Evaluation of the Impacts of the Tentative Determination of the Maximum Annual Yield for the Arbuckle-Simpson Aquifer on Chickasaw National Recreation Area

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Introduction

Chickasaw National Recreation Area (Chickasaw NRA) is located in Murray County in south-central Oklahoma. The Arbuckle-Simpson aquifer is the primary source of groundwater discharge to springs and streams that emanate within the boundaries of the park (Figure 1). The objective of this report is to evaluate the Oklahoma Water Resources Board's proposed management recommendations for the Arbuckle-Simpson aquifer on springs and streams that emanate from the aquifer within Chickasaw NRA.

The Oklahoma Water Resources Board conducted a comprehensive multiyear hydrologic study in cooperation with the U.S. Bureau of Reclamation, the U.S. Geological Survey (USGS), Oklahoma State University and the University of Oklahoma to describe the hydrogeology of the aquifer and to develop a groundwater-flow model that could be used to simulate groundwater discharge to springs and streams in the eastern Arbuckle-Simpson aquifer. The purpose of the hydrologic study was to provide OWRB with the scientific information necessary to determine the amount of water that could be withdrawn from the aquifer without reducing the natural flow of springs and streams.

The USGS Scientific Investigations Report (SIR) 2011-5029 (Christenson et al., 2011) describes the hydrogeology of the aquifer and the development of the MODFLOW (Harbaugh et al., 2000) groundwater-flow model for the Arbuckle-Simpson aquifer. The report also describes the results of simulations performed to calibrate the model and to evaluate changes in stream and spring flows associated with a range of groundwater-withdrawal scenarios.

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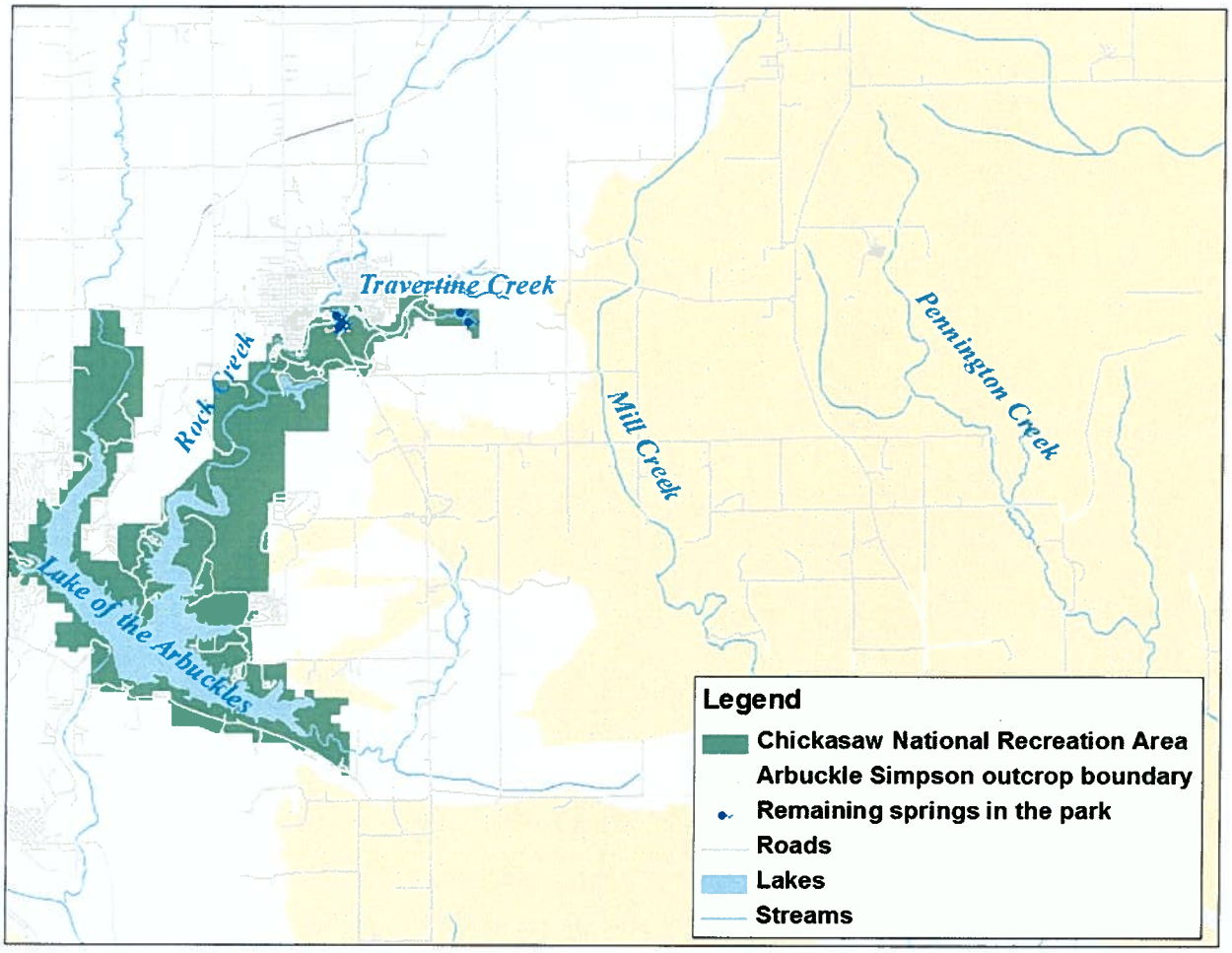

