

Hydrogeologic Evaluation of Sandstone Mining in Izard County, Arkansas.
Jay S. Johnston, C.P.G., R.P.G., D. Todd Fugitt, R.P.G.

Introduction

The St. Peter and Calico Rock Sandstones in north-central Arkansas are planned for surface mining in the immediate future. The purpose of this report is to evaluate the possible hydrogeologic impacts of ground-water use associated with this type of mining operation in the Salem Plateau of north-central Arkansas. Two surface mining permits (Evergreen and Bluebird) were approved by ADEQ early in 2010 (Figure 1). Mining interests in the area have also been expressed by other companies, and as many as 5 to 10 mines could be developed along the outcrop belt. These mines will provide economic benefit to the state and local communities, and assist the shale-gas resource industry by supplying “frac-sand” to serve expanding world-wide demand required in shale-gas resource development. Though there is no allocation of ground-water use in Arkansas, the planned mining activities will probably impact the states natural resources. Therefore, it is beneficial that all agencies and commissions involved with natural resources take a prudent view to the proposed mining operations of the study area, and consider all possible hydrologic impacts, as well as environmental, and economic impacts to the State, County, and citizens. This report is based on existing hydrogeologic data. Information on mining operation technology was obtained from Evergreen Inc., Crisp Industries, and Marshall, Miller, and Associates, and through web-site research.

The population of Izard County in 2000 was 13,249, and 89% of the population is served by municipal ground water. Estimates of domestic wells in the county equal ~650 wells serving ~1450 people. More than 300 relatively shallow (<600') Ozark domestic wells, serving ~700 citizens are estimated to occur within 5 miles of the proposed mining areas. Figure 2 shows all water wells appearing on the ANRC/USGS water well data base in the area (wells installed prior to ~1990 are not shown).

State Permitting Requirements

ADEQ requires permits for mining operations including construction storm water, air quality, and NPDES (National Pollutant Discharge Elimination System) permits. Submittal of a Notification of Intent prior to initiation of stone mining in Arkansas is required. This notice includes a map of the planned mined area, and information regarding planned reclamation of the mined area. NPDES permitting for discharges and stream buffering are included as part of the mining requirements. This permitting process provides an evaluation of water quality impacts. All hazardous wastes used in the mining operations process must adhere to ADEQ rules. The impacts regarding the ground-water system, water use and particularly private wells, are not considered in stone mining quarry operations in Arkansas.

The ANRC has authority to allocate surface water use in times of shortage, but there is no such ground-water allocation authority. Ground-water use requires only proper reporting and that wells be constructed by licensed water well contractors. However, if any water is transferred away from the riparian property, a non-riparian permit is required. Transfer to a different hydrologic unit requires an additional level of permit requirements and public hearings.

Geology and Hydrogeology

Izard County is underlain by essentially flat-lying sedimentary strata of the Salem Plateau. The younger Springfield Plateau (Mississippian) underlies <10% of the extreme southern part of the county, just east of Guion, and north of the White River.

The St. Peter Sandstone unconformably overlies the Everton Formation which contains the Calico Rock Sandstone member. Both of these formations are middle Ordovician in age. Both sandstone units exhibit relatively clay-free, fine to medium grained, well-rounded quartz sand, which has excellent characteristics for the shale-gas, frac-sand industry. The St. Peter Sandstone is a typically massive formation which is approximately 175 feet in thickness. The formation generally is found at land surface throughout the proposed mining area, though some thickness of overlying regolith may be present.

The Ozark aquifer in Arkansas ranges in thickness from approximately 1100 ft. to more than 4000 ft. The aquifer consists of an alternating sequence of dolostone, limestone, sandstone, chert, and shale (in order of dominance). The aquifer is a complex, semi-confined (unconfined near surface, and confined in deeper units), anisotropic/heterogeneous aquifer with considerable variability in structure and stratigraphy (Figure 3 shows a cross-section of the planned mining formations within the Ozark aquifer to portray the stratigraphic complexity of these units and demonstrate the complexity of the entire Ozark section). Table 1 shows a basic stratigraphic column that lists the various rock units of the Ozark aquifer and their hydrogeologic character. The Ozark confining unit is absent throughout the planned mining area, allowing the Ozark to be classified as an unconfined to semi-confined aquifer.

Water levels in the Ozark aquifer in Arkansas during the past 40 years have shown minimal drawdowns as demand has not exceeded potential yield of the aquifer (USGS, SIR 2008-5137). In Arkansas, some counties have shown declines while other counties have shown rising potentiometric heads. One well completed in the Cotter Dolomite in Izard County showed only a minimal annual decline of just over 1 foot per year. Greater water demand in growing population centers of Missouri, Kansas, and Oklahoma, however, have shown development of cones of depression with noted drawdowns in the Ozark aquifer.

