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ORIGINAL ARTICLE

Proposals for integrating karst aquifer evaluation methodologies into national environmental legislations

Case study of a concentrated animal feeding operation in Big Creek Basin and Buffalo National River Watershed, Arkansas, USA

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Abstract Characterization of karst aquifers in order to reduce the impacts of human activities on these vital groundwater resources poses a significant challenge for scientists, land managers and policy makers. Methods and criteria for improvement of karst management have been suggested by the scientific community in order to assure the preservation of karst groundwater resources. However, these methods are rarely integrated into national groundwater protection policies. A case-based study of a swine confined animal feeding operation sited on mantled karst terrain in the southern Ozark Highlands in the State of Arkansas, United States of America helped illustrate why karst-specific evaluation methods should be implemented in national legislation. Through the review of the area's geomorphology and hydrogeology, dye tracer test results, and existing state and federal legislation and permitting processes for confined animal feeding operations, proposed improvements to existing legislation for confined animal feeding operations were developed. The study provides an example of how integrating science into policy-making can enhance protection of valuable groundwater resources.

Keywords Karst aquifers · Vulnerability · Groundwater protection · Legislation · CAFO

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Introduction

Karst aquifers are unique, complex and sensitive groundwater bodies that are extremely susceptible to contamination and human impacts (see, for example, Ford and Williams 2007; Kačaroğlu 1999; Goldscheider and Drew 2007; Chapman et al. 2015). Considering that karst aquifers provide 25 % of the world's drinking water (van Beynen 2011), their characterization, and an understanding of the contamination processes in karst groundwaters is of extreme importance.

Numerous science-supported methodologies have been developed in order to assure coherent and thorough characterization of karst aquifers, drawing on event-based sampling strategies, artificial and natural tracing methods, water-quality mapping, water-budget assessment, and karst field mapping (Goldescheider and Drew 2007; Ravbar and Goldscheider 2007). Additionally, criteria have been discussed and suggested, for the proper management of karst, and comprehensive protection of karst groundwaters (see, for example, van Beynen 2011; Ravbar and Šebela 2015).

Nevertheless, little has been done to actually implement these karst-specific methods in national legislation. To do so requires close cooperation between the scientific and policy-making spheres. However, opinions regarding the combining of science and policy vary among experts of different fields. For example, some consider scientific studies expensive, and potentially contributing to increased uncertainties due to the accumulation of information (Rayner 2006). On the other hand, some point out the failure of science to solve day-to-day issues faced by environmental decision makers due to lack of sufficient data (Robertson and Hull 2003). Although these might be valid concerns in some areas of environmental policy-making, the implementation of karst-specific scientific methods into groundwater protection policies is vital for assuring preservation of karst groundwater resources.

In an effort to illustrate the importance of integrating scientific evaluation techniques into policy-making process, the authors performed a case-based study of a confined animal feeding operation (CAFO) located on a karst terrain.

The studied CAFO is located in the Ozark Highlands of the United States (USA) State of Arkansas. It is situated in close proximity to the Buffalo National River (BNR) Park, within the Big Creek drainage Basin. Permitting and construction of the studied CAFO was conducted with few karst-specific evaluation methodologies.

Through a review of the geomorphology and hydrogeology of the studied area, tracer test results, and existing state and federal legislation, the study sought to describe: (1) shortcomings of existing preliminary geological investigations for siting of CAFOs on karst terrain, and suggestions to improve these preliminary investigations; (2) shortcomings in the legislative system that can lead to deterioration of important groundwater resources and water resources of protected areas, e.g., National Parks; (3) the importance of using site-specific evaluation methodologies and proper site-specific protection measures while siting hazardous operations on karst terrain; (4) how the scientific approach can help improve the protection of important surface and groundwater resources on karst terrains while still allowing the agricultural development of the area.

Additionally, proposals for (1) implementing karst-specific evaluation methods into CAFO regulations and (2) improvements to national legislation were developed.

General description of cafos and associated hazards for karst terrain

A CAFO may be loosely defined as a factory-farm operation in which a very large number of farm animals are kept in a relatively small area. The USA Environmental Protection Agency (EPA) considers a CAFO as a point source, as defined by the Clean Water Act (CWA) [§ 502(14)] (Field 2011).

All swine CAFOs utilize open waste lagoons which store liquefied animal manures; these manures are sprayed on approved spray fields. Spraying accomplishes two objectives: (1) it prevents over-storage of manure in the waste lagoons; and (2) the liquid manure serves as a nutrient for grass and hay crops, which are used to feed livestock.

Multiple studies of CAFOs have shown that both waste lagoons and spray fields present significant environmental threats to karst terrains and underlying groundwater (Field 2011; Brahana et al. 2014; Chapman et al. 2015; Ham 2002; Kelly et al. 2009).

Groundwater contamination from CAFOs can occur from various sources, such as: leaking lagoons, breaches in piping or barn infrastructure, and land application of liquid and solid wastes (Hutchins et al. 2012). Such leakage has been associated with increased levels of nitrates, phosphates, pathogen bacteria, steroid hormones, heavy metals, antibiotics, and other pharmaceuticals in groundwater bodies and soil (Hong et al. 2013; Mallin and Cahoon 2003; Lapworth et al. 2012). The nitrate form of N is especially mobile in soils and can pass readily through soils to contaminate groundwater (Mallin and Cahoon 2003).

