George A. Austin P.E., L.S.

d.b.a. Aqueous Fortis Consulting

Examination of Model data and reports on the City of Wichita, *Equus* Beds Aquifer and Storage Recovery Project

Examination of Model data and reports on the City of Wichita, *Equus* Beds Aquifer and Storage Recovery Project

Background.

The matter was brought to my attention via a phone call from Tessa Wendling, Attorney-at-Law, on November 1,2018. Subsequent meeting with Ms. Wendling on November 13, 2018, highlighted her client's concerns and the direction of my examination of the materials available. The main purpose of my examination would be to review any aspects of the input and output data of the Models used to simulate the effects of the groundwater pumping and recharge elements and account for the City of Wichita's administration of the *Equus* Beds Aquifer Storage and Recovery Project (ASR).

Procedure

Several publications were acquired through online means or were provided by Ms. Wendling. The publications were examined in connection to various concerns expressed by Ms. Wendling. Certain excerpts from the various publications were excerpted regarding the various concerns.

Model Data Files

Several data files were downloaded. Examination of the various files provided some information as to input and output of the USGS MODFLOW 2000 Model. Originally It was believed comparison the data sets used in different MODEL runs would be of value. After review of the data sets, it was determined that further comparisons would be better served based on the reported results in the various report.

Review of Reports

U.S. Geological Survey Scientific Investigation Report 2013-5042, Simulation of Groundwater Flow, Effects of Artificial Recharge, and Storage Volume Changes in the *Equus* Beds Aquifer near the City of Wichita, Kansas Well Field, 1935–2008, reports on the MODFLOW model used to simulate the effects of groundwater pumping, artificial recharge, precipitation, river and stream interactions, natural recharge and other factors on groundwater. Operation of MODFLOW, as calibrated, assigns quantifiable volumes for each of these effects.

There are scale and time distributions that limits the Model. "2. The groundwater-flow model was discretized using a grid with cells measuring 400 ft by 400 ft. Model results were evaluated on a relatively large scale and cannot be used for detailed analyses such as simulating water level drawdown near a single wall. A grid with smaller cells would be needed for such detailed analysis." (p. 72, Model Limitations) and "Although irrigation pumpage was assumed to occur only in May through August, annual irrigation rates were calculated and used in the simulation." (p. 43). Additionally, "Groundwater pumpage data for 1935 to 1979 were obtained from Spinazola and others (1985) and Myers and others (1996). Groundwater pumpage for the stress periods from 1935 through 1979 was distributed in the model based on the spatial and temporal distribution of pumping in Spinazola and others (1985). The model cells from Spinazola and others (1985) are 1 mile on each side and pumping was assigned to the center of each cell. Pumping wells were placed in the current model to coincide with the center of each cell in the model from Spinazola *[highlight added]* and others (1985). Pumping was distributed vertically across all model layers by using the MultiNode Well Package. Locations of simulated pumping wells for 1935 through 1979 are shown in figure 29." (p.39, Wells)

The grid scale and using annual rates rather than a distributed rate based on usage and the one-mile square grids are important because it shows the large scale of the impacts. The "cone of depression" of each well is aggregated at the one-square mile grid for 1935-1979 (rather than the 400' square grid for pumping after 1980 and other elements) which creates a deeper depression at one location rather than at the point of the actual well diversion. Clearly the MODFLOW Model does not address individual well impacts either in scale or location.

One of the priorities of the ASR was regarding the saltwater intrusion from the Burton well field and the Arkansas River. *"In March 2006, the city of Wichita began construction of the Equus Beds Aquifer Storage and Recovery project to store and later recover groundwater, and to form a hydraulic barrier to the known chloride-brine plume near Burrton, Kansas. In October 2009, the U.S. Geological Survey, in cooperation with the city of Wichita, began a study to determine groundwater flow in the area of the Wichita well field, and chloride transport from the Arkansas River and Burrton oilfield to the Wichita well field."* (p.1, Abstract) And "*Sophocleous (1983) simulated chloride transport in the Equus Beds aquifer, Spinazola and others (1985) developed a model to simulate groundwater flow and chloride transport in the Equus Beds aquifer and underlying Wellington Formation…"* (p.6, Previous studies)

US Geological Survey, Scientific Investigations Report 2010–5023. Water Quality in the *Equus* Beds Aquifer and the Little Arkansas River Before Implementation of Large-Scale Artificial Recharge, South-Central Kansas, 1995–2005

The Study of the movement of the chloride in the *Equus* Beds as reported by SIR 2010-5023 provides the basis of the ASR water quality. " *The primary sources of chloride to the Equus Beds aquifer are from past oil and gas activities near Burrton and from the Arkansas River. Computed chloride concentrations in the Little Arkansas River near Halstead exceeded the Federal SDWR of 250 mg/L about 27 percent of the time (primarily during low-flow conditions). Chloride concentrations in groundwater exceeded 250 mg/L in about 8 percent or less of the study area, primarily near Burrton and along the Arkansas River. Chloride in groundwater near Burrton has migrated downgradient about 3 miles during the past 40 to 45 years. The downward and horizontal migration of the chloride is controlled by the hydraulic gradient in the aquifer, dispersion of chloride, and discontinuous clay layers that can inhibit further downward migration. Chloride in the shallow parts of the Equus Beds aquifer migrated less than 0.5 mile during the past decade. Migration is slower because of the decrease in the hydraulic gradient since 1992. On the basis of these results, artificial recharge (especially at depths of 100 to 150 feet) could create an effective barrier to saltwater migration. "(*p. 1, Abstract) The rise of groundwater elevations in the Basin Storage Area would lessen the groundwater hydraulic gradient and therefore, movement of the chloride would be slowed. Of course, the barrier to saltwater migration is related to the Wichita well field. There's no forecast as to whether the chloride plume will move in a different direction nor if that movement would be accelerated. Generally, comparison of groundwater elevations does not indicate a change in direction.

ASR Permit Modification Proposal Revised Minimum Index Levels & Aquifer Maintenance Credits by Burns & McDonnell, 3/21/2018.

The studies also do not address the lowering of the index elevation the 1993 levels which were historical lows. The pumping to the lower levels would increase hydraulic gradients and potentially accelerate the movement of chlorides.

Another important element in the Modification Proposal is changing the recharge accounting from the current Model driven accounting to a routine calculation. "*A one-time, five percent (5%) initial loss will be deducted from the total number of AMCs applied in each index cell. This initial loss accounts for losses to the aquifer inherent in the injection and recovery process. An average annual recurring loss of three percent (3%) will be applied annually to recharge credits to account for recharge credit migration from the BSA. This recurring loss will be gradational geographically across the BSA*..." (p. 4-3) In the model-based accounting, based upon the report's tabulation, the increase in the accumulated credits from 2006 to 2015 would increase from 4978 acre-ft to 5867 acre-ft (p. 4-6, Table 4-2). The values used are the calculated recharge credits from Model calculations. The Aquifer Maintenance Credits would be based on the City of Wichita diversions from the Little Arkansas River, which are reported in the Recharge credit reports. The amount in 2015 was reported at 1,048 acre-ft of the 2925 af diverted or about 36%. (p.2-4, Aquifer Storage and Recovery Project,2015 Annual Accounting Report prepared for City of Wichita, Kansas February 2018) Approximately, 9 percent of the water pumped to the water treatment plant was used in operation. This would indicate if AMC concept is adopted the initial losses should be at least that 9%.

The authors of this report had available to them, recharge values based on river flows infiltrating in to the Basin Storage Area Index Cells or outflowing to the river. In the USGS SIR 2013-5042, the dilemma of assigning a credit to use of river water rather than groundwater pumping results in the following contradiction *"Increasing recharge either increases flow from the aquifer to the Arkansas and Little Arkansas Rivers or decreases flow from the rivers to the aquifer."* (p. 66 ibid). The previous quote offers two choices in the impact of increasing recharge, when really the it is a composite of the two. For instance, in the same report, during the steady-state simulation flow budget, inflow into the groundwater system represents 30.5% of the total inflows second only to the 64.7% from natural recharge but represents 51.8 % of the total outflows. (See Reproduced Table 8 below.) (p.48 Ibid.)

Table 8. Steady-state calibration simulation flow budget.
[ft3/day, cubic feet per day; acre-ft/day, acre feet per day; --, not applicable]

Budget component	Flow rate, in ft3/day	Flow rate, in acre-ft/day	Percent of total flow
Inflow			
Head dependent boundaries	2,320,409	53.3	4.7
Recharge	31,855,858	731.3	64.7
River leakage	15,024,649	344.9	30.5
Well pumping	0	0.0	0.0
Total in	49,200,916	1,129.5	100
Outflow			
Head dependent boundaries	1,167,715	26.8	0.2
Evapotranspiration	18,569,682	426.3	38.8
Drains	2,129,863	48.9	4.6
River leakage	25,165,966	577.7	51.8
Well pumping	2,204,735	50.6	4.6
Total out	49,237,960	1,130.3	100
Total in - out	37,044	0.9	
-Percent difference	-0.08	-0.08	

In 2015, the Aquifer Storage and Recovery Project,2015 Annual Accounting Report prepared for City of Wichita, Kansas February 2018, reported that *"Infiltration from the Little Arkansas River throughout the Basin Storage Area was approximately 5204 acre-feet, … The model shows that a total of 38,717 acre-feet of water migrated from the aquifer in the Basin Storage Area to the Little Arkansas River in 2015."* (P. 4-7.)

Conclusion and Findings

The review of the data and the reports indicate substantial scientific fit to the measured conditions. However, the MODFLOW model cannot be used to look at individual impacts with any degree of certainty. The scale both geographically and temporally are large enough that impacts are general to the study area rather than specific to any one location.

The Aquifer Maintenance Credit concept doesn't take in account the fact the stream flow diverted to the water treatment plant and then piped to Wichita is in part, outflow from the aquifer and the diversion stream flow is subtracting from water available for aquifer infiltration. In 2015, the infiltration from the Little Arkansas River was 5,204 AF and outflows to the Little Arkansas River were 38,717 AF. This would indicate that if a proportional factor based on the infiltration to total surface-water/groundwater interaction were applied that only 11.8 percent of the diversion would possibly be assigned as AMC. At the steady-state, the proportion of the total surface water – groundwater interaction, is 38 percent infiltration. This indicates that the quote from the MODFLOW report: *"Increasing recharge either increases flow from the aquifer to the Arkansas and Little Arkansas Rivers or decreases flow from the rivers to the aquifer"* reflect the rise in recharge storage levels.