Figure 1. Location of Chickasaw NRA and the outcrop area of the Arbuckle-Simpson aquifer.

The Arbuckle-Simpson groundwater model can be used to predict impacts to important water resources in Chickasaw NRA from existing and proposed groundwater withdrawals under proposed management scenarios. Of primary concern are the potential effects on groundwater discharge to Antelope and Buffalo Springs and the base flow of Rock and Travertine Creeks located within the historic part of the park commonly referred to as the Travertine District.

Determination of Maximum Annual Yield for the Arbuckle-Simpson Aquifer

The Oklahoma Water Resource Board (OWRB) is required to establish a Maximum Annual Yield (MAY) for each groundwater basin in the state prior to issuing permits for groundwater withdrawals. The passage of Senate Bill 288 established additional requirements for the Arbuckle-Simpson aquifer. In the determination of MAY for the Arbuckle-Simpson aquifer, OWRB must ensure that any permit will not reduce the natural flow of springs or streams (82 O.S. Section 1020.9A). In addition, OWRB must determine whether a proposed use is likely to degrade or interfere with springs and streams (82 O.S. Section 1020.9A). Degradation or interference is interpreted to mean the cumulative impact of pumping from existing and proposed wells that may impact a stream by more than 25% of base flow (Tentative Conclusion,Tentative Determination of MAY, issued March 13, 2012).

OWRB contracted with the USGS to construct the Arbuckle-Simpson groundwater model to evaluate the effects of distributed pumping on the natural flow of streams due to the maximum annual yield determination. The model was used to simulate base flow to streams under a range of groundwater management scenarios that assumed equally distributed groundwater withdrawals across the land area overlying the aquifer. The three management scenarios shown in the USGS Report (Christenson et al., 2011) include equal proportionate shares of 0.125, 0.250 and 0.392 (acre-ft/acre)/year.

Following the completion of the multi-year hydrologic study and publication of the USGS report (Christenson et al., 2011) on the hydrogeology and groundwater-flow model for the Arbuckle-Simpson aquifer, OWRB issued a tentative determination for a MAY for the Arbuckle-Simpson aquifer (Tentative Determination of MAY, issued March 13, 2012). OWRB selected a MAY of 78,404 acre-ft per year based on the scientific information contained in the USGS report as well

as other administrative and practical considerations. A MAY of 78,404 acre-ft/year is equivalent to an equal proportionate share (EPS) of 0.20 (acre-ft/acre)/year for distributed groundwater withdrawals from the aquifer.

Model Calibration in the Vicinity of Chickasaw National Recreation Area

The transient model was optimized to simulate base flow to streams for the five year water year period beginning October 1, 2003 through September 30, 2008 (Christenson et al., 2011). For the purposes of model calibration, base flow was optimized to best represent the USGS gage on Blue River near Connerville and the USGS gage on Pennington Creek near Reagan.