The central issue regarding these types of micropollutants and CAFOs is that they may readily be released in large quantities from a CAFO without any form of treatment (Field 2011) since microbes generated by CAFOs are not exposed to secondary treatment or chlorination to disinfect the material (Mallin and Cahoon 2003). This latter concern is particularly important in karst terrains where rapid and direct groundwater migration often occurs, and where low groundwater temperatures may slow microbial die-off (Davis et al. 2000).

CAFO manure lagoons are typically excavated into the soil and lined with clay; even when properly constructed, such lagoons tend to leak. Slow leakage can release large amounts of contaminants over time. Calculations have shown that nitrogen losses from a lagoon of approximately 2.5 ha could exceed 230,000 kg over a period of 25 years (Ham 2002). Lagoon leakage can be increased due to environmental factors (e.g., drying, wetting, and freezing) that may cause additional cracks in their structures. Since their performance is dependent on site-specific factors (e.g., soil type, chemistry of waste, climate), scientists have proposed a logical framework for determining the optimal lagoon design. It is based on evaluation of site-specific conditions through geological assessment, vadose-zone soil analysis, and depth to the water table (Ham and De Sutter 2000). However this proposed framework has not been universally implemented.

Study area

Geological, geomorphological and hydrological settings

In 2012, a 6500 head swine CAFO was approved by the Arkansas Department of Environmental Quality (ADEQ) (ADEQ 2012) to be situated on a karst area in Big Creek Basin near the town of Mount Judea in Newton County, Arkansas (Fig. 1). The location is approximately 110 m up-gradient from Big Creek and less than 10 km from the confluence of Big Creek with the BNR (Fig. 1).

Geomorphologically the area consists of the Buffalo River Valley (approximately 200 m asl) and the valleys of its tributaries intersected by hills that can reach elevations of just over 672 m asl. Based on the geologic map of the Mt. Judea quadrangle (Braden et al. 2003), the geology of the study area is characterized by relatively flat-lying sedimentary rocks of Ordovician through Upper Carboniferous (Pennsylvanian) age. The ridges typically consist of Pennsylvanian age sandstones, shale and siltstones. The lower elevation foothills and valleys are formed on the underlying Mississippian of Lower Carboniferous (Boone Formation on Fig. 1) and Ordovician rocks (St. Peter Sandstone and Everton Formation on Fig. 1), dominantly impure limestone, sandstone and dolomite.

The main strata of interest in this study are the Boone Formation (Fig. 2), which consists of about 7 m of relatively pure limestone in its upper reaches, underlined by 80–90 m of thin, cherty limestone. The Boone Formation directly underlies the studied CAFO as well as part of the spray fields downstream from the CAFO (Fig. 1). The lowest reaches of Big Creek and much of the BNR valley are formed in the Ordovician aged carbonates of the Ferndale, Plattin, and Everton Formations, and the St. Peter Sandstone (Fig. 1). All of the latter except the St. Peter Sandstone are karstified. The valley of Big Creek is typically covered in non-indurated sediments, primarily chert gravel, and terrigenous sediments overlying the Boone Formation. The alluvium in tributary valleys varies in thickness from a feather-edge to about 8 m. Outcrops of the Boone Formation are common in the streambed through the entire study area. They tend to develop obvious karst features, including sinkholes, sinking and dry streams, swallow holes and caves on exposed bedrock surfaces (Fig. 2).

Big Creek is the fifth largest tributary to the BNR and encompasses approximately 8 % of the total drainage of the BNR drainage area (Mott and Luraas 2004). During