Water quality related to the chloride plume indicated that the restoration of the Equus Bed Aquifer to historic levels does serve as a barrier to movement towards the Wichita well field. The studies do not forecast future movement, though pumping the aquifer to levels below historical levels would certainly accelerate movement towards the pumping source.

The references and their hyperlinks that I reviewed at least partially are listed below

https://pubs.usgs.gov/sir/2010/5023/ Water Quality in the Equus Beds Aquifer and the Little Arkansas River Before Implementation of Large-Scale Artificial Recharge, South-Central Kansas, 1995–2005 Scientific Investigations Report 2010–5023

https://pubs.usgs.gov/sir/2013/5042/sir2013-5042.pdf Simulation of Groundwater Flow, Effects of Artificial Recharge, and Storage Volume Changes in the Equus Beds Aquifer near the City of Wichita, Kansas Well Field, 1935–2008. Scientific Investigations Report 2013–5042.

https://pubs.usgs.gov/sir/2014/5185/pdf/sir2014-5185.pdf Status of Groundwater Levels and Storage Volume in the Equus Beds Aquifer near Wichita, Kansas, 2012 to 2014. Scientific Investigations Report 2014–5185.

https://pubs.usgs.gov/sir/2016/5042/sir20165042.pdf Effects of Aquifer Storage and Recovery Activities on Water Quality in the Little Arkansas River and Equus Beds Aquifer, South-Central Kansas, 2011–14 U.S. Department of the Interior U.S. Geological Survey Scientific Investigations Report 2016–5042 https://pubs.usgs.gov/sir/2015/5121/sir20155121.pdf Groundwater-Level and Storage-Volume Changes in the Equus Beds Aquifer near Wichita, Kansas, Predevelopment through January 2015 Scientific Investigations Report 2015–5121

https://pubs.usgs.gov/sir/2016/5165/sir20165165.pdf Status of Groundwater Levels and Storage Volume in the Equus Beds Aquifer near Wichita, Kansas, January 2016 Scientific Investigations Report 2016–5165

https://www.agriculture.ks.gov/WichitaASR Division of Water Resources, Kansas Department of Agriculture. Link to various reports and documents.

INVESTIGATION REPORT

ON USE OF SURFACE WATER FOR

ALTERNATIVE MAINTENANCE CREDITS

By

Carl E Nuzman, P.E., P.Hg.
Consulting Engineer/Hydrogeologist

33314 NW Huxman Rd
Silver Lake, KS 66539

Cell 785 224 9929
cenuzman@gmail.com

For

Water Appropriators of GMD 2

November 28, 2018

INTRODUCTION

The City of Wichita, Kansas has developed an artificial ground water recharge system to supplement the natural recharge from precipitation to the Equus Beds aquifer from which the City has depended on for a major portion of the city water supply for many years. In spite of some short-comings, artificial recharge to the aquifer has been achieved.

The source of recharge water has been flows in excess of Minimum Desirable Streamflows from the Little Arkansas River (K.S.A. 82a-703c) and from infiltration of river water by means of wells adjacent to the river. During extended drought conditions, artificial recharged is needed for the City to use its allocated appropriation quantity of water established under senior water rights. As precipitation returns to more normal annual precipitation and streamflow's are available, the need for artificial recharge becomes limited.

The City is now asking the Chief Engineer of the Division of Water Resources, KDA, to approve special groundwater recharge credits, now called Alternative Maintenance Credits (AMC) to the Equus Beds Aquifer for the direct use of surface water from Little Arkansas River directly to a water treatment plant for public consumption. This action if approved would have the effect of illegally increasing the available appropriation of water under existing senior water rights of the City of Wichita to the potential detriment of other appropriators from the same local source of supply.

BACKGROUND

In other states, their water laws distinguishes between surface water, that water drawn directly from a stream or river for beneficial use, largely for irrigation or mining, the first it Time is the first in Right. Ground water use came along later and followed somewhat the same laws as was established for surface water. However several variations exist among the several states. This doesn't work well with wells of junior water rights located between or near wells with senior rights since the direct mutual interference between wells is limited. Wells need to be considered as individual straws all pulling from the same common source of supply.

Kansas Water Appropriation Act made no specific distinction between surface and ground water rights. This was good in some ways and poor in other ways. Traditionally, the direct use of surface water is not mixed with ground water rights and the water rights are kept separate. It has been well established that the pumpage of ground water from wells where the aquifer is connected to the river system can greatly diminish stream flow. Likewise consumptive diversion of stream flow limits the availability of surface water to recharge the aquifer where they are connected.

The Equus Beds aquifer has several sources of recharge; the Little Arkansas River on the east, natural recharge from precipitation and return flows from irrigation spread over the area, some inflow from the Arkansas River to the southwest, some subsurface inflow from the north, and some leakage from the surrounding bedrock formations. This aquifer has never had aquifer storage depleted to the point that it would never recover like the Ogallala aquifer to the west.

EVALUATION TOOL

To evaluate and make aquifer calculations we have a wonderful tool called MODFLOW developed by staff members of the USGS that uses a finite-difference computing technique. This model is well adapted to our present day digital computing systems but has some limitations. The model is excellent in calculating the volume of change from one general water level to another assuming there is a uniform storage coefficient and specific yield that applies equally, everywhere in the model.

We assume the hydraulic conductivity is constant throughout each layer of the model, but since this is an alluvial deposit, the depositing stream flow energy varied greatly from place to place throughout the area changing the hydraulic conductivity. That's always evident in locating wells in that usually three or more test holes have to be drilled to find the best location for a high capacity well site.

MODFLOW has difficulty simulating the five (5) sources of recharge inflow to the aquifer because these are highly variable and inflow rates can vary with the head differential and areal location. The inflow from the Little Arkansas River not only varies with head differential but with wetted perimeter, and variations in riverbed conditions that are associated with changes in geology.

Infiltration from precipitation varies with soil type, field management technique used, soil cover or lack thereof, type and intensity of precipitation and antecedent conditions at time of precipitation occurrence.

The Arkansas River to the southwest has over the years developed a water quality issue that needs to be recognized in any evaluation. Fortunately due to the distance and low hydraulic gradient in that direction it is not of great concern at this time.

The effect of inflow from the north can be minimized by extending the model area in that direction.

The leakage from the surrounding bedrock and possible leakage from the bottom is unknown and thought to be within the margin of error of the calculations.

The MODFLOW model is a good tool but not perfect by any means. The primary deficiency is in simulating real world boundary inflow from the original steady state conditions, for changed conditions, and how stream infiltration and boundary inflow can change spatially.

THE ISSUE

At issue is, "Can the direct use of surface water to a water treatment plant" be used for groundwater recharge credits, renamed water maintenance credits, when the water never ever entered the aquifer?

A review of the Kansas Water Appropriation Act in K.S.A. 82a=701, Definitions does not mention surface water or ground water. K.S.A. 82a-703a, 703b, and 703c list minimum streamflows. Streamflow implies movement of the visible portion of water moving down gradient in a natural channel. K.S.A. 821-707(d) contains the sentence; *Any surface water right held in the custodial care of the state shall neither directly benefit nor impair any other surface water right within the stream reach designated for recovery.* Surface water diversion relates to that portion of water removed from a flowing stream or river to which the owner has developed a water property right to use in accordance with the governing law.

K.S.A. 82a-711(b) In ascertaining whether a proposed use will prejudicially and unreasonably affect the public interest, the chief engineer shall take into consideration: (1) Establish minimum desirable streamflow requirements; (2) the area, safe yield and recharge rate of the appropriate water supply; {At the time this Act was passed this referred only to the natural recharge to the aquifer} (3) …;(4) …; (5) all other matters pertaining to such question.

If the use of water maintenance credits does in fact constitute an additional appropriation from the Equus Beds aquifer then such action should be acted on as a new appropriation.

In K.S.A. 82a-711a., it shall be an express condition of each appropriation of surface or ground water that the right of the appropriator….. This sentence implies that surface water rights and ground water right are two separate rights.

In accordance with historic use and practice, water rights to the diversion of surface water and water rights to the use of water extracted from the ground by means of wells should not be intermixed.

K.S.A. 82a-706a provides the authority for the chief engineer to promulgate and enforce such rules, regulations and standards necessary to achieve the purpose of this act.

In K.A.R. 5-1-1 Definitions (g), "Artificial recharge" means the use of source water to artificially replenish the water supply in an aquifer.

The source water certainly can be streamflow from the Little Arkansas River but it clearly states the use is to artificially replenish the water supply in an aquifer not to divert the water by pipeline directly to a water treatment facility. Further the City of Wichita is asking for water recharge credits to withdraw ground water at a later date which then would constitute an additional appropriation of ground water in excess of existing senior water rights.

K.A.R. Article 5-12 specifically covers aquifer storage and recovery and requires appropriate accounting of the recharge of water to the aquifer and the withdrawal of said water.

ALTERNATE USE

It is suggested as an alternate use that some of the streamflow in excess of minimum desirable stream flows from the Little Arkansas River be used to maintain a hydraulic barrier to prevent the Burrton area contamination plum from spreading further into the Equus Beds aquifer. Approximately 85% or more of the injected water in the hydraulic barrier can be recovered down gradient, which water can then be removed by wells and used directly by the city. This would be a true maintenance use of the water.

IN SUMMARY

The direct use of surface water to a water treatment plant to establish aquifer maintenance credits for future aquifer use is in direct conflict with the definition of aquifer recharge listed in K.A.R.5-1-1(g).

The use of the aquifer model MODFLOW to establish aquifer maintenance credits seems somewhat like a smoke screen to provide ground water recharge credits that are not consistent with present Rules and Regulations and are avoiding the main purpose of the aquifer storage and recovery project. When the aquifer is full its full and developing additional ground water recharge credits from surface water use is inconsistent with the intent of the water laws.

