CAFOs on Karst—Meaningful Data Collection to Adequately Define Environmental Risk, with a Specific Application from the Southern Ozarks of Northern Arkansas

By Van Brahana[1], Joe Nix[2], Carol Bitting[3], Chuck Bitting[4], Ray Quick[5], John Murdoch[6], Victor Roland[7], Amie West[7], Sarah Robertson[8], Grant Scarsdale[9], and Vanya North[5]

[1]Department of Geosciences, 20 Ozark Hall, University of Arkansas, Fayetteville, AR 72701; [2]Ouachita Baptist University Water Lab, Arkadelphia, AR 71988; [3]HC 73, Box 182 A, Marble Falls, AR 72648; [4]National Park Service, Harrison, AR, 72601; [5] Department of Geosciences, 216 Ozark Hall, University of Arkansas, Fayetteville, AR 72701; [6]11908 Elk Ridge Rd., Wesley, AR 72773; [7]Program of Environmental Dynamics, 216 Ozark Hall, University of Arkansas, Fayetteville, AR 72701; [8]243 South Gregg Avenue Fayetteville, AR 72701; [9]303 Oxford, Harrison, AR 72601.

Abstract
Karst typically contains a noticeably larger percentage of groundwater in its hydrologic budget than insoluble lithologies. Because subsurface flow is not directly observable, flow quantity, flow direction, flow velocity, water quality, groundwater basin delineation, and hydrologic variation with changing water levels are key components essential to characterizing the hydrogeology and assessing contaminant risk in karst aquifers. Concentrated animal feeding operations (CAFOs) are but one of the many sources of contamination that have been documented in karst, and owing to the large concentration of animal wastes generated by these factory farms and their potential for allowing pollution to enter nearby waters, these nonpoint sources require thorough and careful study prior to permitting by State and Federal environmental agencies. Environmental impact statements and preconstruction studies are essential to preserve the environmental and ecological integrity of karst basins. Remediation is typically much more expensive, and commonly requires more time to mitigate the damage.

The state environmental protection agency (Arkansas Department of Environmental Quality [ADEQ]) approved the construction of a 6,500-head swine CAFO in accordance with existing regulations on karst terrain in the area of Big Creek basin in Newton County, Arkansas. The CAFO lies less than 10 kilometers from the confluence of Big Creek with the Buffalo National River, a National Park Service (NPS) facility that is the main drain from this karst drainage basin. The Buffalo National River is one of the few free-flowing rivers remaining in the contiguous 48 states, hosting various recreational activities, including canoeing, fishing, and swimming, in addition to ecosystems for a large number of unique aquatic and endangered bat species. This CAFO was permitted under a General Permit which did not require appropriate investigations, including a hydrogeologic study, a karst study, and an evaluation of groundwater/surface water interaction. Newton County is characterized by karst hydrogeology, containing more known caves than any other county in Arkansas. Operation of the CAFO has been the subject of much debate and has pitted the landowners and small family farms against big-agriculture factory farming. This paper describes the resulting *pro bono* research that was undertaken to fill in essential data originally missing (hydrogeology, karst inventory, dye tracing, water quality), and the continuing effort to educate the local landowners about a resource that moves unseen beneath the ground. It has strong technical components, but more importantly, has a direct relevance to the human impacts of our science on environmental justice and policy.

INTRODUCTION

Karst regions typically are considered to be vulnerable with respect to various anthropogenic land-use activities, owing to the intimate association of surface and groundwater. Inasmuch as the soluble rocks of the karst can be dissolved to create large, rapid-flow zones that compete successfully with surface streams, groundwater and subsurface flow represent a much larger component of the hydrologic budget in karst regions than in areas where non-soluble rocks predominate. Karst areas typically are distinguished by being unique, but some general approaches can be applied to characterize the hydrology of the area. These approaches include an evaluation of the degree of karstification, the hydrologic attributes of the groundwater flow system, the baseline water quality, the time-of-travel through the karst flow system, and the general flux moving through the system. The nature of potential contaminants and their total mass and range of concentrations are critical to understanding the potential environmental risk. Using these approaches, it is possible to represent a minimum level of hydrogeologic characterization to assess environmental risk in a karst area. Well-established, fast-flow systems with structural deformation likely will demand more complete study, but lacking the aforementioned minima, the cost of remediating contamination is typically increased many fold.

CAFOs are but one of many industrial activities that pose a threat to the environmental integrity of a karst basin. The typically large number of animals (from hundreds to more than a hundred thousand animals—most commonly cattle, pigs, chickens and turkeys) generate wastes in solid, liquid, and gaseous phases. Our focus in this paper is limited to nitrate and