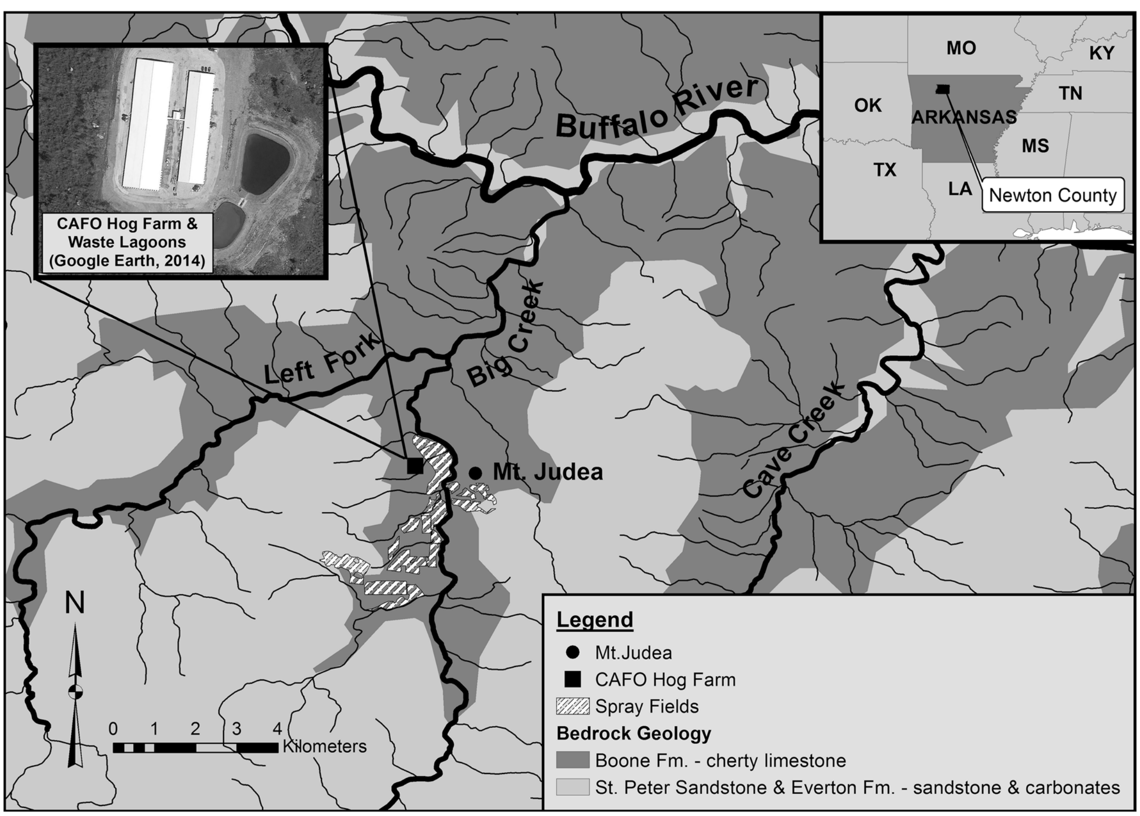

Fig. 1 Generalized geological and hydrological settings [including major surface drainages, the CAFO and its spray fields (Google Earth 2014)]

Fig. 2 Typical karst feature in Boone Formation, Left Fork of Big Creek, AR

heavy rains, the steeper slopes and shale bedrock of the headwater areas result in fast-rising floods on the BNR and other Ozark streams (Mott and Luraas 2004).

The study area is typified by karst drainage, but owing to the high concentration of chert and clay that weathers from the Boone Formation, karst landforms are typically mantled and not usually obvious in that portion of Big Creek (Brahana et al. 2014). However, karst hydrogeology is present throughout both Big Creek and BNR valleys, with extensive surface-water and groundwater interaction and numerous springs. Upper reaches of most creeks are dry during late summer months.

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 lithology (Brahana et al. 2014).

The climate of the BNR basin is characterized by long, hot summers and relatively short, mild winters. Annual rainfall totals vary from 760 to 2030 mm, with an average of 1170 mm (Mott and Luraas 2004). The greatest amounts of precipitation typically occur in winter and spring with approximately 100–120 mm per month. Average winter snowfall is 30 cm (Mott and Luraas 2004). Minimum precipitation amounts typically occur between July and October, when average monthly precipitation is approximately 80 mm. In spite of the fairly uniform precipitation, runoff varies widely by season, with dry river sections commonly occurring in late summer and fall. Large storms are most likely to occur during spring months (Mott and Luraas 2004), if occurring after the dry season they can cause excessive flooding of streams and rivers.

Subsurface characteristics

Ground Penetrating Radar (GPR) surveys were performed after siting of the CAFO by the Department of Agriculture from the University of Arkansas. Survey results of three spray fields identified several subsurface features that were wavy in nature and resemble the dissolution features that are manifested in cutter and pinnacle karst (Cochran 2013), these features appeared to be present at depths ranging from 0.5 to 1.5 m. Excavation to positively identify these subsurface features was not feasible due to rocky conditions (Cochran 2013).

Economic activities and natural resources

Prevailing economic activities in the area are cattle farming and tourism (fishing, floating, swimming, hiking and climbing). Tourism occurs primarily in the BNR Park which is managed by the National Park Service (NPS). The Buffalo River has been designated as an Extraordinary Resource Water (ERW) and Natural and Scenic Waterway by the Arkansas Pollution Control and Ecology Commission (APC&EC). These designations identify high-quality waters that constitute an outstanding state or national resource and should therefore be protected by (1) water quality controls, (2) maintenance of natural flow regime, (3) protection of instream habitat, and (4) encouragement of land management practices protective of the watershed (APC&EC Reg. 2.203, 2014a). However, this regulation does not have the authority over private property.

Since water flowing in the Buffalo River during its base flow stage is supplied by groundwater recharge, threats to the groundwater supply also mean threats to the water quality of the Buffalo (Mott and Luraas 2004).

Waste handling at the studied CAFO

The waste lagoons of the studied CAFO (Fig. 1) were excavated in the clay soil and lined with a fat, high plasticity clay. No additional synthetic or concrete liners to prevent leakage of liquid waste into the subsurface were used. As stated in the National Pollutant Discharge Elimination System (NPDES) permit application, the leakage from the lagoons, with a combined area of approximately 0.85 ha is limited to approximately 7659 liters/ha/day as required by ADEQ (ADEQ 2012).