STATE OF KANSAS
BEFORE THE DIVISION OF WATER RESOURCES
KANSAS DEPARTMENT OF AGRICULTURE

In the Matter of the City of Wichita's	)	
Phase II Aquifer Storage and Recovery Project	)	**Case No. 18 WATER 14014**
in Harvey and Sedgwick Counties, Kansas	)	
	)	

Pursuant to K.S.A. 82a-1901 and K.A.R. 5-14-3a.

TECHNICAL ASSESSMENT

ASR PERMIT MODIFICATION PROPOSAL
REVISED MINIMUM INDEX LEVELS & AQUIFER MAINTENANCE CREDITS

CONTENTS

Figures - 1 through 8 (end of report)

INTRODUCTION

Balleau Groundwater, Inc. (BGW) has been retained by Wendling Law, LLC and Adrian & Pankratz, P.A. to provide technical information and opinions regarding hydrologic effects associated with City of Wichita ASR Permit Modification Proposal (hereafter "the Proposal") (Burns & McDonnell, 2018a). Wendling Law, LLC provided model files and a transmittal (Macey, 2018) with the files associated with the City of Wichita Aquifer Storage and Recovery (ASR) Permit Modification Proposal. The City's ASR Permit Modification Proposal includes analysis based on the USGS model (Kelly and others, 2013) of the Equus Beds aquifer. Burns & McDonnell (BMcD) performed the model analysis. The USGS model provides a technical basis for the City's Proposal and for annual accounting (Burns & McDonnell, 2018b) of ASR recharge credits compatible with a condition of approval in existing permits required to capture, store and recover water for the City's beneficial use. BGW's assessment of hydrologic effects related to the City's Proposal emphasizes information contained in the Proposal and considers related technical documents (listed in the references section of this report). BGW also obtained a copy of the original distribution of the USGS model to inspect the files and modeled water budget.

As part of the technical assessment, we inspected and ran the model files the City (Macey, 2018) provided and compared the files to the original USGS files. In the course of doing so, we observed a difference between specifications in the USGS model and the model provided by the City, namely the ratio of horizontal to vertical hydraulic conductivity simulated between model layers. BMcD reports that no changes were made to the original construction or hydrogeologic properties of the original USGS model (Burns & McDonnell, 2018a, p. 2-7 and 2018b, p. 4-1). The reason for the change is not clear. The upshot is that we found the alteration to model specifications does not result in a significant change to certain technical aspects we evaluated in the Proposal. For example, we evaluated the BMcD analysis that defines the proposed minimum index levels in both model versions and found the change is on the order of a few feet or less. However, unless there is a reason to deviate from the original USGS model concept, we recommend the City accounting of recharge credit and the analysis in the Proposal be updated accordingly to confirm that other potentially significant factors do not turn up. Keeping the ratio of horizontal to vertical hydraulic conductivity the same as in the USGS model should improve simulation of hydrologic conditions in west Harvey County (northwest corner of the basin storage area) where anisotropy between model layers is known to occur. The description of the ratio of horizontal to vertical hydraulic conductivity represented in the model is described by the USGS (Kelly and others, 2013, p. 34).

In our technical assessment, we evaluated the City's Proposal using the model as provided by the City and using the USGS model in its original form. We found that the results in both sets of model simulations are not different enough to affect our overall conclusions. To remain consistent with the original USGS concept, herein we present results from our assessment with the model in its original USGS form.

HYDROLOGIC EFFECTS OF 1% DROUGHT SIMULATION IN PROPOSAL

BMcD describes the 1% drought simulation in the Proposal to stem from a decision by the City to utilize a 1% exceedance probability drought for resource planning of future water supplies. The decision prompted BMcD to develop a drought analysis with the USGS model to assess hydrologic conditions in the Basin Storage Area (BSA). In the process of evaluating scenarios of prolonged drought, BMcD found that some water levels in the BSA[1] are projected to drop below the minimum index water levels, which triggers a condition that prevents diversion of ASR recharge credit water in the City's current ASR permit. Accordingly, BMcD's analysis is the technical basis for the Proposal to revise the minimum index levels by lowering them so the City could divert ASR recharge credit water during an extended drought.

The BMcD analysis in the Proposal presents results of the 1% drought simulation in the context of water-level elevations and percent of saturated thickness of the aquifer. The results are based on the total City pumping (non-credit and ASR recharge credit) represented in the 1% drought simulation (Burns & McDonnell, 2018a, Table 2-5). The model has the capability of isolating hydrologic effects from components of City pumping. For example, the BMcD 1% drought analysis can be adapted to quantify the hydrologic effect of pumping the ASR recharge credit. **Figure 1** shows how the hydrologic system responds to City ASR recharge credit pumping in the 1% drought simulation. Initially, the pumping produces most of the water from aquifer storage, but as pumping continues, the cone of depression from groundwater pumping induces (depletes) flow from the Little Arkansas and Arkansas rivers. A notable observation on **Figure 1** is that stream depletion continues to occur for years after groundwater pumping ceases. This lagged depletion response occurs because, even though pumping has stopped, stream depletion continues to fill in the cone of depression that was caused when the well was pumping.

The proximity of the City wells to the rivers results in groundwater operations (diversion/injection) affecting river flow within one year of pumping. Below we expand on this technical approach of analyzing hydrologic effects from different components of City pumping (**Figure 1**) with an examination of hydrologic effects that considers an example of diverting groundwater that causes drawdown to the level of the proposed minimum index level.

[1] In the Proposal, BMcD reports that water levels in about half of the index cells lowered below the current minimum index level in their 1% drought analysis (Burns & McDonnell, 2018a, Table 2-10).

The BMcD 1% drought analysis results in some water levels in the BSA dropping below the current minimum index level, thereby preventing the City from diverting ASR credit water. To clarify, the revised minimum index levels in the Proposal do not directly represent the modeled water levels in the BMcD drought analysis. To determine the revised minimum index level in the Proposal, BMcD added a contingency to the water levels modeled at the end of the drought simulation. That is, the proposed minimum index levels are at a lower elevation than that modeled in the 1% drought analysis. We are interested in quantifying hydrologic effects associated with the City potentially diverting ASR recharge credit from the depth limited by the proposed minimum index level. Accordingly, to quantify the hydrologic effects associated with the Proposal, model analysis in addition to the BMcD scenario is needed.

In our assessment of City groundwater pumping, we used the model to quantify hydrologic effects from three categories of pumping: **A**) diversion of groundwater without ASR credit (i.e. pumping 40,000 AF/y), **B**) diversion of ASR recharge credit water with the constraint of the existing minimum index level (1993 level) and **C**) diversion of ASR recharge credit water with the lowering of the existing minimum index level to the proposed level. The analysis approach allows for quantifying the potential hydrologic effect of the Proposal (i.e. presenting an example of hydrologic effects if the City diverted groundwater that caused drawdown to the proposed minimum index level). An assessment of the categories of pumping associated with causing drawdown to the minimum index levels is possible with the Multi-Node Well package (Konikow and other, 2009) that is used in the USGS model.

The MNW package has utility for analyzing well yield that is limited in association with a lowered pumping water level, typically near the pump intake. For example, when the pumping water level in a well approaches the pump intake, a threshold is eventually crossed when the yield must decline to prevent air from entering the intake. That threshold can be set as a limit in the modeled representation of pumping wells. The same concept can be used to estimate credit water diverted from City wells by setting a limit that matches the minimum index water level. Running a series of simulations compatible with the BMcD 1% drought scenario, with limits set at both the current (1993) and proposed minimum index levels for ASR credit pumping, allows for analyzing the hydrologic effects of the three categories of pumping described above.

Hydrologic Budget Analysis

Scenario A – City Pumping 40,000 AF/y (without ASR Credit)

The pumping schedule to assess the effect of pumping without ASR credit is based on the City goal of using 40,000 acre feet per year (AF/y) from the Equus Beds wellfield (EBWF) prior to use of ASR recharge credits (Burns & McDonnell, 2018a, p. 2-5).[2] **Figure 2** shows the hydrologic system response to the City pumping 40,000 AF/y during the 1% drought scenario. In the first year of pumping, approximately 20 percent of the pumping amount (10 cfs) is depleted from the river system; by the second year, about 35 percent of the pumping amount (20 cfs) is depleted.

Scenario B – City Pumping ASR Recharge Credit to Current Minimum Index Level

The pumping schedule for diverting ASR recharge credit is based on using the model to solve for the amount of credit water that can be diverted from above the current minimum index level. The analysis is derived by running the 1% drought scenario with the City goal of diverting 40,000 AF/y and using the MNW-well capability to determine the amount of water remaining above the current minimum index levels that can also be diverted. That amount of water remaining is the ASR recharge credit water that can potentially be diverted with the City's existing ASR permit (subject to also pumping 40,000 AF/y). The analysis allows for isolating the potential ASR recharge credit water that can be diverted in the 1% drought scenario. **Figure 3** shows the quantity of that water and the hydrologic system response of pumping it. The total amount water diverted is about 14,900 acre feet, which indicates that, if the City prioritizes pumping 40,000 AFY to pumping ASR recharge credit, much of the water diverted from above the current minimum index level is to satisfy the goal of diverting 40,000 AF/y.

Scenario C – City Pumping ASR Recharge Credit to Proposed Minimum Index Level

Analyzing the effect of the Proposal (Scenario C) is similar to Scenario B, except the limit on the minimum index level in the MNW wells is lowered from the current permitted level to the proposed level. The analysis identifies the potential ASR recharge credit that could be diverted if

[2] This is similar to the BMcD 1% drought scenario which simulates approximately 40,000 AF/y of non-credit water diverted from the EBWF in all eight years of the drought, except the first year when 34,202 AF is diverted.

drawdown from City pumping occurred to the level of the proposed minimum index level. **Figure 4** shows the hydrologic system response to that diversion and indicates the amount of ASR recharge credit water that could produced is 79,500 acre feet, which is in addition to the 14,900 acre feet produced in Scenario B.

Discussion of Budget Analysis

The hydrologic budget analysis provides insight to system response in the context of City pumping that causes drawdown to the proposed minimum index level. Points are apparent regarding stream depletion in consideration of minimum desirable streamflow (MDS) and surface-water availability.