Groundwater discharge from the Arbuckle-Simpson aquifer to springs and streams in the park is represented in the groundwater-flow model as drain cells in the areas of Rock Creek, Travertine Creek, and Veterans Lake within Chickasaw NRA (Figure 2). Antelope and Buffalo Springs are not explicitly modeled in the MODFLOW model but their discharge was considered to be part of the groundwater discharge to Travertine Creek. Nearly all the groundwater discharge in the park occurs along Travertine Creek with only a minor portion discharging to drain cells along Rock Creek or Wilson Creek, which flows into Veteran's Lake.

The USGS gage on Rock Creek at Sulphur is located in the Travertine District of the park. Most of the base flow measured at the Rock Creek gage occurs as groundwater discharge to Travertine Creek. Synoptic streamflow measurements conducted by USGS in 1988 (Hanson and Cates, 1988) and by NPS in recent years confirm that groundwater discharge occurs along the length of Travertine Creek and supplies most of the base flow of Rock Creek during relatively dry periods.

Base flow to Rock Creek is represented in the model primarily by base flow to Travertine Creek plus a minor amount of base flow discharging to Rock Creek above the gage. Base flow can also be calculated from measured data at a gage. The USGS computer program PART was used to estimate base flows for Rock Creek (Rutledge, 1998). The program uses streamflow partitioning to estimate a daily value of base flow from a streamflow record.

Direct comparison between observed and simulated base flow to Rock Creek shows good agreement even though the model was not calibrated to base flows of Rock Creek (Table 1). Average base flow calculated by PART for the five year period was 14.86 cubic feet per second (cfs). Average base flow of Rock Creek for the five year period simulated by the model was 15.42 cfs.