There are 17 spray fields covering approximately 243 ha, ranging from 4 to 33 ha in size. Spray fields are predominantly located in areas underlain by the Boone

Formation and Big Creek alluvium both of which drain to springs along Big Creek and Left Fork (Fig. 1).

Methodologies used

Legislation analysis

In order to assess the legislative and regulatory processes associated with CAFOs and environmental protection, various State and Federal policies and programs were reviewed. These reviews enabled an assessment of the CAFO permitting process and related groundwater protective measures. They also provided a framework within which proposed improvements to existing policies have been formulated.

As part of this review the following Federal acts and regulations were analyzed: the CWA, which is the primary act protecting USA waters, also referred to as Federal Water Pollution Control Act; the Resource Conservation and Recovery Act (RCRA); EPA's CAFO regulations from Title 40 of the Code of Federal Regulations (40 CFR), published in the Federal Register (FR). Additionally, the following State regulations from APC&EC were analyzed: Regulation No. 2, Establishing Water Quality Standards for Surface Waters of the State of Arkansas; Regulation No. 5, Liquid Animal Waste Management Systems; and Regulation No. 6, Regulations for State Administrations of the National Pollutant Discharge Elimination System (NPDES).

Acts in the USA present approved laws and are published in the U.S. Code, while the USA regulations explain the technical, operational, and legal details necessary to implement these laws. Regulations are mandatory requirements that can apply to individuals, businesses, state or local governments, non-profit institutions, or others (EPA 2014). They are typically written by governmental agencies, which are designated as the Regulatory Entities for the subject matter involved, and when approved, are published in the CFR. For example, EPA is one of the Regulatory Entities for the Protection of the Environment that is published under the 40 CFR. Every state then has separate regulations that must comply with federal laws but can include more stringent requirements.

The EPA has ten regional offices across the USA, responsible for a subset of states, territories or special environmental programs. The State of Arkansas is included in Region 6, and therefore implements rules and regulations from the Region 6 Office.

The environmental policy-making body for Arkansas is the APC&EC. With guidance from the Governor, the Legislature, the EPA and others, the Commission determines the environmental policy for the state (ADEQ 2013). The ADEQ is designated to implement those policies.

Figure 3 illustrates relationships relevant to this study, between the State and Federal regulators, their policies, and the subject CAFO.

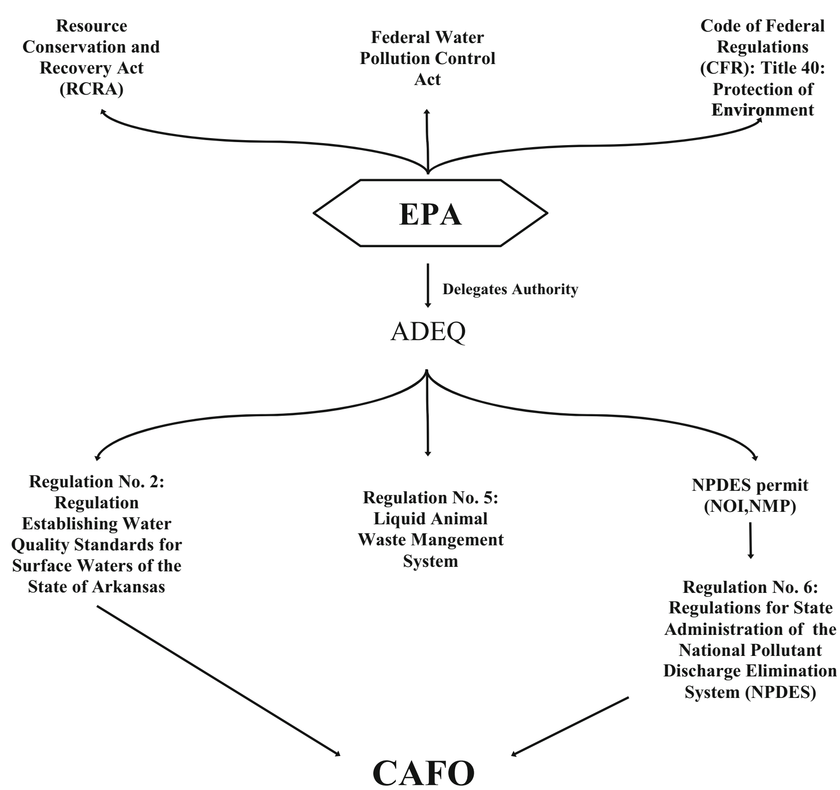

Fig. 3 Flowchart of legislations and regulatory entities for CAFOs on Federal and State level

Tracer test

After the construction of the studied CAFO, a pro-bono private interest group of scientists and volunteers, including several of the authors, performed a dye tracer test for the purpose of characterizing possible groundwater and surface water connections in the area of the CAFO, Big Creek Basin, and the BNR.

Eosin dye was injected in a private well located between spray fields (Fig. 4). This dye injection point was chosen based on the hydrogeological setting of the area, direct accessibility to the aquifer, and proximity to the CAFO and its spray fields.