Minimum Desirable Streamflow

The permit that regulates the City's ASR project restricts the recovery of recharge credits to periods when water levels are above the established minimum index level (Burns & McDonnell, 2018a, p. 1-1). The proposal seeks to revise the minimum index level to a lower elevation, which would allow a new diversion of groundwater. **Figure 4** shows the potential credit water that could be diverted results in up to 10 cubic feet per second (cfs) of depletion to the Little Arkansas and Arkansas rivers

The minimum desirable streamflow (MDS) established at the gage on the Little Arkansas at Valley Center is 20 cfs.[3] **Figure 5** shows a chart of flow at that gage during the two years (2011 and 2012) that characterize the 1% drought scenario. During that time, flow at the gage is below 20 cfs 49 percent of the time. A change in flow of 5 cfs at that gage (assuming about half of the impact occurs on the Arkansas River) during the drought, would impact MDS flow so that it is less than 20 cfs about 53 percent of the time (**Figure 5**). The percentages translate to about one month of MDS flow not met due to drawing down water levels from the current minimum index level to the proposed level.

The City wells are located in between the Little Arkansas and Arkansas rivers and analysis indicates that diversion/injection of water into the BSA affects river flow. During times when water

[3] The minimum desirable streamflow on the Little Arkansas River is 20 cfs every month of the year (K.S.A. 82a-703c.)

levels are low in the BSA, injection of credit water into the aquifer will initially fill aquifer storage and eventually add flow to the river system and to evapotranspiration. However, during times of drought, when MDS flow is generally of concern, the Proposal seeks to recover credit water from below the current minimum index level, which will cause a new depletion to the river system that impacts MDS flow.

Surface-water availability

The USGS model simulates the Little Arkansas and Arkansas rivers as a boundary condition that does not account for total streamflow. That is, if segments of the river near the City dry out or have low flow during a drought, the model does not account for it. In that setting, there is potential for the model to overestimate river depletion from pumping, which translates to an underestimation of drawdown to aquifer water levels. The situation would affect accounting of ASR recharge credit. We inspected flow on the Little Arkansas River during the drought of 2011 and 2012 and found flow was less than 1 cfs about 30 percent of the time; on the Arkansas River, flow was less than 10 cfs over 20 percent of the time. Those quantities of flow can be depleted by the City pumping 40,000 AF/y (i.e. Figure 2 shows pumping 40,000 AF/y causes 10 cfs of river depletion in the first year of pumping and 20 cfs by the second year). Accordingly, we recommend calibrating the model with a river boundary condition that accounts for routed streamflow to improve conditions represented in adjacent rivers.

Drawdown to Aquifer Water Levels and Well Impacts

Scenarios A, B and C described above provide a basis for an examination of an example City pumping condition that draws down water levels to the proposed minimum index level (i.e. diverting 40,000 AF/y and ASR recharge credit water). **Figure 6** shows drawdown from each of the scenarios at the eighth year of the drought.[4] The drawdown illustrates an example of potential water-level impacts from City pumping if the Proposal is approved. Information on local wells can be compared to the drawdown on **Figure 6** to assess potential impacts to well water columns. The total drawdown to the proposed minimum index level is the sum of drawdown from Scenarios A, B and C.

[4] On Figure 6, Scenario B shows generally less than 1 foot of drawdown in most of the BSA.

For an assessment of potential impacts to local wells, we accessed well construction information from the Water Well Completion Records (WWC5) database available from the Kansas Geological Survey (KGS).[5] We supplemented the WWC5 well data with additional well information[6] provided by the Intervenors (Ecomm, 2019). We then mapped the wells in the area of the drawdown resulting from Scenarios A, B and C and compared total drawdown to well water columns (less 10 feet)[7] to assess whether the wells could be impacted from lowering water levels to the proposed minimum index level. **Figure 7** shows 35 wells with water columns less than the total drawdown from Scenarios A, B and C indicating potential for some wells in the BSA to lose capacity to produce water as a result of City pumping that could occur if City groundwater withdrawals cause drawdown to the elevation of the proposed minimum index level. Out of the 35 wells, 29 are impacted from the City pumping 40,000 AF/y and 6 are impacted from pumping ASR recharge credit down to the minimum index level. The aquifer drawdown assessment herein represents an example City pumping scheme that causes drawdown to the proposed minimum index level. Other City pumping schemes are possible that can affect the number of impacted wells. However, the analysis herein clarifies that the overall magnitude of drawdown to the minimum index level, caused by City well diversions, exceeds the water column expected to be needed by some wells in the area.

Figure 7 shows the locations of City wells as red circles. The red circles represent the location of the well and a 660-foot buffer around the well location. We note that out of the wells potentially impacted, many of them are located at distances greater than 660 feet from the City wells. This indicates that the minimum well spacing regulation (K.A.R. 5-22-2) for domestic wells (660 feet), from other wells in a subject application, is not sufficient to provide protection from

---

[5] Since 1975, drilling companies have been mandated by state legislation to provide well information that typically includes well depth and a static depth to water (http://www.kgs.ku.edu/HighPlains/data/, data accessed Jan 18, 2019). We quantified well water columns from reported depth to water and well depths in WWC5. The available data is not expected to include all area wells since wells are anticipated to have been drilled prior to 1975.

[6] The information provided for most of the Intervenor wells included a water rights number. For those wells, we cross-referenced water rights numbers with the Water Information Management and Analysis System (WIMAS) to determine well location. For wells that did not have a water rights number, we mapped the wells to the nearest section of the Public Land Survey. Most of the Intervenor wells did not have depth to water. To estimate well water columns, we cross-reference the well locations with a year 2016 digital water-level surface adapted from the USGS (https://www.sciencebase.gov/catalog/item/5824e0b9e4b0c05b678c45dd).

[7] We subtracted 10 feet from the well water columns to allow for pump submergence while the well is operating with a pumping water level. This is a general estimate that could be refined in a case-by-case setting if specific area wells are examined for impacts from groundwater pumping.

excessive drawdown, suggesting a case-by-case assessment is needed to consider impacts from City well diversions.

Water Quality Change

The USGS evaluated chloride transport in the Equus Beds aquifer in a preliminary study (Klager and others, 2014) that is based on the USGS groundwater flow model used for the analysis described herein. The USGS analysis examines pumping scenarios (and one recharge scenario) involving variations in regional and municipal pumping to develop an understanding of chloride displacement that may occur. A summary of selected USGS results is shown on **Figure 8**, which is adapted from Figure 27 of Klager and others (2014). **Figure 8** shows the greatest potential for chloride migration is located generally north of the Arkansas River along the southern portion of the BSA. Similar to the USGS technical approach, we examined chloride displacement based on the Proposal and found potential for hundreds of feet of displacement of water with chloride resulting from lowering water levels to the proposed minimum index level; the displacement is generally in the same location (southern portion of the BSA) as that of the USGS analysis. However, the USGS notes that modeled chloride in this area moved northeast at a higher rate than is observed in the field data (Klager and others, 2014, p. 72).[8] Accordingly, the modeled displacement of chloride in this area is overestimated. The USGS also reports their analysis results indicate potential for the Burrton plume to continue migrating toward the City wellfield (Klager and others, 2014, p. 72). If the City diverts groundwater resulting in lowering water levels to the proposed minimum index level, there is increased potential to induce migration of chloride from the areas of Burrton and the Arkansas River.

In the USGS study, the groundwater flow model was not altered to calibrate the solute-transport model to observed chloride concentration data (Klager and others, 2014, p. 71). The USGS indicates achieving better performance of chloride transport may require changes to the groundwater model and that future model updates will allow opportunities for that type of calibration. We agree with that assessment. In the Proposal, the City does not describe potential water quality changes associated with lowering the minimum index level. We are not familiar with the level of detail in which the City has evaluated potential water quality impacts in the context of the Proposal. Further development of the chloride displacement analysis along the line described by

[8] In the shallow part of the aquifer, the model simulated chloride movement at a rate about 2x that of observed data; in the deep aquifer, the modeled rate of movement was about 4x that of observed.

the USGS is expected to enhance the model for use in assessing potential water quality impacts. We recommend proceeding along that line in attempt to identify potential issues that may arise if drought conditions prompt the City to divert groundwater that causes drawdown to the proposed minimum index level.

PROPOSED ASR ACCOUNTING METHODOLOGY

Section 4.0 of the Proposal describes an accounting method for ASR credits. The method uses a response-function type of approach that considers a 5 percent initial loss from the BSA the first year and a 3 percent loss in subsequent years. BMcD shows that the proposed recharge accounting mirrors the current accounting approach, but with a deviation that occurs when water levels increase in the BSA.

BMcD indicates the calculation of tracking recharge credits across the BSA is a very detailed procedure requiring a substantial amount of data preparation and processing and that there is shared interest (DWR, GMD2 and the City) in developing a simplified accounting process. Accordingly, there is utility in simplifying the accounting process with a response-function type of approach. However, the USGS model accounts for the physical structure of the aquifer system and the associated change in aquifer system/river response associated with changes in water levels in the BSA. If using the USGS model is definitively too burdensome, we recommend developing a response function that accounts for both low and high water levels in attempt to improve the performance of the simplified accounting method over varying aquifer conditions. Technical coordination with BMcD would provide insight to the basis behind the proposed simplification approach and whether development of an alternative response function can provide an improved simplification technique.

SUMMARY AND CONCLUSIONS

1. The City of Wichita currently has a permit for ASR water operations that is conditioned to allow recovery of ASR recharge credit if water levels are above a specified minimum index level. The City is proposing to lower the minimum index level to allow for diverting additional ASR recharge credit that may be needed in the event of a drought.
2. On behalf of the City, BMcD developed a 1% drought simulation as a basis for the ASR Permit Modification Proposal. The analysis engine for the simulation is the USGS model of

the Equus Beds aquifer (Kelly and others, 2013). The model the City provided to GMD2 differs from the USGS model in that ratio of horizontal to vertical hydraulic conductivity is modified. We found the modification does not affect the model analysis enough to affect our overall conclusions described herein. However, unless there is a reason to deviate from the original USGS model concept, we recommend the City accounting of recharge credit and the analysis in the Proposal be updated accordingly to confirm that potentially significant factors do not arise.