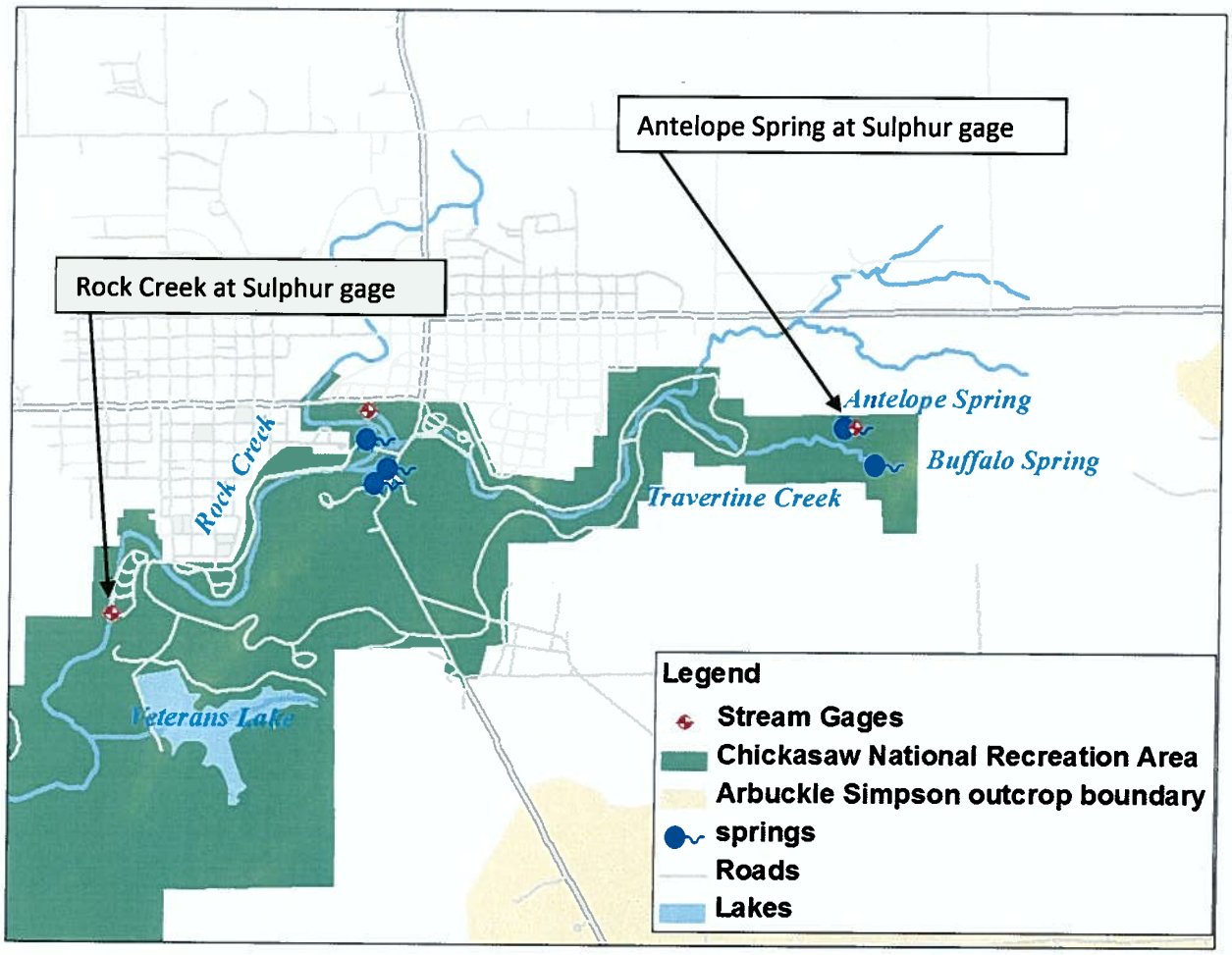

Figure 2. Major area of groundwater discharge in Chickasaw NRA simulated by the Arbuckle-Simpson groundwater flow model.

Table 1. Comparison of MODFLOW Computed to PART Computed Base Flow to Selected Streams.

	Blue River near Connerville	Pennington Creek near Reagan	Rock Creek at Sulphur
	cfs	cfs	cfs
Base Flow from Measured Data	61.28	32.47	14.86
Base Flow from Model Simulations	61.34	32.19	15.42*

*includes model simulated groundwater discharge to Travertine Creek and Rock Creek above the gage.

Model Simulations

The USGS report (Figures 42 and 43, Christenson at al., 2011) shows the response of model simulated base flow to streams as the maximum annual yield increases. Three simulations of equal proportionate share are shown (Table 24, Christenson et al., 2011) to represent points across a range of possible values. These three simulations represent equally distributed groundwater withdrawals as an EPS of 0.125, 0.250 and 0.392 (acre-ft/acre)/year. Simulated five-year average base flow to streams decreases as EPS increases.

The USGS report does not include model simulations of an EPS of 0.20 (acre-ft/acre)/year. Therefore, NPS obtained the Arbuckle-Simpson groundwater model input and output files and conducted model simulations to evaluate the effect of the proposed EPS of 0.20 (acre-ft/acre)/year on base flow to streams in the vicinity of Chickasaw NRA. Results are shown for Travertine Creek and selected streams in Table 2.

The simulated depletion of average base flow for Travertine Creek over the five-year period from 2004 - 2008 is shown in Table 3. Simulated depletion for the five-year average base flow of Travertine Creek relative to reported use for an EPS = 0.20 (acre-ft/acre)/year is 28%.

Table 2. Model Simulated Five-Year Average Base Flow to Selected Streams with a Proposed EPS = 0.20 ac-ft/ac/year.

	Blue River	Pennington Creek	Travertine Creek	Mill Creek
	cfs	*cfs*	*cfs*	*cfs*
No Withdrawals	63.68	32.5	16.9	8.96
Reported Water Use	61.3	32.2	15.4	8.5
EPS = 0.125	45.0	24.4	13.6	6.1
EPS = 0.20	32.2	18.9	11.1	4.3
EPS = 0.25	28.2	16.7	9.3	3.4
EPS = 0.392	11.6	8.0	2.6	1.0

Average annual reported water use for the five year period 2004 – 2008 was 5,713 acre-ft/ year. However, the reported use is not equally distributed across the basin. In fact, about 25% of the reported use during the five year period from 2004 – 2008 occurred within two miles of Antelope Spring in Chickasaw NRA.

Table 3. Model Simulated Depletions in Five Year Average Base Flow for Travertine Creek.

	5 Year Average Base flow	Depletion
	cfs	*%*
Reported Water Use	15.41	0
EPS = 0.125	13.59	12
EPS = 0.20	11.13	28
EPS = 0.250	9.28	40
EPS = 0.392	2.61	83

NPS has been concerned for some time that both historic and current groundwater development in the vicinity of Chickasaw NRA may affect stream and spring flows in the park. The USGS report (Christenson et al., 2011) describes an additional model simulation designed to quantify the effects of current reported water use on groundwater discharge to streams and springs. Therefore, NPS performed a similar analysis to evaluate the effects of current reported water use on Travertine Creek.