Dye receptors were placed at 140 monitoring points in private or NPS springs, wells and caves. Several monitoring points were also located in the stream beds of Big Creek and BNR. The sampling utilized active charcoal dye receptors which enabled the time-integrated monitoring of a large number of locations (Goldscheider and Drew 2007).

Three kg of Eosin, previously diluted with 5 l of water, were injected on May 12, 2014 and flushed with 20 l of water. Two days thereafter a rain event of 89 mm precipitation occurred. Dye receptors were collected periodically over a period of four months, with a sample frequency of days to weeks depending on hydrological conditions. Receptors were cleaned, dried and eluted with a mixture of 70 % of isopropanol and 5 % potassium hydroxide (Aley 2002). The resulting eluent was analyzed after 5 h, using a scanning Shimadzu spectrophoflurimeter at the University of Arkansas.

Results

Legislation analysis

The CWA defines a point source as any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, CAFO, or vessel or other floating craft, from which pollutants are or may be discharged. This term does not include agricultural stormwater discharges and return flows from irrigated agriculture (§502(14), 2011).

Nonpoint sources of contamination are defined as agricultural and silvicultural activities, including runoff from fields, and crop and forest lands (CWA §304 (f) (A), 2011) and the disposal of pollutants in wells or in subsurface excavations (CWA §304 (f) (D), 2011).

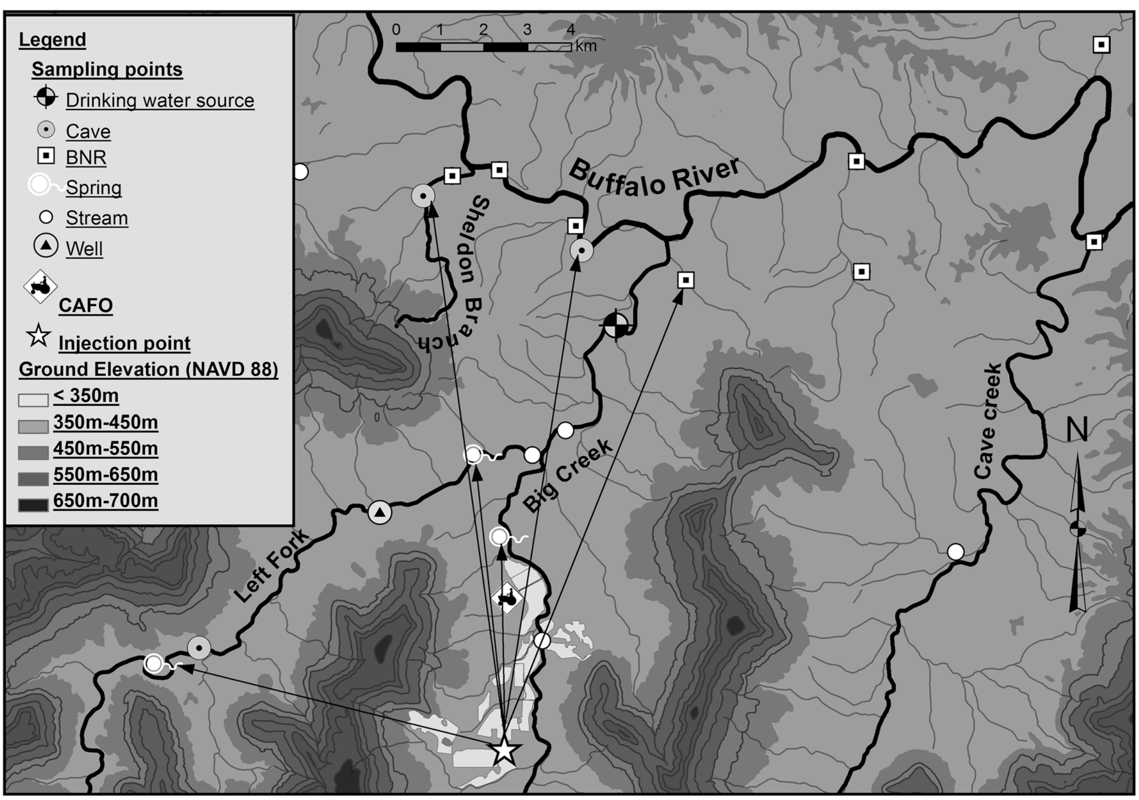

Fig. 4 Tracer test results (showing selected eosin positive detections, groundwater connections and elevations for the area)

All CAFOs that propose to discharge manure, litter or processed wastewater into waters of the USA must obtain NPDES permits under the 40 CFR § 122.23. Usually the permit is issued by EPA, however states can also implement their own NPDES programs and issue NPDES permits if approved or authorized by EPA under 40 CFR Part 123 (40 CFR § 122.23, 2015). The State of Arkansas has been authorized by the EPA to administer the NPDES Program in Arkansas, including the issuance of general permits to categories of dischargers under the provisions of 40 CFR § 122.28, as adopted by reference in APC&EC Reg. 6.104 (2014b). Under this authority, ADEQ may issue a single general permit to a category of point sources located within the same geographic area, whose discharges warrant similar pollution control measures or if they, in the opinion of the Director of ADEQ, are more appropriately controlled under general permit than under individual (Arkansas Department of Environmental Quality 2011a, b). These ADEQ NPDES programs must comply with the CWA and those federal regulations incorporated in Regulation No. 6 from APC&EC (2014b). ADEQ is also the responsible department for verifying if all the NPDES procedures are properly performed. In order to obtain an NPDES permit, a proposed operation needs to submit an NPDES Permit Application, a Notice of Intent (NOI) and a Nutrient Management Plan (NMP) to ADEQ.