3. The BMcD analysis of the 1% drought simulation presents hydrologic results in terms of general water-level elevations and percent of saturated thickness in the Basin Storage Area (BSA). The model analysis illustrates that pumping proposed during the 1% drought results in lowering about half of the water levels in the index cells of the BSA below the current minimum index level. The proposed minimum index level is lower than that derived from the model simulation. However, BMcD does not present an analysis quantifying hydrologic effects from pumping that could cause drawdown to that proposed minimum index level.
4. We present an analysis of an example scenario in which the City pumps groundwater, consistent with a goal to utilize 40,000 AF/y from its wellfield prior to use of ASR recharge credits. The scenario represents diversion of groundwater causing drawdown to the proposed minimum index level to characterize associated hydrologic effects. We also illustrate that the USGS model utility for simulation of wells includes capability for separating the hydrologic effects of City pumping non-credit water from ASR recharge credit water with consideration of the current and proposed minimum index levels. The assessment provides insight to hydrologic effects in the context of the new pumping that could occur if the minimum index levels are lowered.
5. The proximity of the City wells to the Little Arkansas and Arkansas rivers, and the aquifer properties, results in a high degree of connection between groundwater in the BSA and the rivers. In the first year of City pumping, approximately 20 percent of the pumping amount is depleted form the river system. If the City diverts ASR recharge credit water causing drawdown to the proposed minimum index level, a new depletion is anticipated to occur at the Valley Center MDS gage. Given that the Proposal is based on pumping during drought conditions, the impact is consistent with a time when MDS gage flows are a concern. The MDS flow at the Valley Center gage is 20 cfs every month of the year.
6. We recommend calibrating the USGS model with a representation of rivers that accounts for total streamflow. During drought conditions, flow on the Little Arkansas and Arkansas rivers has lowered to quantities compatible with estimated stream depletion from City

groundwater pumping. In that setting, there is potential for overestimating stream depletion, which translates to an underestimation of aquifer storage depletion. Refining the technique of modeling the rivers would improve representation of local hydrologic conditions and may translate to an improved account of ASR recharge credit.

7. We examined aquifer water-level response in the BSA from an example of City groundwater pumping that causes drawdown to the level of the proposed minimum index level. The drawdown is caused by the City pumping 40,000 AF/y in combination with diverting ASR recharge credit. The total drawdown is up to approximately 30 feet. We compared the drawdown from the scenario to information on local well water columns. The result indicates that up to 35 wells are identified with potential to lose capacity to produce water from the total drawdown. Out of the 35 wells, 29 are impacted from the City pumping 40,000 AF/y and 6 are identified to be impacted from the City diverting ASR recharge credits down to the proposed minimum index level. This observation indicates that some wells in the area can be reasonably anticipated to require a remedy associated with lowering water levels to the proposed minimum index level. Information on local well water columns is from the WWC5 database that includes records beginning in 1975. Accordingly, we anticipate the drawdown assessment does not include all of the local area wells. Some of the wells (domestic) are located greater than 660 feet from City wells indicating the minimum well spacing regulation (K.A.R 5-22-2) is not sufficient to provide protection from excessive drawdown caused by City pumping. This observation suggests a case-by-case assessment is needed to consider impacts from City well diversions.
8. Preliminary USGS study of chloride transport indicates potential for migration from the Burrton area and generally north of the Arkansas River along the southern portion of the BSA. The USGS notes that modeled chloride (along the southern portion of the BSA) moved northeast at a higher rate than is observed in the field data. If the City diverts groundwater resulting in lowering water levels to the proposed minimum index level, there is increased potential to induce migration of chloride from the areas of Burrton and the Arkansas River toward other wells in the area. The USGS chloride transport analysis was based on the existing groundwater flow model without alterations to improve performance of the solute transport model. It would be prudent to proceed with further development of the chloride displacement analysis in attempt to identify potential issues that may arise if drought conditions prompt the City to divert groundwater that causes drawdown to the proposed minimum index level.

9. The calculation of tracking recharge credits is reported to be a detailed process. The Proposal describes a response-function type of approach to simplify the accounting method. The simplified approach deviates from the current approach under conditions of high water levels. The USGS model provides the best approach for accounting. If a simplified approach is necessary, we recommend development of a response function that accounts for both low and high water levels in attempt to improve the simplified accounting method over varying aquifer conditions.

QUALIFICATIONS AND EXPERIENCE

I am a Certified Professional Hydrologist (08-HGW-1817) with the American Institute of Hydrology. I am President of Balleau Groundwater, Inc. and have over 20 years of experience in major aspects of hydrology and hydrogeology with emphasis on analysis of hydrologic processes involving the interaction of groundwater and surface-water. Development of field-testing programs, assessment of wellfield performance and yield, water-resource planning and management, arid zone hydrology, artificial recharge, mine dewatering and water rights litigation support have also been major activities.

I have developed, adapted or worked with more than 100 hydrogeologic models. My experience includes analysis of the local and regional water budgets for both natural hydrologic conditions and changes induced to the natural system from development of surface water and groundwater. I have evaluated recharge and recovery of groundwater credit water in southwestern New Mexico and peer reviewed analyses of artificial recharge in southern California. Over the past decade I have analyzed hydrologic effects in the Rattlesnake Creek Basin in the area of Stafford County, Kansas and I am one of the authors of the model currently used by KDA-DWR for analysis of hydrologic effects in the area of Groundwater Management District No 5. I have advised cities and peer reviewed hydrogeologic analyses for municipal water districts regarding water resources in settings that involve groundwater pumping, artificial aquifer recharge, aquifer recharge from flooding and remediation of groundwater contamination. I have also advised industrial water users, irrigation and conservancy districts, state and federal agencies, Indian tribes, water associations and private water users with matters involving source water availability. I have presented at conferences involving groundwater hydrology and I have been invited to publish in a Theme Issue of the peer-reviewed journal *Groundwater* on research related to analysis of groundwater flow.

I attest to the contents and substance of the above report.

AMERICAN INSTITUTE OF HYDROLOGY
Certificate Number 1817
Dave Romero
Professional Hydrologist-Ground Water

Dave M. Romero, P.H.

Date: Feb 18, 2019

REFERENCES

Burns & McDonnell, 2018a, ASR Permit Modification Proposal – Revised Minimum Index Levels & Aquifer Maintenance Credits: prepared for City of Wichita, Kansas, Project No. 71395, report dated: 3/12/2018.

Burns & McDonnell, 2018b, Aquifer Storage and Recovery Project – 2016 Annual Accounting Report: prepared for City of Wichita, Kansas, Project No. 104024, report dated: April 2018.

[Ecomm] Electronic Communication, Feb 13, 2019, from: Tessa Wendling, Esq. to Dave Romero, P.H. of Balleau Groundwater, Inc.

Hansen C.V., Lanning-Rush J.L., and Ziegler A.C., 2013, Revised shallow and deep water-level and storage-volume changes in the *Equus* Beds Aquifer near Wichita, Kansas, predevelopment to 1993: U.S. Geological Survey Scientific Investigations Report 2013–5170, 18 p., http://pubs.usgs.gov/sir/2013/5170/.

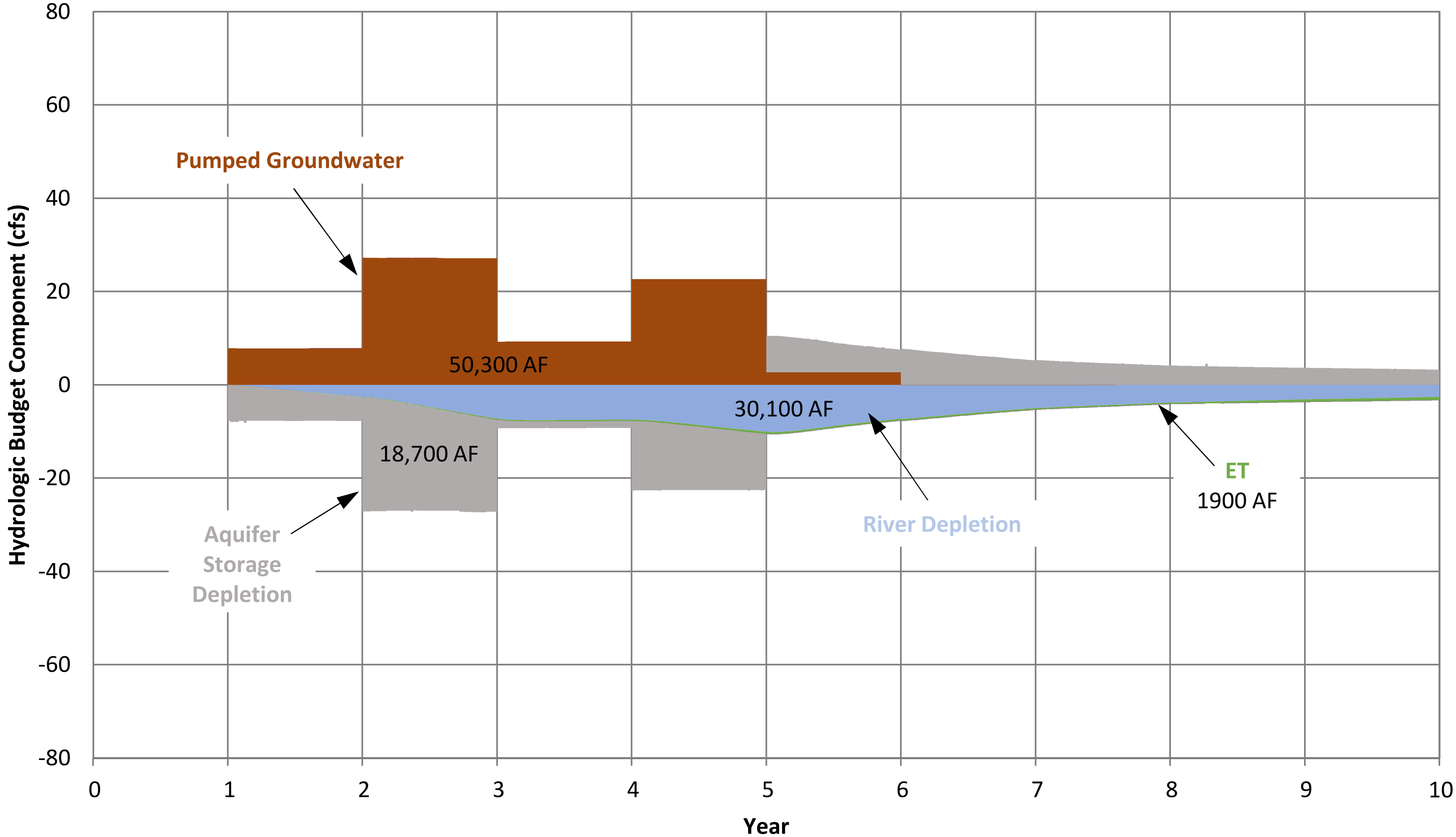
Kelly, B. P., Pickett, L. L., Hansen, C. V. and Ziegler, A. C., 2013, Simulation of Groundwater Flow, Effects of Artificial Recharge, and Storage Volume Changes in the Equus Beds Aquifer near the City of Wichita, Kansas Well Field, 1935-2008: prepared on cooperation with the City of Wichita, Kansas, as part of the Equus Beds Groundwater Recharge Project, Scientific Investigations Report 2013-5042.