Results of model simulations comparing the five year average depletion in base flow relative to no withdrawals show that existing groundwater withdrawals in the vicinity of Chickasaw NRA have a measureable effect on base flow (Table 4). The simulated reduction in base flow between the No Withdrawal and Reported Withdrawal scenarios is about 9%. Simulated depletion of the five-year average base flow of Travertine Creek for an EPS = 0.20 (acre-ft/acre)/year relative to No Withdrawals is 34%. The depletion in base flow of Travertine Creek exceeds 25% when compared to either the No Withdrawal simulation or the Reported Water Use simulation. Not all reported withdrawals in the vicinity of the park are subject to the MAY determination.

Table 4. Model Simulated Depletions in Five Year Average Base Flow Relative to No withdrawals for Travertine Creek.

	5 Year Average Base flow	Depletion
	cfs	*%*
No Withdrawals	16.9	0
Reported Water Use	15.41	9
EPS = 0.125	13.59	20
EPS = 0.20	11.13	34
EPS = 0.250	9.28	45
EPS = 0.392	2.61	85

A graph of the simulated depletions in base flow at Travertine Creek associated with distributed withdrawals under an EPS of 0.125, 0.250 and 0.392 (acre-ft/acre)/year provides insight into the response of the aquifer to the effects of groundwater withdrawals. Figure 3 shows the percent depletion in base flow of Travertine Creek with increases in groundwater withdrawals in the eastern portion of the aquifer simulated by the model.