CAFOs in Arkansas, operating under the NPDES general or individual permits, are excluded from Regulation No. 5 (Fig. 3). Regulation No. 5 addresses those CAFOs not otherwise required to obtain an NPDES permit, and establishes the minimum qualifications, standards and procedures for issuance of permits for CAFOs using liquid animal waste management systems within the State of Arkansas, and for the issuance of land application sites within the state (APC&EC Reg. 5.102, 2012). The requirements from regulation No. 5 and those issued as part of the NPDES General Permit are generally consistent with each other, however some differences do exist. For example, both suggest a minimum 30 m setback distance for application of manure, litter, and process wastewater to any down-gradient surface waters, open tile line intake structures, sinkholes, agricultural well heads, or other conduits to surface waters and 90 m from ERW. However, Regulation No. 5 also applies buffer zones of 30 m to intermittent streams, springs, rocky outcrops, etc. (APC&EC Reg. 5.406(D), 2012), while the NPDES general permit does not. Additionally, the NPDES permit allows a CAFO to substitute the 30 m setback with a 11 m wide vegetated buffer, or to demonstrate that neither of them is necessary if implementation of alternative conservation practices or field-specific conditions will provide equivalent or better pollutant reduction (ADEQ 2011a, b).

There is a liner requirement for CAFO lagoons in EPA Region 6 which requires a permittee to document that no direct hydrologic connection through groundwater exists between the contained wastewater and surface waters of the United States. Where the permit cannot document that no direct hydrologic connection through groundwater exists, the ponds, lagoons and basins of the containment facilities must have a liner which will prevent the potential contamination of surface waters (EPA 2011). However, this requirement does not apply to the State of Arkansas because of the authorization to implement their own NPDES programs (EPA 2015).

EPA also implements RCRA, the goals of which are (1) to protect human health and the environment from the potential hazards of waste disposal, (2) to conserve energy and natural resources, (3) to reduce the amount of waste generated, and (4) to ensure that wastes are managed in an environmentally sound manner. RCRA regulates the management of solid waste (e.g., garbage), hazardous waste, and underground storage tanks holding petroleum products or certain chemicals (EPA 2013). Currently, agricultural wastes are largely exempted from regulation under RCRA (40 CRF §261.4(b), 2015).

The RCRA program assumes that all lagoons and landfills will leak. Therefore, it requires that all hazardous waste disposal sites on land be lined with double liners and have both leak detection and leak collection systems installed (Field 2011).

Tracer test

Based to the data available to the authors, fifty-nine positive detections were identified in the tracer test, some of which were located in different surface-drainage basins. Forty-four detections were located in various springs and streams, 26 of which are privately owned. Fourteen of the detections were located in caves or springs managed by the BNR, and three of these detections were located in the BNR itself. One of the positive detections occurred in a private well that is used for extraction of potable water. The groundwater straight-line flow directions are oriented west, north, northwest and northeast. For illustration purposes, only 21 selected positive detections (including streams, springs, caves and wells) are presented on Fig. 4. The arrows on this figure illustrate the assumed straight-line groundwater flow directions between injection point and the sampled springs and caves (excluding streams and wells).

Discussion

Based on the information reviewed as part of this study, site evaluation conducted prior to issuance of the NPDES permit for the studied CAFO did not incorporate adequate karst-specific evaluation methods to address potential hazards to nearby groundwater and surface water resources.

The GPR surveys conducted at the analyzed CAFO spray fields suggest that shallow karst features may be present beneath the spray fields (Cochran 2013). The underlying Boone Formation is characterized by karst dissolution features and secondary porosity (e.g., caves, conduits) presenting an increased risk of infiltration and migration of potential hog farm wastes (e.g., liquefied manure). However, because these features were not further evaluated, the true potential vulnerability of the aquifer associated with rapid infiltration of contaminants remains unknown. In the absence of more detailed investigations to characterize the potential risks, contamination of groundwater through rapid infiltration may go unnoticed until detected at offsite locations, at which point remediation would be made more complex and expensive.

The presence of the Boone Formation beneath the waste lagoons presents a similar potential contamination risk, with the added hazard associated with the potential formation of sinkholes and subsurface voids leading to increased leakage of contaminants into the subsurface. Some multiparameter studies of the vadose zone have shown that the localized source of pollution with higher concentration of nitrates, chlorides, phosphates and sulfates such as leakage waters from landfills, foster increased dissolution of limestone (Kogovšek in Knez et al. 2011). A subsurface investigation utilizing soil borings was conducted as part of the permitting process prior to construction of the waste lagoons. However the scope (number of borings and total depth) was very limited, and such investigations may not be well suited to evaluating karst areas due to the potential for solution features to go undetected (see, for example, Hoover 2003; van Beynen 2011; Goldscheider and Drew 2007). Therefore more comprehensive karst-specific investigation prior to siting of the waste lagoons should have been performed, and alternative site-specific construction practices (e.g., the addition of a synthetic liner) should have been considered.