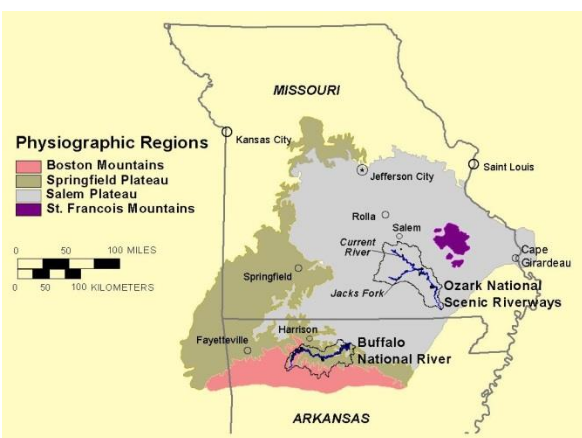


Figure 1. General area of major physiographic regions of the Ozark Plateaus, including the Buffalo National River and the Ozark Scenic Riverways, two unique and extraordinary-water resouces that are part of the National Park Service. The karst area discussed in this study is restricted to the Springfield Plateau in the area of the Buffalo National River. (Figure acknowledgement is Adamski et al., 1995).

total phosphorus, major dissolved constituents, organics, sediment and pathogens.

The objectives of this paper are threefold. The first is to describe minimal requirements for siting any facility on karst. From a hydrogeologic standpoint, much of this objective is a reiteration of commonly well-known sampling requirements in karst (Quinlan,1989; Alexander, 1989). The second objectives to provide an abbreviated case study from the southern Ozarks in northern Arkansas, in the drainage basin of the Buffalo National River (figure 1), which shows implementation of meaningful environmental impact studies for potentially risky industrial activities on karstlands is fraught with politics and emotion. The third objective is to propose a scientifically-sound, thorough, fair approach for the ultimate achievement of environmental justice for the greatest number of stakeholders.

MINIMAL STUDY REQUIREMENTS FOR INDUSTRIAL ACTIVITIES PROPOSED ON KARSTLANDS

Based on the seminal work of Quinlan (1989), we have modified his original assessment of required study components to include what we believe are minimum questions that should be answered prior to siting CAFOs on karst.

1. Compile, study and interpret topographic, soils, and geologic maps, and all related previous hydrogeologic studies of the area. Fully document this in a list of selected references;

2. Conduct a complete karst inventory, including input, flowthrough, and discharge features accurately plotted on topographic and geologic maps of appropriate scale;

3. Determine groundwater-flow directions, flow type, velocities, water budgets; estimate groundwater basin boundaries using the principle of normalized base flow (Brahana, 1997);

4. Characterize the baseline water quality of the shallow karst aquifer and overlying

and underlying aquifers to assess interaquifer transfer of flow and contaminants, including dissolved major constituents, original contaminants and their breakdown products from the industrial operation, and in the case of CAFOs, key nutrients, pathogens, sediments, and other unique water-quality indicator parameters;

5. Conduct dye-tracing studies concurrently with items 3 and 4, using study results to answer questions raised in item 2.

6. Integrate items 1 through 5 into a report that synthesizes groundwater hydrologic characteristics in the karst aquifer, proposes a defensible conceptual model, and accurately assesses the background water quality prior to the permitting of the industrial operation. Insofar as the complexity of the karst is not well understood by disciplines outside geology, this study should be conducted only by a registered professional geologist.

CASE STUDY OF THE INDUSTRIAL HOG CAFO ON THE KARST OF BIG CREEK BASIN, NEWTON COUNTY, ARKANSAS

The approval by the ADEQ of a 6,500-head swine facility on Big Creek less than 10 kilometers upstream from the Buffalo National River (figure 2) was approved on August 3, 2012. This approval came as a surprise to almost all stakeholders in the region, not the least of whom was the National Park Service (NPS), the agency responsible for maintaining the environmental quality of Buffalo, which is classified as an Extraordinary Water Resource. The resulting furor brought deeply held emotions to the surface. Unfortunately, space constraints for this paper limit discussion to only key elements of the controversy, but the interested reader is directed to the following websites, each of which offers disparate views of the facts. These sources represent web pages of some of the major participants, and additional information can be acquired from pointers on each webpage, or web searches using examples such as the Buffalo National River, Big Creek Hog Farm, or Newton County, Arkansas Hog Farm, to name a few. Some specific connections with the supporters shown in parentheses are: http://www.arfb.com/ (Arkansas Farm Bureau); http://www.adeq.state.ar.us/ (ADEQ); http://www.cfra.org/news/140127/corporate-farming-notes-industrial-hog-operation-divides-community (Center for Rural Affairs); http://www.npca.org/news/media-center/press-releases/2013/groups-go-to-court-to-protect (National Parks Conservation Association); http://www.ozarksociety.net/2013/03/conservation-issue-hog-farm-near-big-creek/ (Ozark Society); http://buffaloriveralliance.org/Default.aspx?pageId=1547312; http://www.npca.org/news/media-center/press-releases/2013/groups-go-to-court-to-protect.html (Buffalo River Alliance).

It should be noted that these sources reflect the bias of each support group, and that misrepresentations or inaccuracies may be present on non-peer reviewed web pages. These are provided to assist the reader and to show how distinctly different interpretations are possible from the same data set. The difference lies in the filters, the fears, the politics, and the emotional reactions of each stakeholder,

Selected Components of the Permitting Process

As previously mentioned, the permit for the CAFO was granted by ADEQ according to existing regulations, which did not include a through characterization of the site. The geology, hydrology, and unique karst terrain were not adequately considered. Additionally, no predevelopment characterization was made to evaluate the true effects of the CAFO on the watershed.