Klager, B.J., Kelly, B.P., and Ziegler, A.C., 2014, Preliminary simulation of chloride transport in the *Equus* Beds aquifer and simulated effects of well pumping and artificial recharge on groundwater flow and chloride transport near the city of Wichita, Kansas, 1990 through 2008: U.S. Geological Survey Open-File Report 2014-1162, https://dx.doi.org/10.3133/ofr20141162

Konikow, L.F., Hornberger, G.Z., Halford, K.J., and Hanson, R.T., 2009, Revised multi-node well (MNW2) package for MODFLOW ground-water flow model: U.S. Geological Survey Techniques and Methods 6–A30.

[Macey] Letter dated Sep 28, 2018 from Scott A. Macey, Water Resources Engineer with the City of Wichita Department of Public Works & Utilities to Mr. Tim Boese, District Manager of the Equus Beds Groundwater Management No.2.

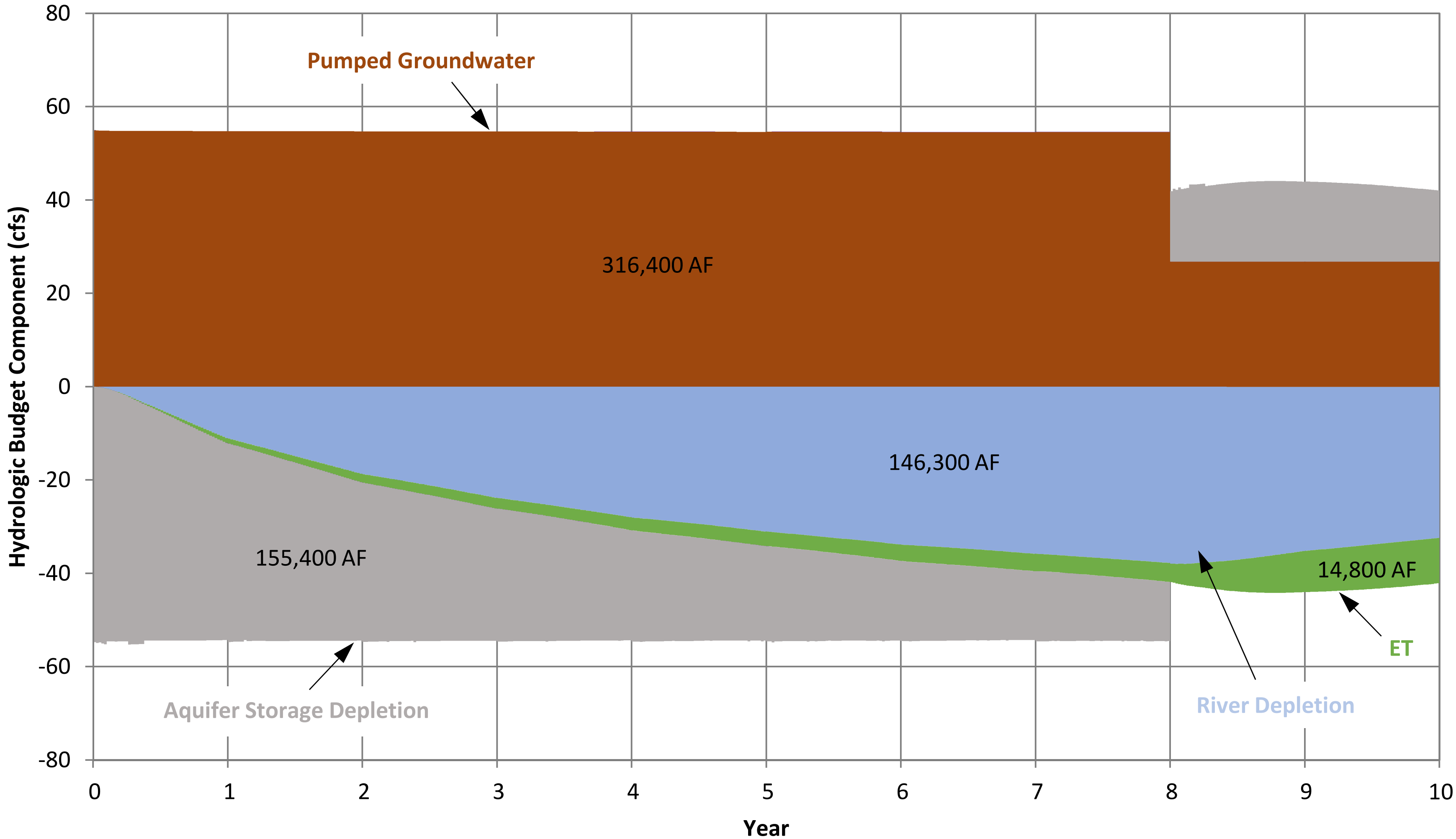
FIGURE 1
HYDROLOGIC SYSTEM RESPONSE TO CITY PUMPING ASR RECHARGE CREDIT



Note: Budget volumes are over 8-year period

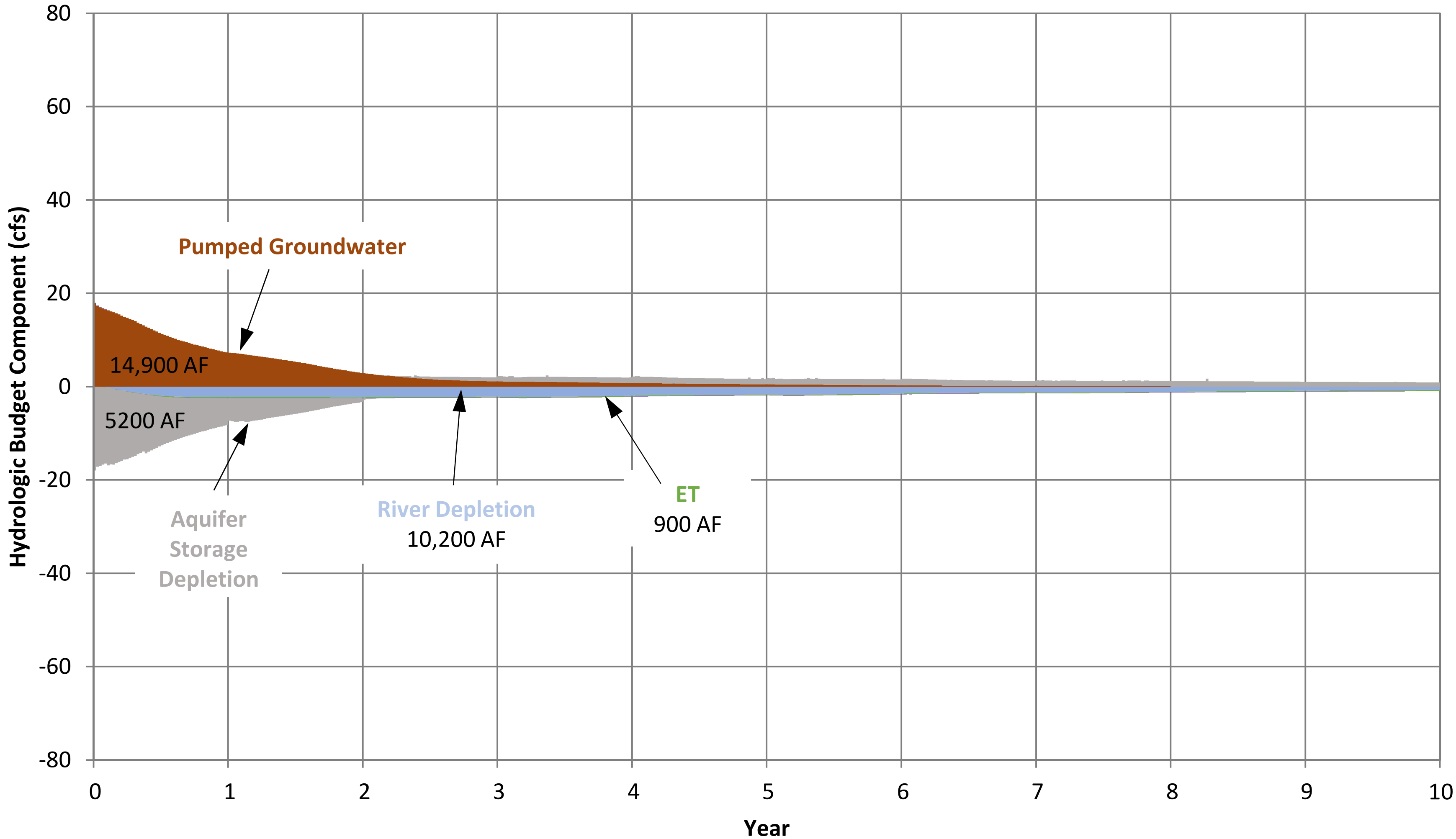
WDMbudgets
BY
2/15/2019

FIGURE 2
HYDROLOGIC SYSTEM RESPONSE TO CITY PUMPING 40,000 AFY (SCENARIO A)