The tracer test performed in the area indicates a linkage between groundwater bodies surrounding the area of the studied CAFO, the spray fields, several private springs, wells, and the BNR. These results, while indicating that possible connections exist, do not provide information regarding the rate and volume of groundwater migration. Therefore, an accurate prediction of the magnitude of contamination risk posed by infiltration of agricultural wastes cannot be made. Only through additional evaluation such as a determination of groundwater discharges, and a more complete delineation of groundwater divides can the real hazards to private water sources, and the BNR be determined. However, based on the indicated groundwater connections, and known physical and operational site characteristics, contaminant migration may already be occurring, presenting a significant risk for surrounding groundwater bodies, surface waters and natural heritage. It should also be recognized that slight changes in groundwater chemistry, while not immediately and dramatically evident, may become so over a longer time frame (Urich 2002). Conducting comprehensive tracer tests prior to the siting of potentially hazardous activities on karst terrain would help minimize these uncertainties and potential risks through accurate delineation of the aquifer.

The NPDES permit for this CAFO requires a buffer zone of 30 m or alternatively, an 11 m vegetated buffer in the vicinity of sinkholes; however it does not include buffers for caves, sinking streams and other existing karst features. Such buffers may reduce the suspended load reaching streams and will biologically strip some nutrients, but will have little effect on pathogenic organisms (Ford and Williams 2007). Various processes act on inorganic, organic and particulate contaminants, but the effectiveness of these processes depends, firstly, upon the properties of the substrate layers through which the contaminants are transmitted and, secondly, on the physical and chemical properties of the contaminants (Ford and Williams 2007). Therefore, in order to properly determine appropriate buffer widths and locations, a more complete evaluation of both surface and subsurface characteristics should be conducted.

Due to karst aquifer heterogeneity, contaminants in groundwater may travel for several km before reaching a spring (see, for example, Knez et al. 2011; Imes and Emmet 1994). Therefore the delineation of karst aquifers is extremely important in order to define potential areas that may be impacted in the event of groundwater contamination.

If the preservation of important water resources e.g., BNR and private potable water sources is to be considered a priority, then more rigorous siting and permitting evaluations should be conducted prior to construction and operation of CAFOs and similar facilities. Doing so not only protects these valuable natural resources, but it enables the agricultural operations to operate undisturbed by additional limitations, and protects neighboring private landowners from unwanted impacts to their groundwaters.

Proposals for implementig karst-specific evaluation methodologies and improving groundwater protective policies

Some scientists suggest CAFO facilities or the application of animal waste from a CAFO on croplands should not be allowed within karst areas (Kelly et al. 2009). Such a restriction could have significant negative socio-economic impacts to local communities. Therefore the following steps were developed with respect to CAFO permitting which would enhance karst groundwater protection while simultaneously allowing for an appropriate level of agricultural activity.

In addition to their current status as point-sources, CAFOs should additionally be regulated as potential non-point sources for contaminants considering that spreading of large volumes of manure on fields and leakage from waste lagoons can cause diffuse discharge of contaminants to the subsurface.

An additional step would be to minimize the probability of CAFO waste lagoon leakage by implementing more strict requirements for site-specific lagoon liners, regardless of whether the NPDES permits are issued by the EPA directly or by the state. Here it should be emphasized that by assigning the EPA as the sole regulatory entity for NPDES programs, the inconsistencies in implementing NPDES permits between states might be avoided (Fig. 5).