Stratigraphic Column and Hydrogeologic Properties of the Ozark Aquifer (USGS, SIR2008-5137)

ERA	PERIOD	GEOLOGIC UNIT	HYDROGEOLOGIC UNIT	LITHOLOGY	THICKNESS (feet)	HYDROGEOLOGY			
Paleozoic	Devonian	Chattanooga Shale	Ozark confining unit	Shale unit that crops out in a narrow band that outlines the Ozark aquifer and is missing where the Ozark aquifer is exposed at the surface.	0 - 200	Unit is relatively impermeable because of large shale content.			
		Clifty Limestone	Ozark aquifer	Chert with lenses of limestone, dolomite, and cherty sandstone.	0 - 250	The residual cherty rubble, weathered from cherty limestone and sandstone of the unit, may yield 2 to 5 gallons per minute.			
	Penters Chert								
	Silurian	Lafferty Limestone		Limestone, dolomite, sandstone, and minor amounts of shale	0 - 2,000	The limestones and dolomites commonly yield 5 to 10 gallons per minute from solution channels, bedding planes, and fractures. Similar yields may be obtained from the sandstone where it is porous or fractured. These units contain many springs. Yields from springs and some wells may exceed 50 gallons per minute.			
		St. Clair Limestone							
		Brassfield Limestone							
		Cason Shale							
		Fernvale Limestone							
		Kimmswick Limestone							
		Plattin Limestone							
		Joachim Dolomite							
		St. Peter Sandstone							
		Everton Formation							
		Smithville Formation							
	Ordovician	Powell Dolomite		Dolomite, dolomitic limestone, and minor amounts of sandstone and shale.	100 - 1,000	The solution channels and fractures in the dolomite and dolomitic limestone commonly yield 5 to 10 gallons per minute. Wells that tap large solution channels may yield more than 50 gallons per minute, but large yields are uncommon. These units yield water to several large springs.			
		Cotter Dolomite							
		Jefferson City Dolomite							
		Roubidoux Formation					Sandstone and sandy dolomite. Not exposed in Arkansas.	100 - 250	Yields of as much as 450 gallons per minute may be obtained from some wells, but yields are highly variable and generally average less than 150 gallons per minute.
		Gasconade Dolomite							
		Gunter Sandstone member of the Van Buren Formation							
		Eminence Dolomite							
	Cambrian	Potosi Dolomite	St. Francois confining unit	0 - 750	Permeability is minimal to moderate. Unit is more permeable where transected by fault and fracture zones.				
		Doe Run Dolomite							
Derby Dolomite									
Davis Formation									

Table 1. Stratigraphy and Hydrogeologic Properties of the Ozark Aquifer

Water Use and Hydrogeologic Impacts

Investigation into sand mining operations in other states and the mining industry has provided data for estimated mining water requirements in Arkansas. Much information has also been provided by Crisp Industries and Marshall Miller and Associates. Surface water is currently used for sand mining in this area, but may not be readily available at all proposed mining sites. Springs have been identified as a potential source of water supply; however, springs in this area may or may not provide adequate volume to meet water use demands depending on the design of the mining operations. ANRC Ground Water Section has estimated potential hydrogeologic impacts and water use at these mining and sand processing plants, and has predicted potential hydrologic impacts expected from the mining process which includes development of water wells in the Ozark aquifer.

Total water use at a single mine may vary, depending on the mining methodology. The reported water use by existing sand-mining operation Unimin Corporation is 2064 gallons per minute (gpm). This is an open-loop mining operations which relies on surface water. Although water is required to mine the sand (via slurry transport) at some mining locations, no water is expected to be required to mine the sand in Arkansas mines. Water is needed, however, to wash and separate the sand (remove fines and sieve) to segregate size particles for its specific use. Total water use at a single sand washing facility may be large; however, much of the water is reused. Evergreen and Crisp Industries have reported water use would not exceed 200 gpm (6 hr. pumping days = 72,000 GPD- gal/day) and would average about 175 gpm at their operating plant. The proposed source of water at this plant is a surface water site (spring). However, research into the sand washing equipment web-site, indicates that more water may be required for some mines due to less efficient technology utilized to remove fines materials. In the absence of plate press, a 10% water loss from a clarifier using 7400 gpm, could result in 740 gpm of lost water. If surface water is not available, the only alternative is the development of deep wells in the Ozark aquifer.