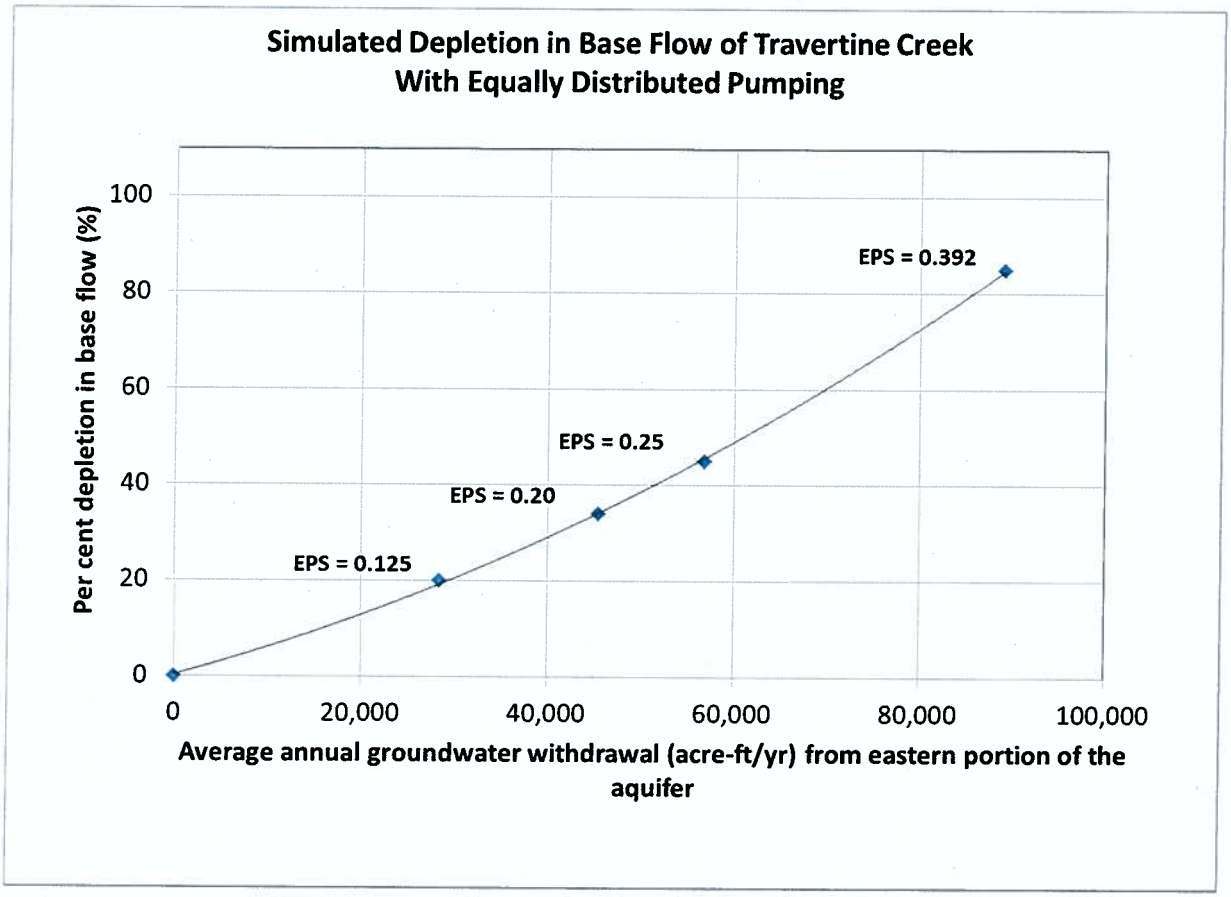

Figure 3. Simulated depletion in base flow for Travertine Creek.

Measured Discharge of Chickasaw NRA Springs and Streams

In addition to the evaluation of model simulations of distributed groundwater withdrawals, NPS also used measured streamflow at two surface water monitoring sites within the park to better understand potential impacts of future groundwater withdrawals on streams and springs. Two stream gages with at least ten years of record are located within Chickasaw NRA. The two stream gages are the Rock Creek at Sulphur gage and the Antelope Spring at Sulphur gage. The Rock Creek at Sulphur gage has been operated since 1989. The gage at Antelope Springs was operated from 1985 through 1989, and from 2003 until present.

Monthly mean streamflow was evaluated for the period of record at the Rock Creek gage at Sulphur (Figure 4) and at the Antelope Spring gage at Sulphur (Figure 5). A preliminary analysis of the hydrologic time series for both gages suggests a reduction in streamflow over time.

A Mann-Kendall trend analysis was performed using the statistical software package MINITAB to investigate the possibility of a trend in streamflow over time. Average annual values for the longer term record at Rock Creek were used for the purposes of the statistical evaluation. The null hypothesis was that there is no trend in average annual streamflow over time. The null hypothesis was rejected ($\alpha = 0.05$, $p=0.0077$) indicating sufficient evidence exists to determine that there is a downward trend.

The apparent reduction in streamflow at the Antelope Spring and Rock Creek gages within Chickasaw NRA may be due to several factors, including changes in precipitation and resulting recharge, groundwater withdrawals or some combination of the two. What is of importance is that streamflow records for both the Antelope Spring and Rock Creek gages suggest a downward trend, and the springs in the park have stopped flowing on several occasions over the past few years. Additional groundwater withdrawals from the Arbuckle-Simpson aquifer will result in greater impacts to springs and streams within the park.

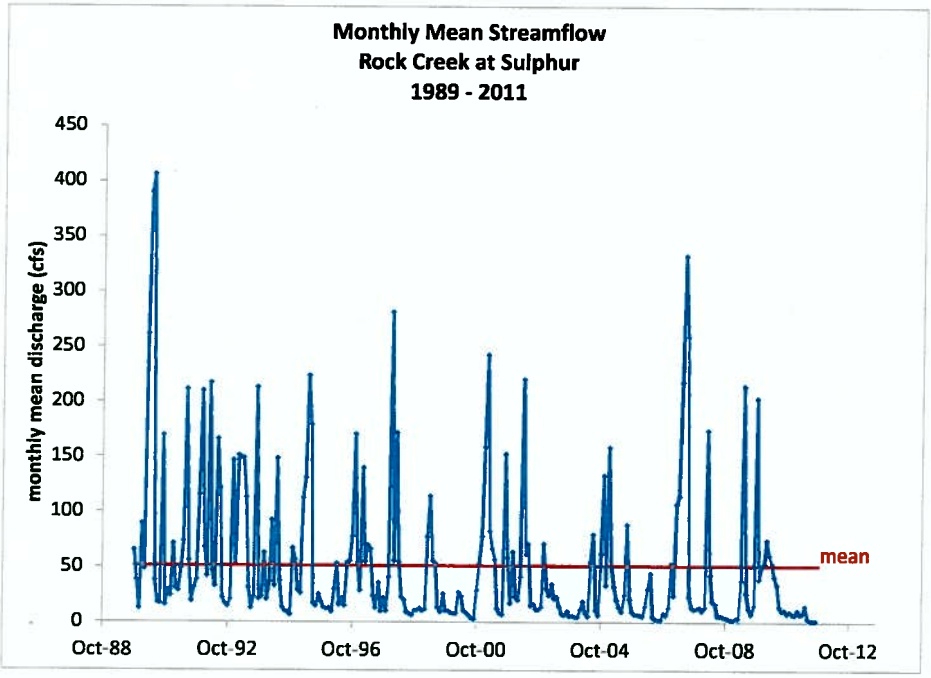

Figure 4. Monthly mean base flow for Rock Creek at Sulphur gage.