Site Geology, Hydrogeology, Karst, and Hydrology

Big Creek is one of the two largest tributaries to the Buffalo National River, encompassing about 8% of the total drainage of the entire Buffalo River drainage area. Physiographically, tributaries head in uplands on terrigenous sediments of Pennsyvanian age of the Boston Mountains Plateau (figure 1) and flow generally toward the north with relatively steep gradients. The stratigraphic units of concern are within the Boone Formation (Braden and Ausbrooks, 2003), an impure limestone that contains as much as 70% chert, much of which was thought to have formed through geochemical alteration of volcanic ash from atmospheric deposition from the island arcs south of the Ouachita orogeny, approximately 150 kilometers (km) south of study area. The upper and lower units of the Boone Formation have much less chert (typically less than 5%) than the middle part of the Boone. Structurally, the Boone is near-horizontal; owing to the high concentration of brittle chert, it has been subjected to extensional faulting and jointing. The upper and lower parts of the Boone Formation host significant caves (Figure 4) in the region (Mott et al., 2000). Intervening layers of limestone are karstified by smaller dissolution features (figure 5), with the chert acting as confining units above and below.

Figure 2. Areal view of 6,500-head industrial hog CAFO, including waste lagoons. The facility is sited on the Boone Formation, a karst aquifer less than 10 kilometers upstream from the confluence of Big Creek with the Buffalo National River.

The geologic unit underlying the CAFO is the Boone Formation, and all formations in Big Creek basin are shown in figure 3. Approximately 50 meters of the middle Boone limestone/chert lithology is exposed in a cliff face about 2 km downstream from the CAFO (figure 6). Big Creek is characterized by both gaining and losing reaches where it crosses the Boone Formation, and during low flow there are entire reaches that are completely dry downstream of flowing reaches.

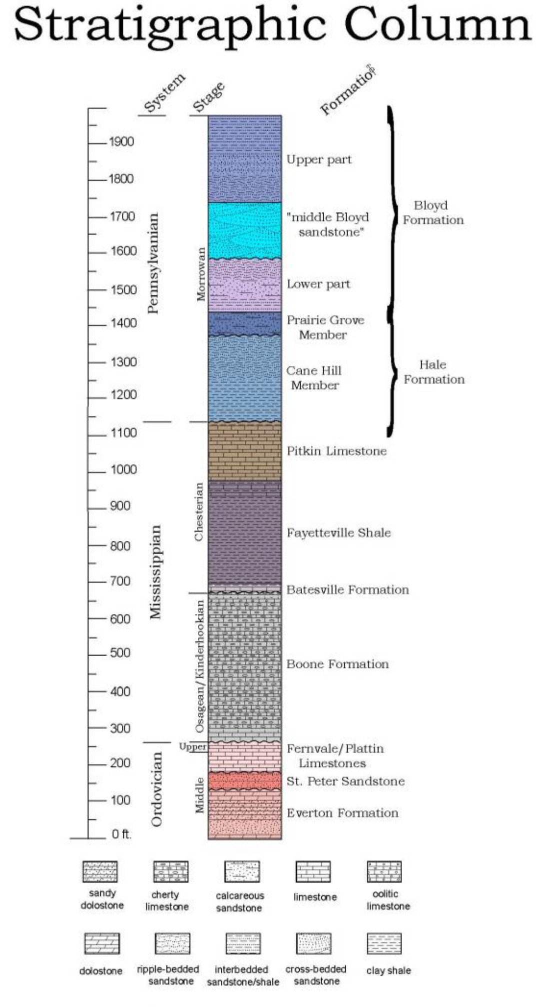


Figure 3. Stratigraphic column of most of Big Creek basin in the vicinity of the CAFO, from the Mt. Judea 7.5-minute quadrangle (Braden and Ausbrooks, 2003).

Big Creek and its major tributary, Left Fork, flow in alleviated valleys composed of nonindurated sediments, primarily chert and terrigenous rock fragments from younger, topographically higher formations (figure 3). The alluvium in these valleys varies in thickness from a feather-edge to about 8 meters (m). Outcrops of the Boone Formation are common in the streambed. Springs are common along the entire reach of Big Creek, ranging from relatively small discharges in the tens of liters per minute range to large discharges in the tens of liters per second. These larger discharges resurge from relatively pure limestone lithologies (Mott et al., 2000).