The mining operation proposed by Evergreen will utilize a surface water source, and utilizes an efficient “press plate” process which requires only 175 gpm. Total ground-water use at a comparable, with traditional, less efficient processing plant technology may be estimated to equal 940 gpm, which will equal 338,400 GPD (6 hr. operation days) or 451,200GPD (8 hr. operation days). Utilizing the less-efficient operating technology, five mines could require 2.25 MGD (million gal/day) (~6 times the current water use of municipalities reported in IZARD County), and ten mines could require up to 4.5 MGD (8 hr. operation day), or ~12 times the water currently utilized by municipalities from the deep Ozark aquifers (Roubidoux and Gunter) in IZARD County (Table 2). Total reported ground-water use in IZARD County is currently, 1.79 MGD (Holland, 2005). Such an increase in water use would probably cause a noticeable decrease in water-levels; however, unless a surface water site is intercepted, significant impacts may not be noticed for several years.

ANRC attempted to determine the expected impacts that ground-water use for sandstone mining will have on the ground-water system in the vicinity of the planned mining operations of IZARD County. The AR Dept. of Health was very helpful in providing a program which calculates expected drawdowns at specified distances from a pumping well. Specified hydrologic parameters for the Roubidoux aquifer were utilized in the program with the following results:

Pumping 200 gpm from one proposed mine in the area (Evergreen's water use estimate) resulted in an estimated 14 feet of drawdown in a well, 5 miles from the pumping well in approximately 2 years, and 18 feet in 9 years (Figure 4). Though such a decline is more severe than the current declines observed in the county, and would be noticeable, the impact may not be adverse. Pumping 450 gpm (expected yield of 3 Roubidoux wells producing 150 gpm) resulted in drawdown of 32 feet, 5 miles from a pumping well in approximately 2 years, and 39 feet in 9 years (Figure 4). The closest municipal wells are approximately 6 miles from the proposed mining area, and about 40 shallow domestic wells are located in the immediate vicinity.

Currently, the potentiometric surface of the Ozark aquifer in the study area of Izard County generally is within 100 feet of land surface. The aquifer is approximately 1500 to 2000 feet in thickness in this vicinity; therefore, these declines could reduce the saturated thickness of a portion of the aquifer near the mining area to 50 percent in approximately 200 years at the lower water-use rate, to 90 years at the higher rate. (The 50 percent saturated thickness is a critical area criterion which reflects the state's current ground-water policy with respect to determination of severe water-level declines.) However, impacts on springs and streams, via stream capture, as well as increased pumping depth requirements may be observed much more quickly. Shallow domestic wells would also be especially vulnerable to water-level declines.

Further research (and perhaps a ground-water model) will be required to determine the total impact of pumping from the proposed mines on municipal wells in the county. The preliminary results, however, reflect the low storativity of the Ozark aquifer, and suggest that large drawdowns in the Ozark aquifer can be expected from the mining water use requirements, particularly if 5-10 mines begin operations. Depending on the degree of intercommunication between the shallow and deep Ozark aquifers, lowering of heads in shallow Ozark aquifers is also possible, as well as reduced flow to springs and streams.

Modeling Capabilities

Ground-water modeling is one valuable tool that may be used in many instances to predict aquifer response from pumping. Any two ground-water scientists may have considerable differing opinions regarding the value of predictive computer modeling in an aquifer such as the Ozark. Most of the hydrologic parameters required to generate a computer model, such as Transmissivity (T) and Storage Coefficient (S), are derived from pumping test data. Equations utilized to calculate flow to a well often assume a homogeneous/isotropic aquifer, however, the heterogeneous and anisotropic character of the Ozark aquifer; render these equations of little value. Consequently, pumping test data and computer models in the Ozark aquifer must be used with caution and may have severe limitations.

Although ~35 aquifer tests have been performed (1940-06) for the Ozark aquifer, most have been Specific Capacity (S) tests in 12 Arkansas counties. Only 1 Cotter pumping test has been performed in Izard Co. Assumptions, regarding proper well construction and test methodology (completely penetrated unit test) were made, which may be incorrect.

S is calculated from estimation of Specific Storage. S and Sy (Specific yield in unconfined aquifers) can be measured during pumping tests, but estimates, particularly of Sy, are subject to error, making field measurements from pumping tests uncertain (Freeze and Cherry, 79). S values (derived from pumping tests) greatest value lies in determination of the potential yield of a well/pumping scenario at that particular location, and should be applied with caution over large

areas in anisotropic/heterogeneous aquifers such as the Ozark, and use in any model could introduce error. In addition, solution fractures or faulting can make these calculations and assignment of model grid values of little value. Consequently, a model in an aquifer such as the Ozark may or may not provide accurate prediction of drawdowns in the aquifer, and only post-audit validation and revision, with model refinement, could insure its accuracy. Though there are limitations when modeling in areas with limestone and dolostone lithology, they can be very effective with proper application. The model developed by the Dr. John Czarnecki with the USGS Water Sciences Center has been extremely useful in developing better understanding of the Ozark aquifer and its response to pumping in Arkansas, Kansas, Missouri, and Oklahoma.