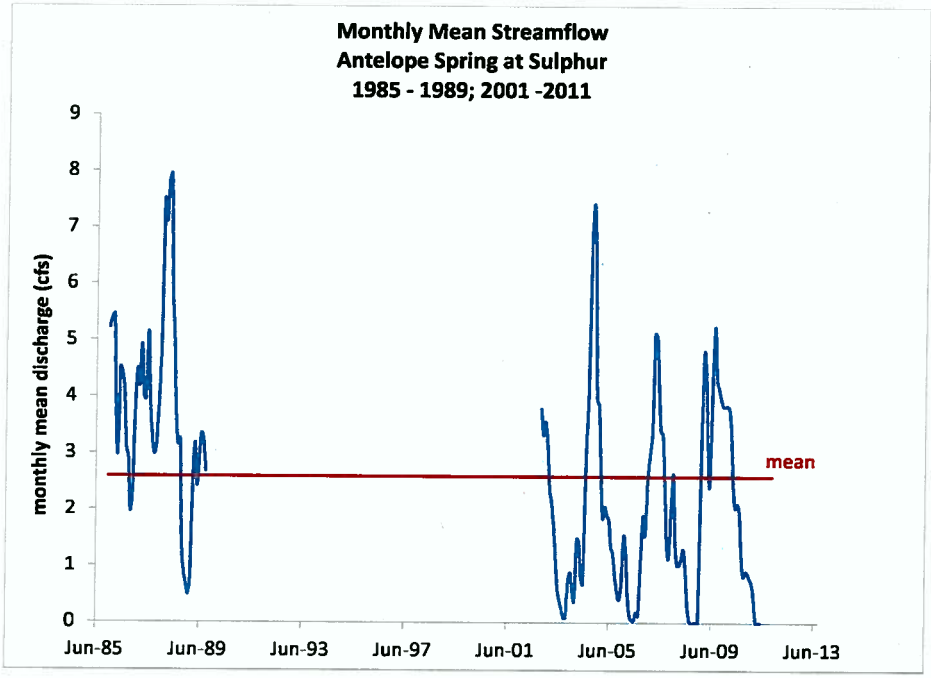

Figure 5, Monthly mean discharge for Antelope Spring at Sulphur gage.

Summary

In general, the Arbuckle-Simpson groundwater model is a useful tool for evaluating the relative effects of a range of aquifer management scenarios. The model demonstrates that as simulated groundwater withdrawals increase, the magnitude of groundwater discharge to streams decreases. The model was optimized to simulate groundwater discharge to Blue River and Pennington Creek, so only the magnitude of base flow depletions to these two streams is considered calibrated. However, the model is still useful for evaluating the effects of groundwater withdrawals on other streams that emanate from the aquifer such as Travertine Creek. Results show that the model simulates the long term average base flow of Travertine Creek reasonably well.

Both model simulations and measured data show reductions in stream flow in Chickasaw NRA under current conditions. Model results indicate that existing water use has a measureable impact on Travertine Creek and that an EPS $\geq$ 0.20 (acre-ft/acre)/year results in depletions in base flow of Travertine Creek by more than 25%. Measured data from Rock Creek and Antelope Spring indicates that discharge in Chickasaw NRA has been declining since the late 1980's. The cause of the reduction in discharge is likely either due to groundwater withdrawals, changes in recharge associated with precipitation patterns, or some combination of the two. Future groundwater withdrawals will exacerbate this condition.

Based on this information, additional measures will be necessary to protect the natural flow of springs and streams in Chickasaw NRA from further degradation. Mitigating measures will need to be incorporated to reduce the depletions in base flow of Travertine Creek to less than 25% with a Maximum Annual Yield of 78,404 acre-ft/acre/year.

References

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