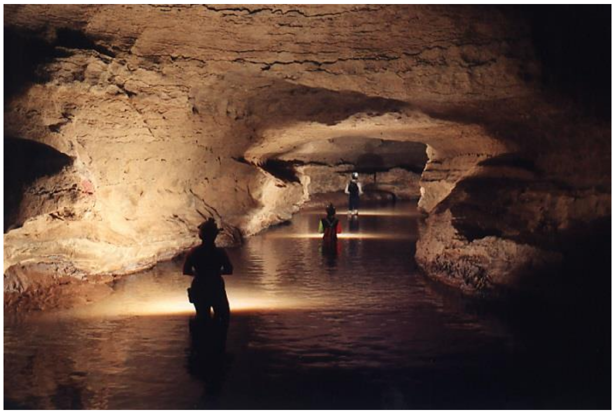


Figure 4. Newton County, where Big Creek occurs, has the largest number of recorded caves of all counties in the state of Arkansas. Most of these, such as this cave just north of Big Creek basin on the banks of the Buffalo National River, are concentrated in the upper and lower parts of the Boone Formation and St. Joe Formation, where the lithology includes more pure limestone. (Photo courtesy of Carol Bitting)

Figure 5. Karst dissolution features in limestone interbedded with chert from the middle Boone Formation. The chert acts as an insoluble confining unit for the karst. The scale of these voids typically ranges from 2 to more than 5 cm.

The existence of well-developed karst near an NPS facility designated as an Extraordinary Water Resource increases vulnerability to anthropogenic sources of contaminants that can move through the hydrologic cycle with little attenuation of contaminants. The concentrated wastes of the CAFO, and the calculated allowable leakage through the clay of the lagoon liner (figure 7) and the waste-spreading fields (figure 8) are perceived as being a risk, not only to the ecology and environmental integrity of Big Creek, but to the Buffalo National River, with the extensive direct contact of its waters to the many tourists who canoe and swim there. The lack of any geologic, hydrogeologic, or karst studies do not allay fears related to assessing the overall risk this CAFO poses.

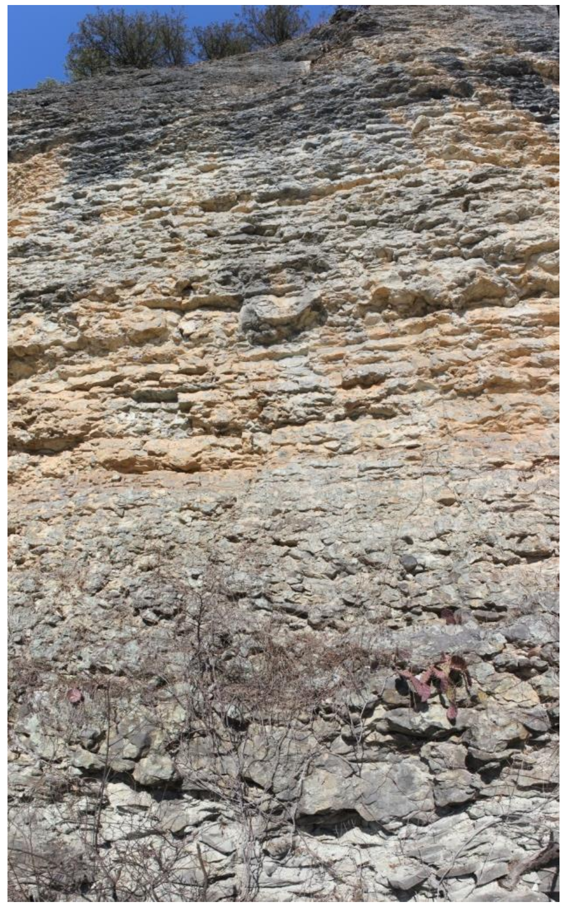


Figure 6. Erosional bluff face showing approximately 50 m of interbedded limestone and chert of the middle part of the Boone Formation near the confluence of Big Creek with its major tributary, Left Fork. The differential weathering suggests that this landscape reflects the solubility of the limestone facies. (Photo courtesy of John Murdoch).

In response to the lack of appropriate hydrogeologic and karst studies of the basin associated with the CAFO, a diverse group of volunteers (the authors) proposed a *pro bono* investigation of several unstudied elements that would minimally describe 1) the karst inventory in Big Creek basin, and its relaton to the geology;

2) the baseline groundwater quality, including an assessment of expected capability of the soil/regolith/bedrock flow system to accommodate additional wastes; and 3) the general flow directions, rates of flow, quantities of flow, and water budgets based on dye tracing. The interpretation of these field data are expected to be shared with all stakeholders in a report.

Geologic, hydrologic, and karst inventories which were outlined earlier under minimal study requirements were conducted. These were accomplished by intensive map and previous published-report study, intensive field work to identify gaining and losing reaches, caves, springs, sinkholes and visible karst landforms, aerial survellance by low-level airplane, and canvassing of the local farmers and landowners.

Strict baseline water quality (pre-CAFO) was not possible, but the slow startup of the CAFO in the summer of 2013 allowed sampling approximately 40 wells, springs, and streams for field parameters, major dissolved constituents, nutrients, and pathogens prior to the major CAFO activity. Quality assurance and quality control, holding times, and sampling procedures employed in this study followed U.S. Geological Survey protocols (U.S. Geological Survey, 2010). Nutrients and pathogens were analyzed by the Arkansas Water Quality Lab on the campus of the University of Arkansas owing to the short holding-time requirements, and dissolved major and selected trace constituents were analyzed by the Water Quality Lab of Ouachita Baptist University in Arkandelphia.

The dye tracing study has yet to be undertaken, because permission to inject non-toxic fluorescent dyes was just granted (mid-March 2014.