Summary and Conclusions

Due to the low storativity of the Ozark aquifer, which includes the Roubidoux formation and Gunter sandstone, pumping of ground-water at volumes required to wash/sieve the sand will result in depletion of heads in the Ozark aquifer in close proximity to the mining operations proposed in the vicinity of the outcropping St. Peter Sandstone in IZARD County, Arkansas. Though the impact of one mine utilizing efficient sand processing technology may be minimal, over extended time periods, lowering of heads could extend for 5-10 miles, and drawdowns of as much as 7 to 15 feet per year are possible. The thickness of the Ozark aquifer in the study area is over 1,000 feet. Therefore, declines in the potentiometric surface would not reduce the saturated thickness of the aquifer to 50 percent for over 70 years. Because of the faulting and variability of the aquifer and depending of the degree on hydraulic interconnection between the shallow and deep strata, potential for lowering of heads (and depletion) in shallow wells is also possible, as well as potential impacts on surface streams and springs. Less efficient sand processing operations would use more water and impact the ground-water system to a greater degree. Long-term impacts from five or more mining operations could adversely impact a much larger area including some public supply wells in IZARD County. Only a pumping test of a properly installed well (with a nearby observation well) could determine the potential long-term effects of pumping at a particular mine location. In addition, further research (including ground-water flow modeling) is required to further estimate the long-term impact of mining water use on shallow and deep Ozark municipal and shallow domestic wells.

In the absence of a ground-water permitting program in Arkansas, detailed scientific evaluation of mining operations, with respect to impacts on the ground-water system, is not performed at this time. Hydrogeologic evaluation, including test wells, and ground-water flow modeling would allow more adequate evaluation, allow for sustainable use of the aquifer while providing greater information useful in resource protection for current and future water users.