Note: Budget volumes are over 8-year period

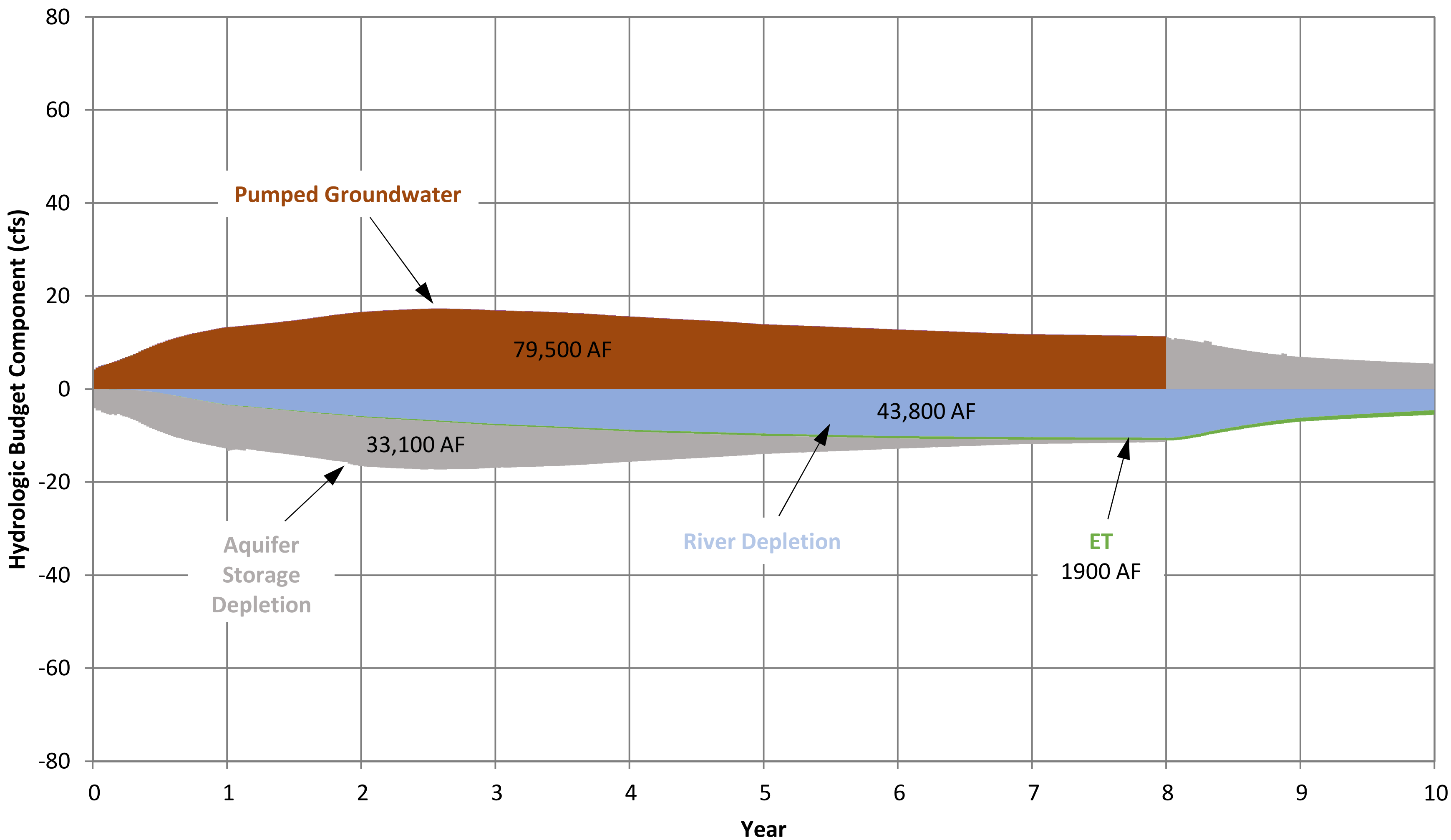
FIGURE 3
HYDROLOGIC SYSTEM RESPONSE TO CITY PUMPING PERMITTED ASR RECHARGE CREDIT (SCENARIO B)



Note: Budget volumes are over 8-year period

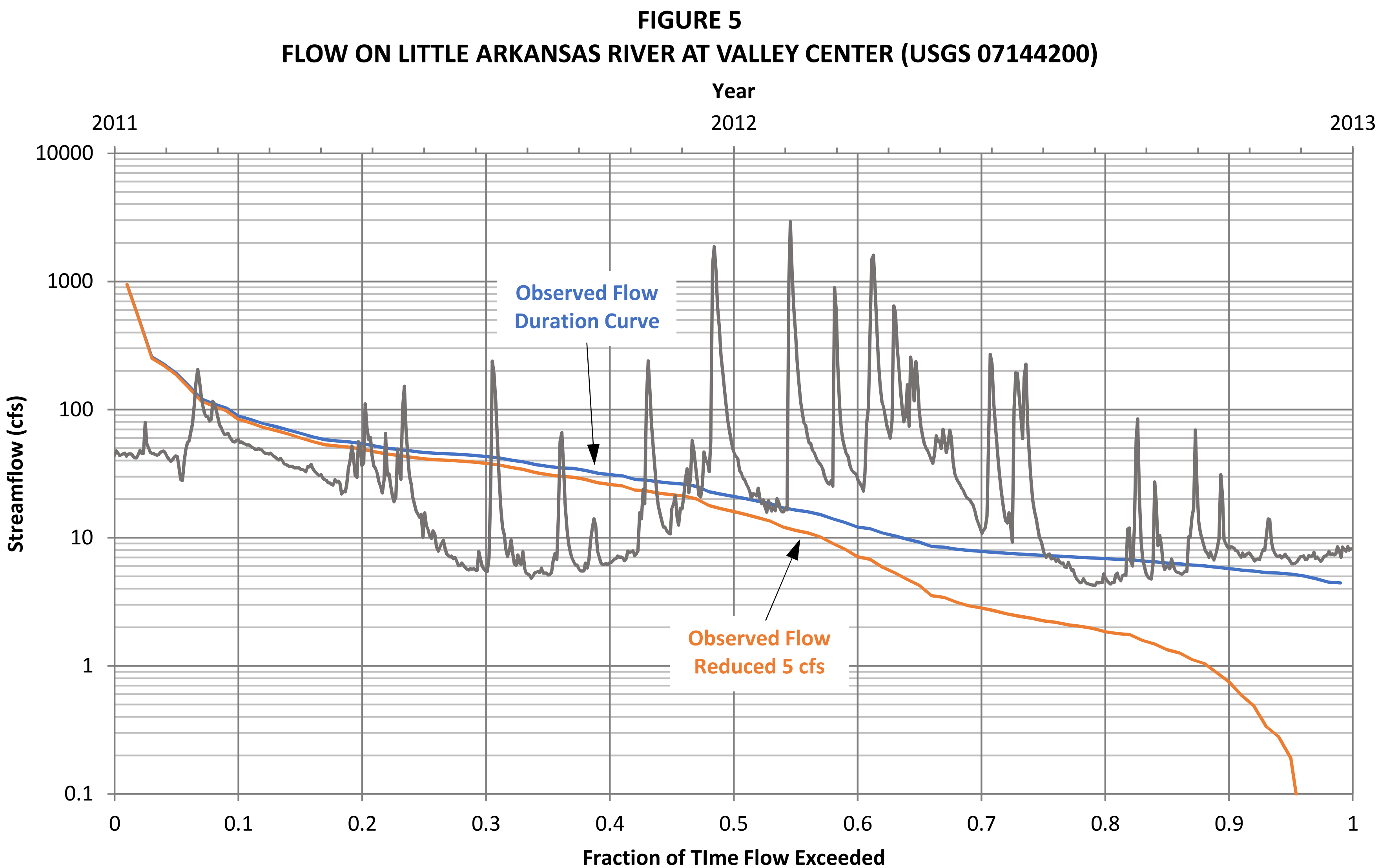
WDMbudgets
BY
2/15/2019

FIGURE 4
HYDROLOGIC SYSTEM RESPONSE TO CITY PUMPING PROPOSED ASR RECHARGE CREDIT (SCENARIO C)