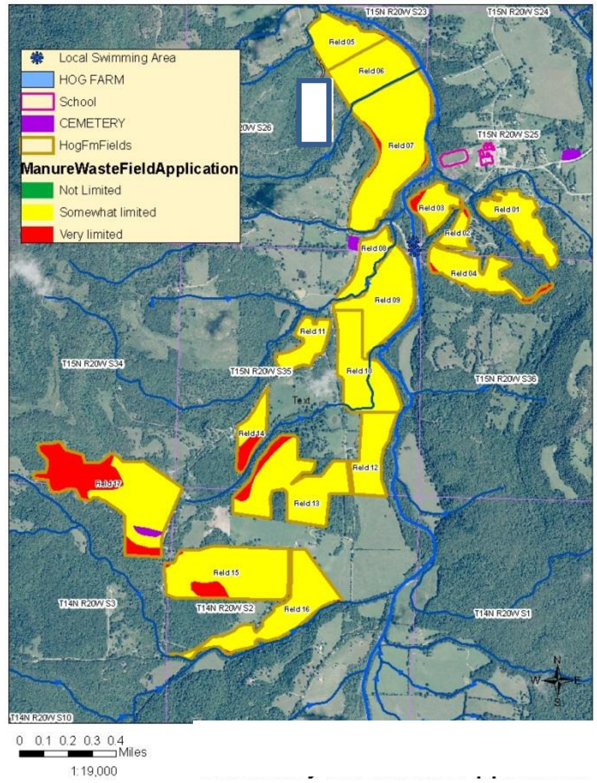


Figure 8. Fields permitted for spreading hog waste along Big Creek by the CAFO (white color) granted by ADEQ. Most of the permitted fields are on alluvium and regolith that directly overlie the Boone Formation at thicknesses ranging from a feather edge to about 8 m. The proximity to Mt. Judea school (magenta color) to the spreading fields is shown in the upper right-hand corner of the figure.

Figure 7. The clay liner shown here is the sole confining entity separating the hog waste in the lagoons from the underlying Boone Formation. This photo, taken after construction of the liner, indicates that in has numerous chert fragments up to fist size within the clay, that it has dessication cracks, and that erosion rills have eroded some of the thickness. These features reduce its ability to confineIt was required to be 30 cm thick, but the owners of the CAFO increased that to 45 cm. (Photo courtesy of Tony Morris, ADEQ).

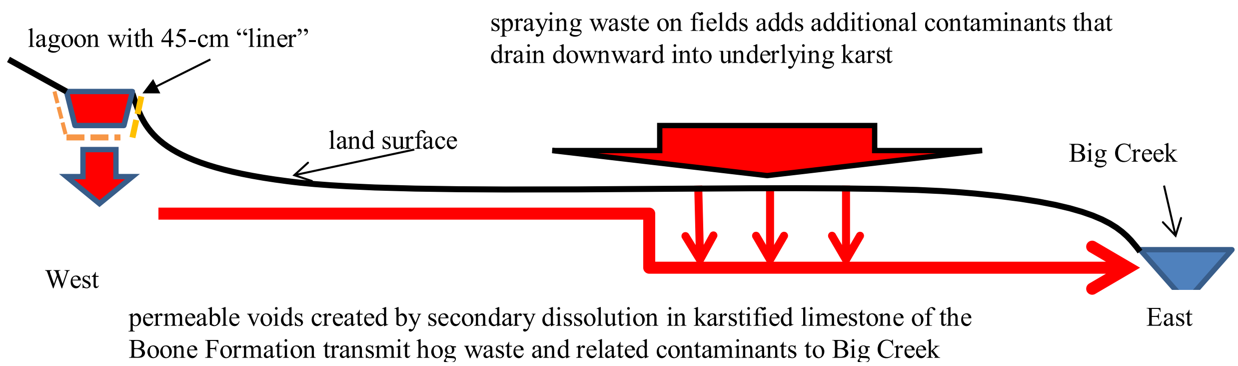


Figure 9. Conceptual model showing surface and groundwater interaction in a cross-sectional view in the area of Big Creek near the hog CAFO. Red arrows identify potential karst flow pathways that were not characterized or previously studied.

Preliminary Results

Description of the geology and karst of Big Creek basin in the area of the CAFO support the observation that the Boone Formation is a mantled karst with numerous springs and a high degree of surface and groundwater interaction. Sinkholes are not typically common in the middle part of the Boone, but springs and secondary zones of dissolution of limestone between chert layers are. The large number of caves in the basin (Figure 10) provides additional support for large discharge, rapid-flow systems with turbulent flow that have the ability to transport not only conservative solutes, but nutrients, sediment and pathogens. At this time, the shallow karst aquifer is dominated by