Proposed study area

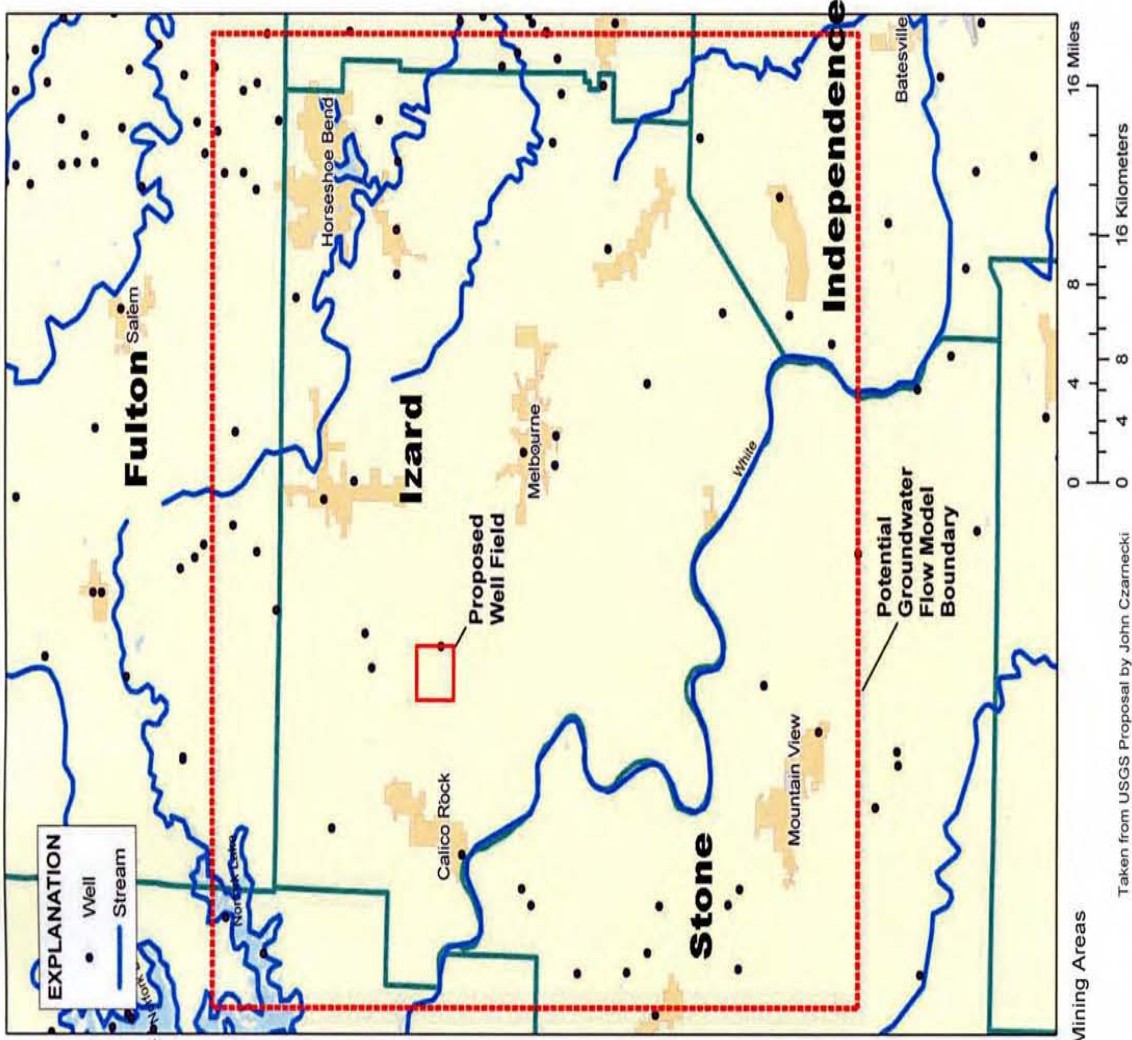
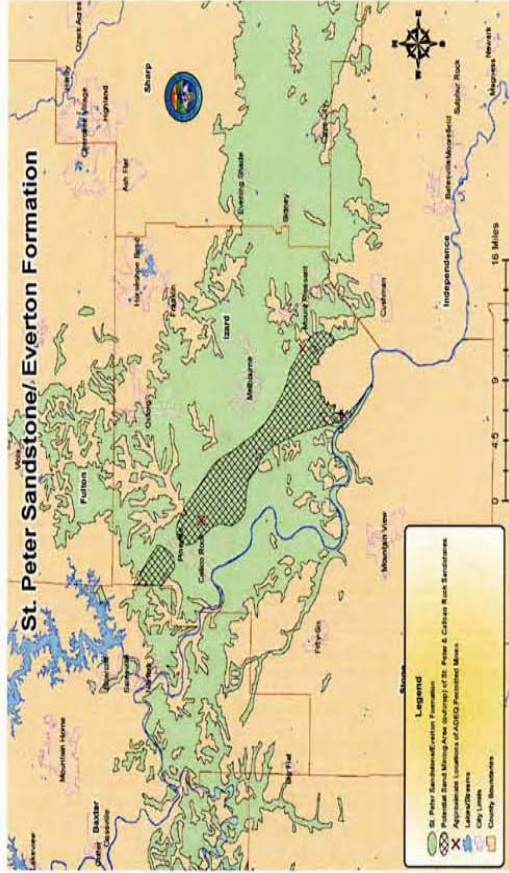
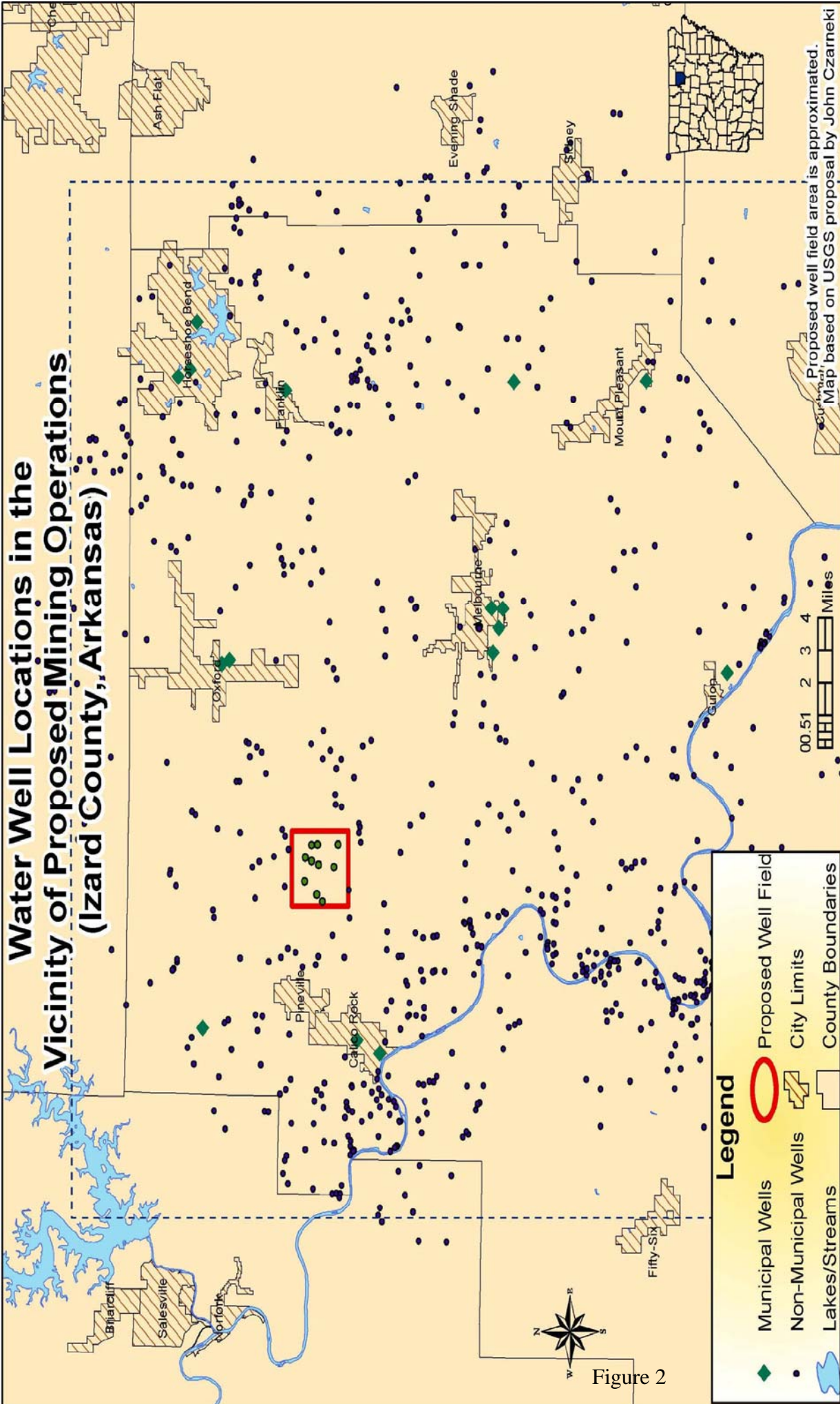


