qualla Jo Ketchum

Candidate for the Degree of

Master of Science

Thesis: DEVELOPMENT OF DIGITAL GROUNDWATER MODELS AND SIMULATION OF GROUNDWATER FLOW OF THE RUSH SPRINGS AQUIFER IN WEST CENTRAL OKLAHOMA

Major Field: Biosystems Engineering

Biographical:

Education:

Completed the requirements for the Master of Science in Biosystems Engineering at Oklahoma State University, Stillwater, Oklahoma in December, 2015.

Completed the requirements for the Bachelor of Science in Biosystems Engineering at Oklahoma State University, Stillwater, Oklahoma in 2013.

Experience:

Water Resources Engineer/Carl Albert Intern May 2013 - Present
Oklahoma Water Resources Board

Undergraduate Research Assistant Jan 2012 – May 2013
OSU Biosystems & Agricultural Engineering Department

BAE 1012 & 1022 Teaching Assistant Aug 2011 – May 2012
OSU Biosystems & Agricultural Engineering Department

Professional Memberships:

American Society of Agricultural & Biological Engineers (Aug 2009 – Present)