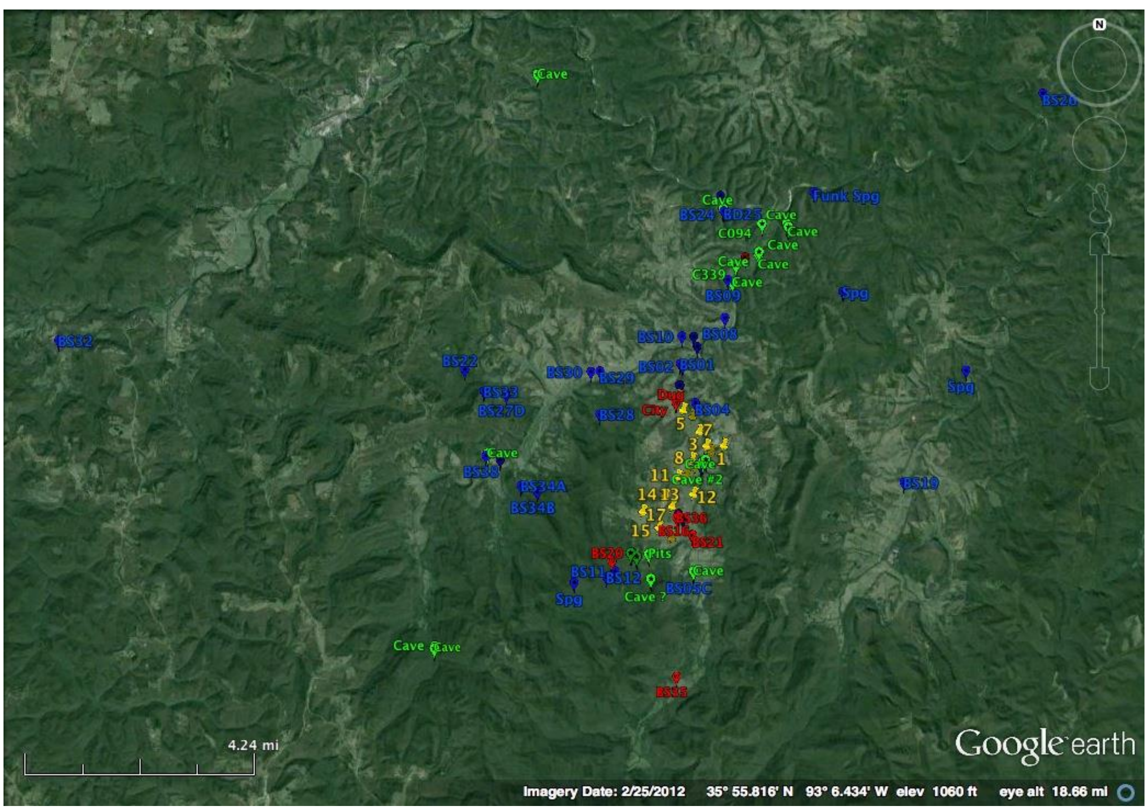


Figure 10. Locations of selected reference points, sampling sites, spreading fields permitted for the CAFO, caves, and springs in Big Creek and contiguous basins. Spreading fields are yellow, springs are blue, caves are green, surface-water sampling sites are red, major roads are in white, forested regions are dark green, and cemeteries are brown. Locations are from GPS measurements plotted on Google earth.

dissolution, with a dominant calcium bicarbonate water type, dissolved solids generally less than 400 mg/L, groundwater temperatures consistent with shallow karst flow (summer temperatures in the 16-19^{o}C range, winter temperatures in the 12 to 14^{o}C range) , nutrients elevated above background (e.g. nitrates in the range of 2 to > 10 mg/L) reflecting effects of anthropogenic land uses, and pathogens, some as high as tens to hundreds of thousands of colony forming units per 100 mL, indicating little or no attenuation. Groundwater currently shows no contamination from the CAFO.

PROPOSAL FOR OPTIMIZING THE INCORPORATION OF SCIENCE, POLICY, AND TRANSPARENCY INTO FUTURE STUDIES OF PERMITTING INDUSTRIAL ACTIVITIES ON KARST

1. Include all stakeholders at the table, exclude no one;
2. Promote an environment of openness, wherein no favored or powerful group dominates other stakeholders;
3. Verify and document all facts and aspects of potential problems, especially if it appears that this is a karst system;
4. If disinformation or deceit are evident, confront these;
5. Be respectful;
6. Use an holistic approach to the proposed activity, including scientific and human considerations that are relevant;
7. Reframe the discussion to avoid words or terms that are incendiary; allow reasonable options;
8. Above all else, base decisions and regulations on science and on treating others the way we would like to be treated.

SELECTED REFERENCES

Adamski, J.C., Petersen, J.C., Freiwald, D.A., and Davis, J.V., 1995, Environmental and hydrologic setting of the Ozark Plateaus study unit, Arkansas, Kansas, Missouri, and Oklahoma: U.S. Geological Survey Water-Resources Investigation Report 94–4022, 69 p.

Alexander, E.C., Jr., 1989, Karst hydrogeology and the nature of reality: Philosophical musings of a frustrated curmudgeon: Keynote address given at 2nd Environmental Problems in Karst Terranes Conference, Nashville, Tennessee, National Water Well Association, Dublin, Ohio.

Aley, T., 1988, Complex radial flow of ground water in flat-lying residuum-mantled limestone in the Arkansas Ozarks; In: Environmental Problems in Karst Terranes and Their Solutions, National Water Well Association, Dublin, Ohio Proceedings, v. 2, p. 159-170.