Figure 1. Permitted Mining Locations and Potential Mining Areas

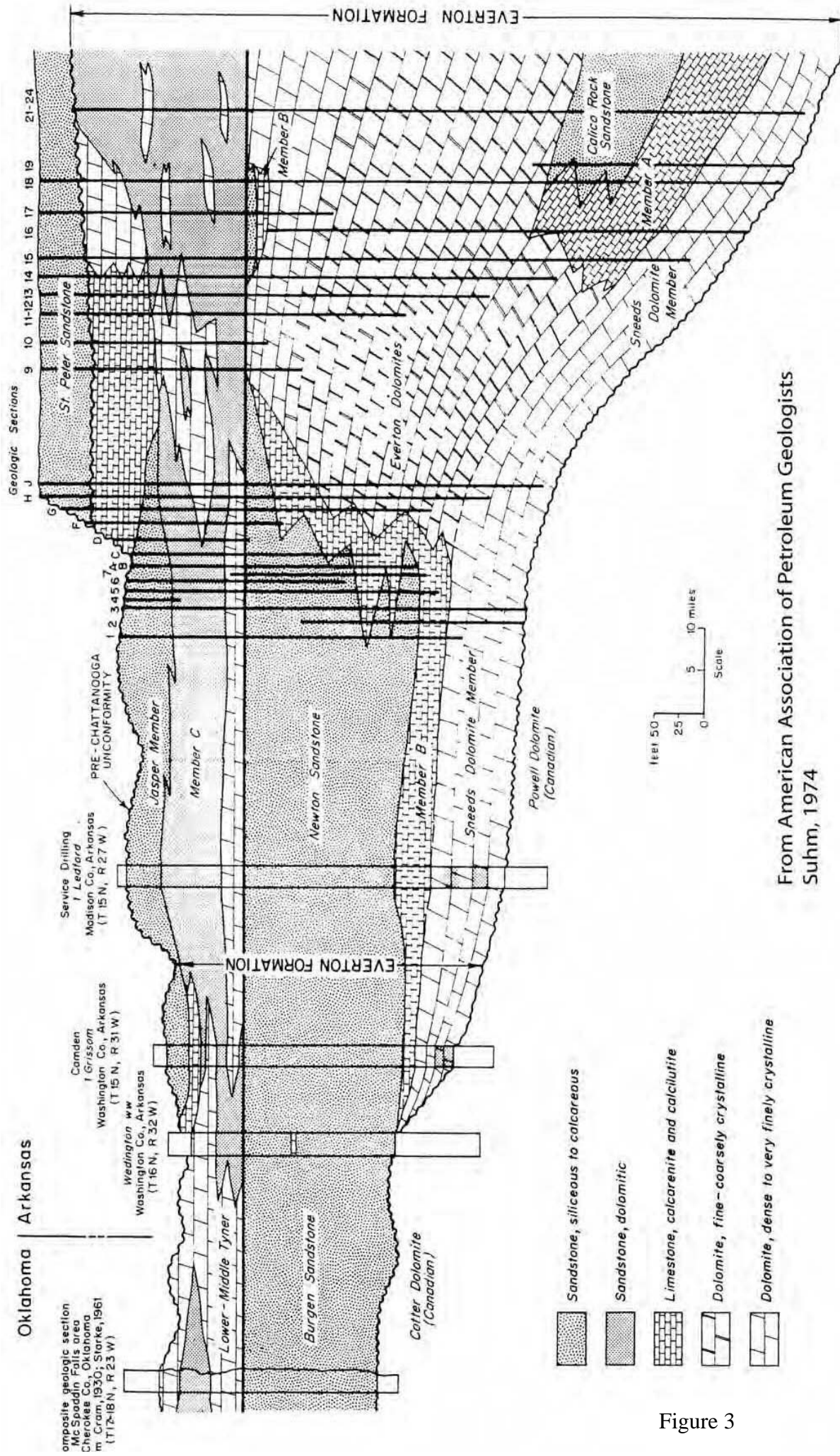
Taken from USGS Proposal by John Czarniecki