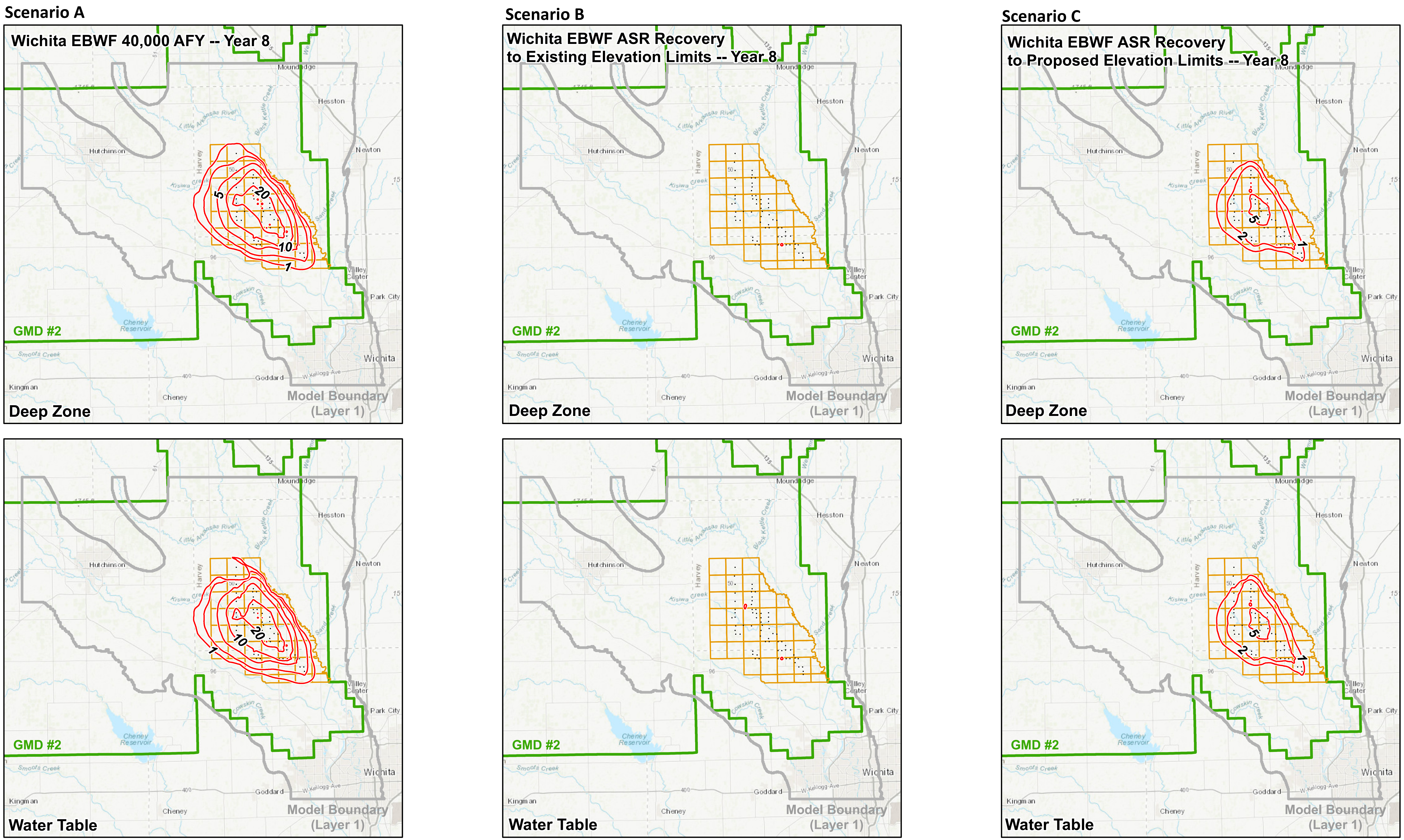


Note: Budget volumes are over 8-year period

WDMbudgets
BY
2/15/2019



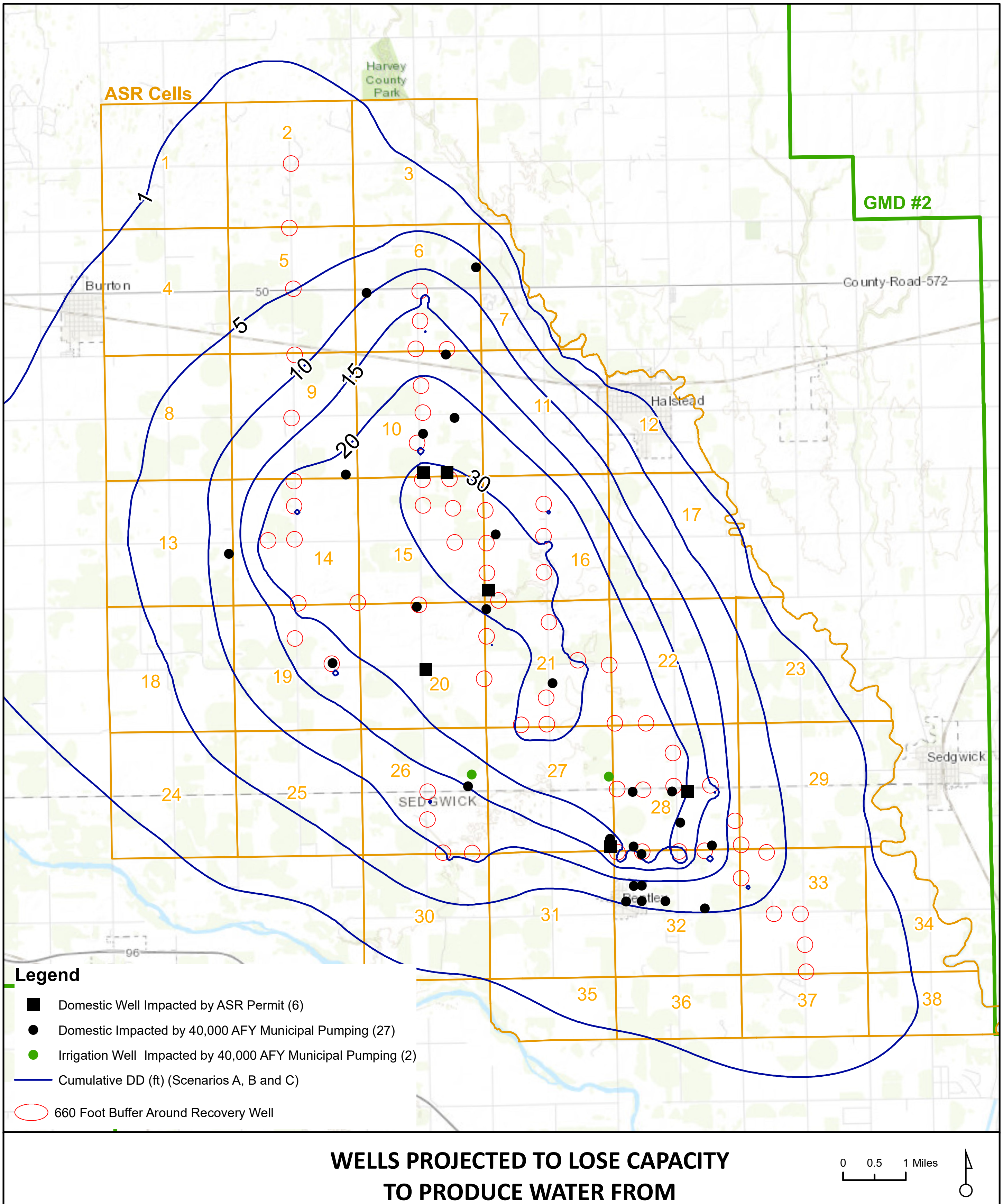
streams
BY
2/15/2019



Countour interval = 1, 2, 5, 10 and 20 ft.

WATER-LEVEL DRAWDOWN FROM SCENARIOS A, B and C
FIGURE 6

0 5 10 Miles
Coordinate System: NAD 1983 UTM Zone 14N

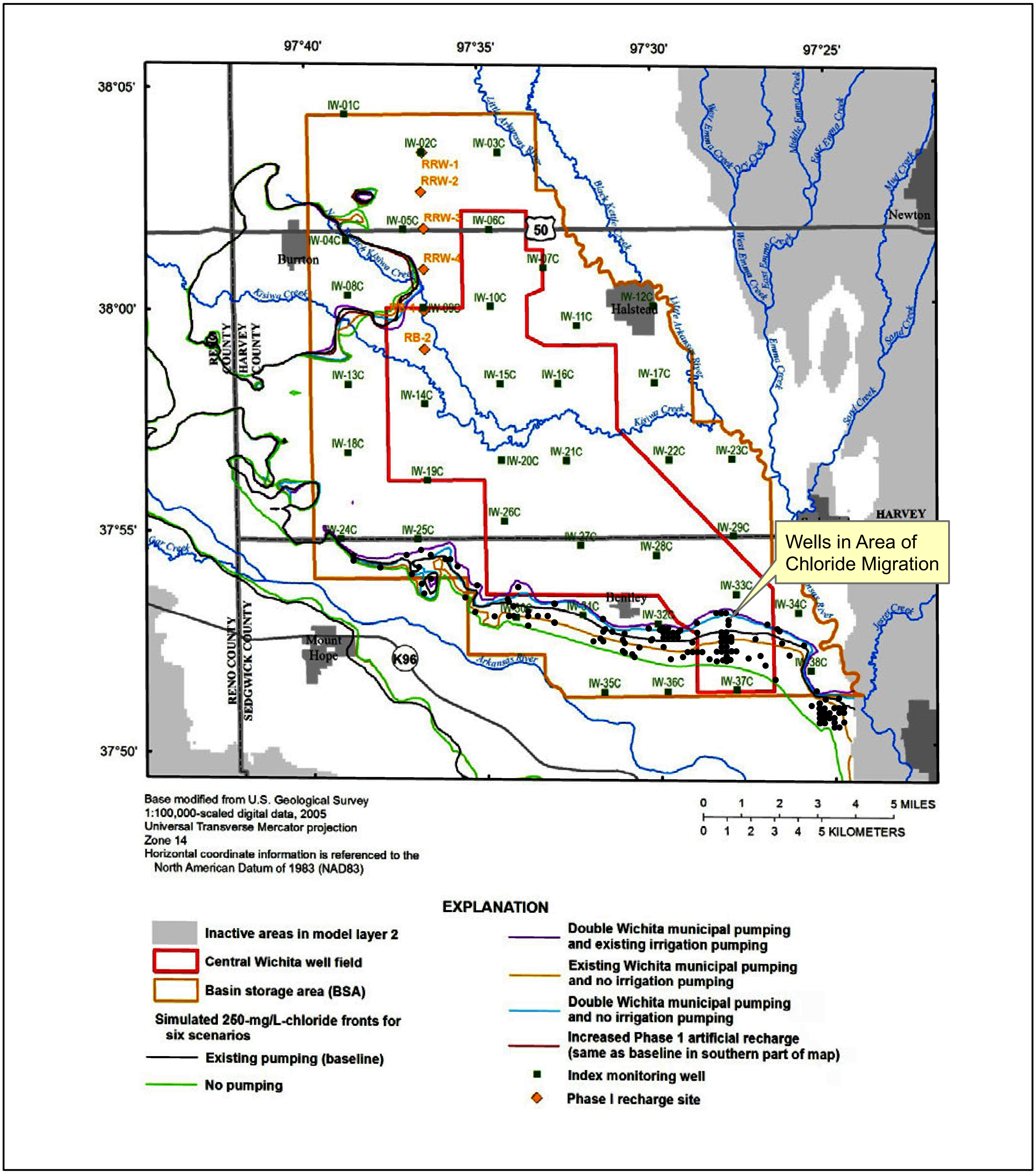


WELLS PROJECTED TO LOSE CAPACITY TO PRODUCE WATER FROM WATER-LEVEL DRAWDOWN TO PROPOSED MINIMUM INDEX LEVEL

FIGURE 7

Data Sources
Base VIA ESRI online.
Recovery wells from GMD #2 data.
Well locations from WWC5 data, accessed January 18, 2019.

: E:\Clients\wendling\Models\Wells2.mxd:2/18/2019 1:18:43 PM



ADAPTED USGS FIGURE 27
KLAGER AND OTHERS (2014)
FIGURE 8

0 0.5 1 2 Miles

Coordinate System: NAD 1983 UTM Zone 14N