Al-Qinna, Mohammed, Scott, H.D., Brye, K.R., Brahana, J.V., Sauer, T.J., and Sharpley, A.N., Coarse fragment effects on soil physical and hydraulic propertiesin a mantled-karst landscape in the Ozark Highlands: Soil Science, 20 p., [in review with journal]

Braden, A.K., and Ausbrooks, S.M., 2003, Geologic map of the Mt. Judea Quadrangle, Newton County, Arkansas: Arkansas Geological Commission, scale 1:24,000.

Brahana, V., 2011. Ten relevant karst hydrogeologic insights Gained from 15 Years of *In Situ* Field Studies at the Savoy Experimental Watershed; *in* Kuniansky, E., ed., U.S. Geological Survey Karst Interest Group Proceedings, Fayetteville, AR, April 26-29, 2011. US Geological Survey Scientific Investigations Report 2011-5031, p. 132-141.

Brahana, Van, 2009, The Savoy Experimental Watershed—A long-term research site for karst hydrogeology: *in* Palmer, A.N. and Palmer, Margaret V., Caves and Karst of the

USA, National Speleological Society Guidebook for the International Congress of Speleology, section 5-Ozark Plateaus, p. 179.

Brahana, John Van, Tennyson, Rodney, Terry, Jim, Hays, P.D., Pollock, Erik, 2009, Reactivated basement faulting as a hydrogeologic control of hypogene speleogenesis in the southern Ozarks of Arkansas, USA: *in* Stafford, Kevin, ed., Advances in Hypogene Karst Studies, National Cave and Karst Research Institute Symposium 1, p. 99-110.

Brahana, J.V., Hays, P.D., Kresse, T.M., Sauer, T.J., and Stanton, G.P., 1999, The Savoy Experimental Watershed—Early lessons for hydrogeologic modeling from a well-characterized karst research site: in Palmer, A.N., Palmer, M.V., and Sasowsky, I.D., editors, Karst Modeling: Special Publication 5, Karst Waters Institute, Charles Town, WV, p. 247-254.

Brahana, J.V., 1997, Rationale and methodology for approximating spring-basin boundaries in the mantled karst terrane of the Springfield Plateau, northwestern Arkansas: in Beck, B.F. and Stephenson, J. Brad, eds., Sixth Multidisciplinary Conference on Engineering Geology and Hydrogeology of Karst Terranes, A.A. Balkema, Rotterdam, p. 77-82.

Brion, G., Brye, K., Haggard, B., West, C., and Brahana, V., 2010, Land-use effects on water quality of a first-order stream in the Ozark-Highlands, mid-southern United States: River Research and Applications, DOI: 10.1002/rra.1394, 19 p.

Daigh, Aaron L., Brye, Kristofor R., Sharpley, Andrew N., Miller, David M., West, Charles P., and Brahana, J. Van, 2009, Five-year change in soil profile chemical properties as affected by broiler litter application rate: Soil Science, v. 174, no. 10, DOI: 10.1097/SS.0b013e3181bdbdb3, p. 531-542.

Davis, R.K., Brahana, J.V., and Johnston, 2000, Ground water in northwest Arkansas: Minimizing nutrient contamination from non-point sources in karst terrane: Arkansas Water Resources Center, University of Arkansas, Fayetteville, 59 p.

Funkhouser, J.E., Little, P.R., Brahana, J.V., Kresse, T.M., Anderson, M., Formica, S., and Huetter, T., 1999, Methodology to study the effects of animal production in mantled karst aquifers of the southern Ozarks: in Palmer, A.N., Palmer, M.V., and Sasowsky, I.D., editors, Karst Modeling: Special Publication 5, Karst Waters Institute, Charles Town, WV, p. 255-258.

Gouzie, D., Dodd, R., and White, D., 2010. Dye Tracing Studies in southwestern Missouri, USA: Indication of Stratigraphic Flow Control in the Burlington Limestone; Hydrogeology Journal, v18, n4, p. 1043-1052.

Hobza, Christopher M., Moffit, David C., Goodwin, Danny P., Kresse, Timothy, Fazio, John, Brahana, J.V., and Hays, Phillip D., 2005, Ground-water quality near a swine waste lagoon in a mantled karst terrane in northwestern Arkansas: *in* Kuniansky, E.L., 2005, U.S. Geological Survey Karst Interest Group proceedings, Rapid City, South Dakota, September 12-15, 2005: U.S. Geological Survey Scientific Investigations Report 2005-5160, p. 155-162.

Imes, J.L, and Emmett, L.F., 1994, Geohydrology of the Oark Plateaus aquifer system in parts of Missouri, Arkansas, Oklahoma, and Kansas: U.S. Geological Survey Professional Paper 1414-D, 127 p.