Water Well Locations in the Vicinity of Proposed Mining Operations (Izard County, Arkansas)



Proposed well field area is approximated.
Map based on USGS proposal by John Czarnecki

Figure 2



-  Sandstone, siliceous to calcareous
-  Sandstone, dolomitic
-  Limestone, calcarenite and calcilite
-  Dolomite, fine-coarsely crystalline
-  Dolomite, dense to very finely crystalline

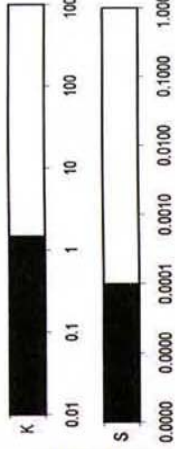
From American Association of Petroleum Geologists
 Suhm, 1974

Figure 3

Drawdown Prediction for Confined Aquifers, Theis(1935)

Input Data for prediction of drawdown

Hydraulic conductivity, K, ft/day	1.49
Aquifer Thickness, b, ft	1000
Storage Coefficient, S	0.0001
Pumping Rate, GPM	200
Distance from well, ft	26400



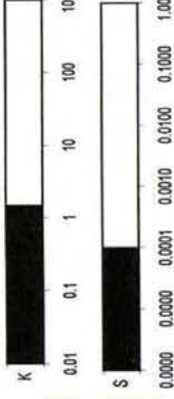
Equation used in prediction

$$s = \frac{Q(W(u))}{4\pi T} \quad u = \frac{r^2 S}{4Tt}$$

s is drawdown, W(u) is the well

Input Data for prediction of drawdown

Hydraulic conductivity, K, ft/day	1.49
Aquifer Thickness, b, ft	1000
Storage Coefficient, S	0.0001
Pumping Rate, GPM	450
Distance from well, ft	26400