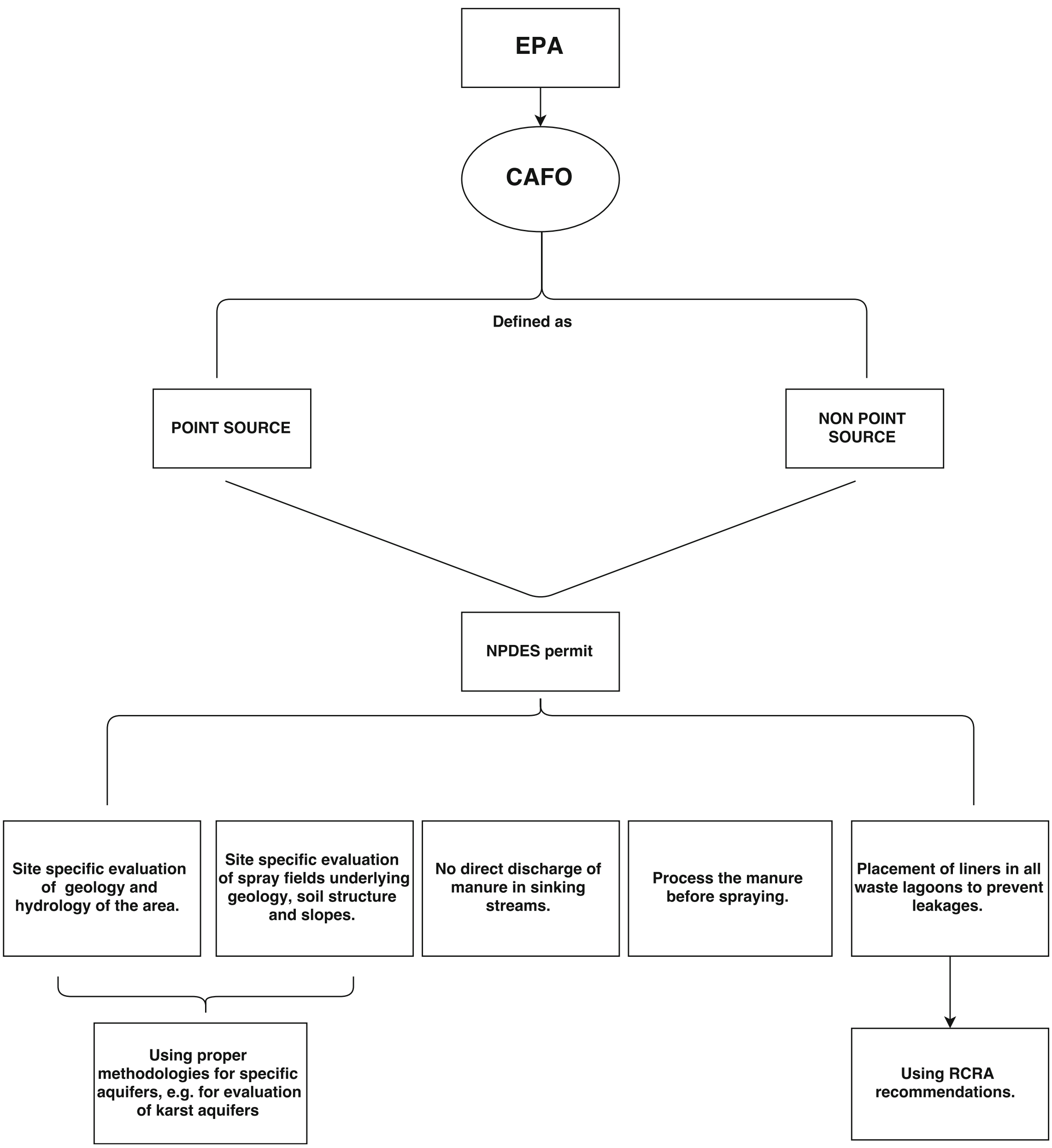

Fig. 5 Flowchart with proposal for improved groundwater protective legislation

Manure lagoons should be constructed or lined in a way that prevents leakage to the soil, groundwater and/or surface water. The liner should be resistant to: physical contact with the waste, pressure gradients, climatic conditions, etc. (Field 2011). The type of liners should be chosen based on the geological, hydrological and soil characteristics of the site (Ham 2002). Stronger, thicker, or multiple liners should be required for vulnerable areas e.g., karst, in order to assure that no leakage will occur. Requirements similar to those used in RCRA could be adopted for waste lagoons and included in the NPDES permit. Alternatively, a better solution might be to regulate CAFOs as part of RCRA since these operations typically generate large volumes of waste, comparable to those generated by industrial facilities currently regulated by RCRA.

Manure could be exposed to secondary treatment or chlorination in order to disinfect the material prior to spreading on spray fields.

Spreading of manure should be strictly prohibited on fields that are underlain by karst features without the express written permission of all landowners that share the delineated aquifer. Failure to do so could be considered a nuisance or even trespassing, since the contaminants may migrate with groundwater onto all properties sharing the aquifer. Also, the possibility of contaminating protected areas (e.g., National Parks) should be more rigorously considered.

Buffer distances from karst features, e.g., caves, sinkholes, swallow holes, sinking streams, should be determined on a site-specific basis.

Most of the proposed steps listed above rely on rigorous characterization of karst features, therefore the following methods of investigation should be considered in the NPDES permit and implemented before siting and construction of waste lagoons and spray fields on karst terrains:

- Arial photo analyses;
- Geologic analyses;
- Geophysical evaluation;
- Airborne light distancing and ranging (LiDAR) surveys;
- Detailed soil surveys and analysis of site-specific qualities;
- Karst inventory and mapping;
- Hydrological analyses (e.g., precipitation monitoring, recharge monitoring, discharge measurement, tracing analyses, hydraulic conductivity measurements, delineation of aquifers);
- Test boring investigation (only if performed based on the prior geological and geophysical evaluation and possible speleological investigations);
- Preliminary and compliance groundwater quality monitoring, incorporating event-based sampling strategies in order to define possible impacts on groundwater quality;
- Vulnerability mapping and contamination risk mapping (developed for karst areas).

Conclusions

Karst groundwater protection policies are still inchoate, which contributes to daily deterioration of these valuable water resources. As presented in this study, integrating scientific methods in policy-making can enhance the preservation of valuable karst groundwater resources, and the protection of highly valued areas such as State and National Parks, all while simultaneously allowing for an appropriate level of agricultural activity. Therefore combining the scientific and political knowledge is a crucial element in the process of achieving protection of karst groundwaters.

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