Jarvie, Helen P., Sharpley, Andrew N., Brahana, Van, Simmons, Tarra , Price, April, Neal , Colin , Lawlor, Alan J. Sleep, Darren, Thacker, Sarah, Haggard , Brian E., 2014, Phosphorus retention and remobilization along hydrological pathways in karst terrain: Environmental Science & Technology, 28 p. [in review with journal]

Leh, M.D., Chaubey, I., Murdoch, J.F., Brahana, J.V., and Haggard, B.E., 2008, Delineating Runoff Processes and Critical Runoff Source Areas in a Pasture Hillslope of the Ozark Highlands: Hydrological Processes, Wiley Interscience, DOI: 10.1002/hyp7021, 15 p.

Luhmann, A., Covington, M., Alexander, S., Chai, S., Schwartz, B., Groten, J., and Alexander, E., Jr., 2012. Comparing conservative and nonconservative tracers in karst and using them to estimate flow path geometry; Journal of Hydrology, v448-449, p. 201-211.

Marshall, David, Brahana, J.V., and Davis, R.K., 1998, Resuspension of viable sediment-bound enteric pathogens in shallow karst aquifers: *in* Brahana, John Van, Eckstein, Yoram, Ongley, Lois K., Schneider, Robert, and Moore, John E., 1998, editors, Gambling with groundwater—Physical, chemical, and biological aspects of aquifer-stream relations: Proceedings Volume of the International Association of Hydrogeologists Congress XXVIII and the Annual Meeting of the American Institute of Hydrology, Las Vegas, p. 179-186.

Mott, D.N., Hudson, M.R., and Aley, T., 2000, Hydrologic investigations reveal interbasin recharge contributes significantly to detrimental nutrient loads at Buffalo National River, Arkansas: Proceedings of Arkansas Water Resources Center Annual Conference MSC–284, Fayetteville, Ark., p. 13–20

Quinlan, J.F., 1989, Ground-water monitoring in karst terranes: Recommended protocols and implicit assumptions: U.S. Environmental Protection Agency, Research and Development, 600/X-89/050, 88 p.

Peterson, E.W., Davis, R.K., Brahana, J.V., and Orndorff, H.O., 2002, Movement of nitrate through regolith covered karst terrane, northwest Arkansas: Journal of Hydrology, v. 256, p. 35-47.

Peterson, E.W., Davis, R.K., and Brahana, J.V., 2000, The use of regression analysis to predict nitrate-nitrogen in springs in northwest Arkansas: *in* Sasowsky, I.D. and Wicks, C.M., editors, Groundwater flow and contaminant transport in carbonate aquifers: A.A. Balkema, Rotterdam, p. 43-63.

Sauer, T.J., Alexander, R.B., Brahana, J.V., and Smith, R.A., 2008, The importance and role of watersheds in the transport of nitrogen: in Follett, R.F., and Hatfield, J.L., eds., Nitrogen in the Environment: Sources, Problems, and Management, Second Edition: ch. 8, p. 203-240.

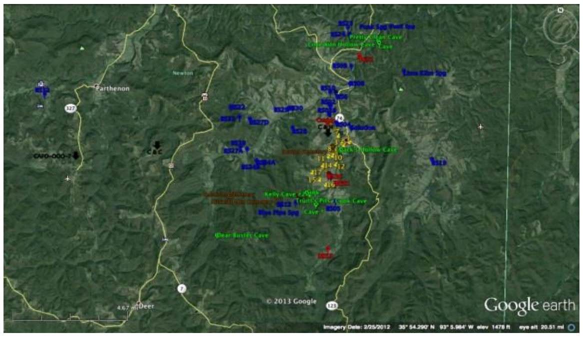
Sheam, Ian, 2012, Whose side is the American Farm Bureau on? Food and Environment Reporting Network, 5 p.

Steele, K.F., Davis, R.K., Brahana, J.V., Godfrey, Lyle, and Tatom, Ginger, 2002, Research and regulatory water-quality perspectives, Ozark Mountain Region, Arkansas: American Water Resources Association, Ground Water/Surface Water Interactions, p. 199-204

Tennyson, Rodney, Terry, Jim, Brahana, Van, Hays, Phil, and Pollock, Erik, 2008, Tectonic control of hypogene speleogenesis in the southern Ozarks—Implications for NAQQA and beyond: *in* Kuniansky, E.L., ed., U.S. Geological survey Karst Interest Group Proceedings, Bowling Green, Kentucky, May 27-29, 2008: U.S. Geolological Survey Scientific Investigations Report 2008-5023, p. 37-46.

U.S. Geological Survey, 2010. USGS water-quality sampling: Standard protocols and procedures: U.S. Geological Survey Fact Sheet, National Monitoring Conference, NWQMC; http://pubs.water.usgs.gov/twri9A.

Varnel, C.J., and Brahana, J.V., 2003, Neuse River-Impact of Animal Production on Water Quality: in Stewart, B.A., and Howell, Terry, eds., The Encyclopedia of Water Science: Marcel Dekker, Inc., New York, p.622-624.


Parthenon
Newton
Deer
Pretty Clean Cave
Kelly Cave
Pipe Pipe Spg
Deer Buster Cave
C&C
© 2013 Google
Google earth
Imagery Date: 2/25/2012 35° 54.290' N 93° 5.984' W elev 1478 ft eye alt 20.51 mi