Equation used in prediction

$$s = \frac{Q(W(u))}{4\pi T} \quad u = \frac{r^2 S}{4Tt}$$

s is drawdown, W(u) is the well

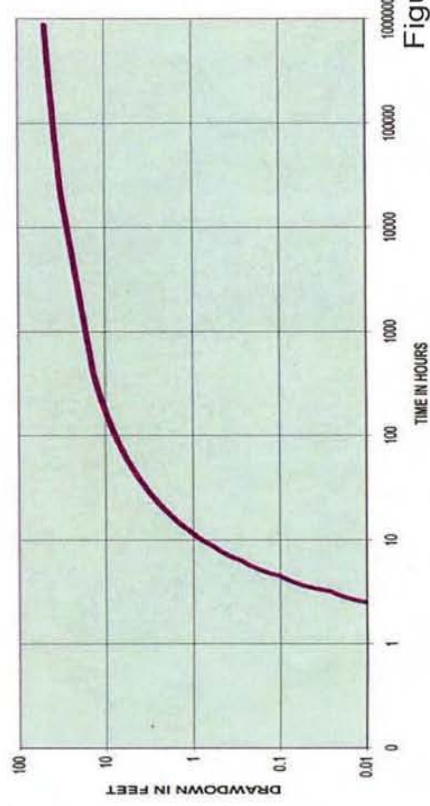
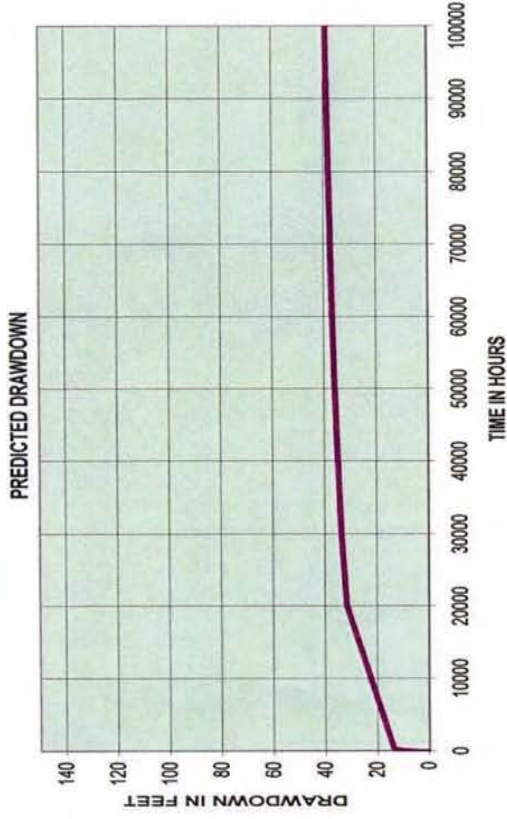
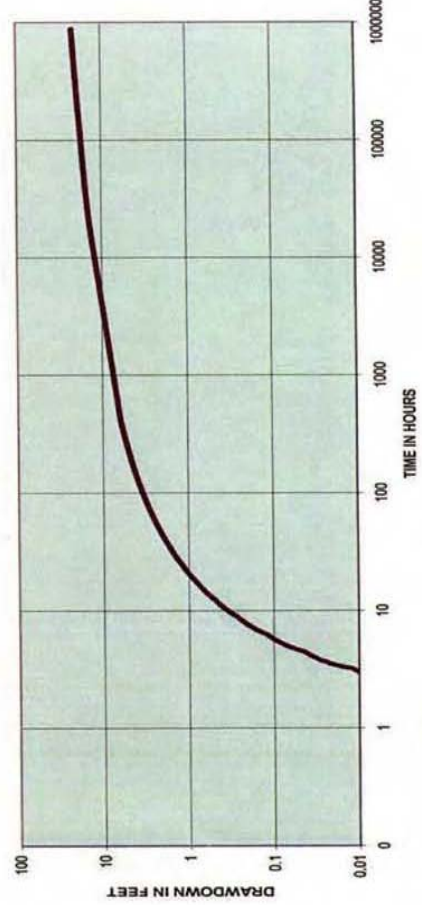
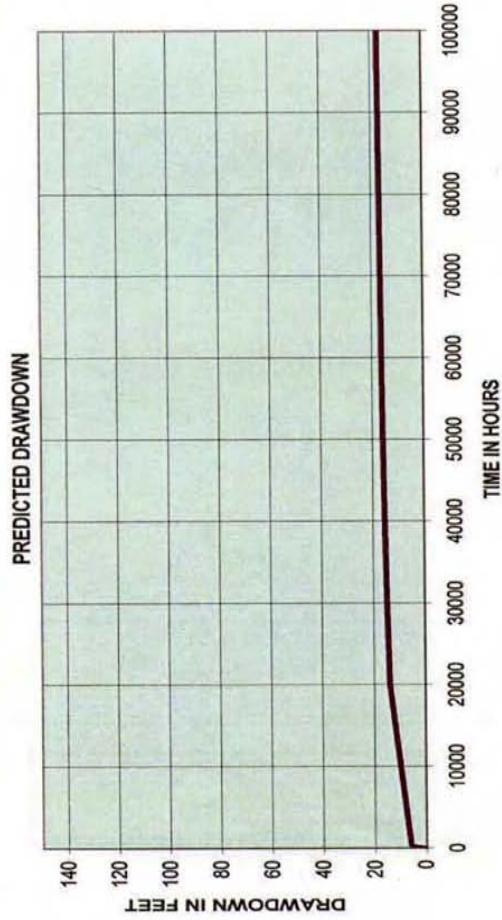


Figure 4

References

Applied Groundwater Modeling-Simulation of Flow and Advective Transport, 1992, Anderson, Mary P., and Woessner, William W., Academic Press

Documentation of Spreadsheets for the Analysis of Aquifer-Test and Slug-Test Data, 2002, Halford Keith J., Kuniansky, Eve L., USGS OFR-02-197

Geohydrology of the Ozark Plateaus Aquifer System in Parts of Missouri, Arkansas, Oklahoma, and Kansas, 1994, Imes, J.L., and Emmett, L.F.. USGS Professional Paper 1414-D.

Groundwater, 1979, Freeze, R.A., and Cherry, J.A., Prentice-Hall.

Groundwater-Flow Model of the Ozark Plateaus Aquifer System, Northwestern Arkansas, Southeastern Kansas, Southwestern Missouri, And Northeastern, Oklahoma, 2009, Czarnecki, John B., and others, USGS SIR2009-5148.

Potentiometric Surface of the Ozark Aquifer in Northern Arkansas, 2007, Pugh Aaron L., USGS SIR 2008-5137.

Stratigraphic Summary of Arkansas, 1998, McFarland, John D., AR Geological Commission, Information Circular 36.