RESPONSE TO THE EXTERNAL PANEL REVIEW OF BCRET FINAL REPORT

In September 2019 a review panel consisting of Carl Bolster (USDA-ARS), Mark Rice (North Carolina State University, retired), Charles Taylor (University of Kentucky), and Martin Shipitalo (USDA-ARS, retired) with expertise in hydrology, water quality monitoring, animal waste and soil management reviewed the draft report "Monitoring the Sustainable Management of Nutrients on C&H Farm in Big Creek Watershed" provided by the Big Creek Research and Extension Team (BCRET). The impetus for the study and the subsequent report was to assess the potential impact of a newly permitted and established concentrated hog feeding operation upstream from the Buffalo National River Watershed in an area with karst geology.

The BCRET in consultation with the outside reviewer panel, including Final Report review team members Bolster, Rice, and Shipitalo, devised a multi-faceted approach with three objectives:

1. Monitor the fate and transport of nutrients and bacteria from land-applied swine effluent to pastures.

2. Assess the impact of farming operations (effluent holding ponds and land-application of effluent) on water quality adjacent to the farm including springs, ephemeral streams, creeks and ground water.

3. Determine the effectiveness and sustainability of alternative manure management techniques, including solid separation, to increase the export of nutrients out of the watershed.

We offer the following comments on the appropriateness of the methodology, interpretation of the results, and conclusions and offer suggestions on how the report can be improved.

Methodology

In general, the team found that the methodology was appropriate for each of the objectives. In particular, the BCRET used a combination of periodic, grid soil sampling and testing, and surface runoff monitoring on three pastures with contrasting soil types. Two of the fields received swine slurry and one received mineral fertilizer at appropriate rates to address Objective #1. The soil sampling protocols were guided in part by a Ground Penetrating Radar (GPR) evaluation of soil depth in each of the three monitored fields.

As part of Objective #2 the BCRET monitored the properties of the slurry stored in the two holding ponds used by the CAFO with time and with depth, an onsite deep well, a nearby spring and ephemeral stream to assess potential leakage from the holding ponds. Additionally, an interceptor ditch was installed down slope from the ponds to assess potential seepage as well as overland flow originating from the holding ponds. This monitored ditch was particularly suitable in areas such as this with a high potential for preferential flow. The review team, however, requests additional information on how the geology of the site was assessed and summary information on the results of any dye tracing experiments that have been conducted in the area that might be applicable to the interpretation of the results.

Response: **Detailed information on the soil profile and geology at the trench site location has been added to Appendix K, in support of trench installation. This information is provided as "Response 1".**

Summary information of dye-tracing studies conducted by Drs. Kosic and Brahana in the monitored portion of the Big Creek watershed have been added to the new section "Karst Geology and the Big Creek Watershed." This information also provided as "Response 2".

The BCRET used analysis of the composition of the slurry with depth to suggest that segregation of the slurry by depth could be used to reduce the potential for nutrient buildup (mainly P) in the fields where slurry was applied in furtherance of Objective #3. Likewise, they used the soil testing data to determine where nutrient buildup is or has occurred to refine application zones within fields. The BCRET mentions in the report that locally sourced limestone and hydrated lime were investigated as potential flocculants to concentrate solids and P in the slurry. Scant information on the methodology used to perform these tests is presented in the draft report. The review team suggests that this information be included in the revision or that justification for not providing these details as well as the results of these experiments be included.

Response: We have provided additional detail on the methods used to investigate the potential for manure amendment and treatment. This information is provided as "Response 3".

Interpretation

Objective #1. The results of the soil testing of the pastures and monitoring of surface runoff were evaluated using appropriate statistical techniques. We agree with the conclusion that available soil P test levels are increasing as a result of slurry application. In some this increase in available P predated slurry application and was related to animal movement and feeding areas - not slurry management. The analysis of P saturation levels document that P levels are still well below levels that research has shown to be of concern.

The loss of nutrients in surface runoff was more related to a few extreme runoff events during the monitoring period than to slurry management practices. This interpretation was supported by the observation that nutrient losses were similar from the pasture that received mineral fertilizer and one of the slurry-amended fields. Furthermore, the rates of nutrient losses were of similar magnitude to those observed in other studies with similar experimental conditions.

Sampling of Big Creek upstream and downstream from C&H Farm combined with two robust methods of trend analysis revealed that flow-adjusted P concentrations decreased while flow-adjusted N concentrations increased upstream and downstream during the monitoring period. We concur that there is insufficient evidence to link these increases to operations associated with C&H. Moreover, comparison of water quality of this reach of Big Creek to other streams in the region further support a finding of limited impact of C&H operations on water quality.

Objective #2. The BCRET documented slight but significant increases in nitrate nitrogen in the well and ephemeral stream associated with the holding ponds, but not in the interceptor ditch. While statistically significant, the increases were small and not at a level that would raise water quality concerns at the present. We agree with the BCRET that the lack of a concurrent increase in chloride levels or electrical conductivity at these sites could be interpreted as indicating that potential leakage from the holding ponds was not a major contributor to the observed increase in nitrate-N. However, given the presence of karst, an alternative interpretation could be made raising the question of whether discrete preferential flowpaths in the subsurface is allowing potential nutrients to bypass these sampling locations. It would be useful if the team could provide information or speculation on other land use practices in the area that might have contributed to the increased levels of nitrate.

<u>Response</u>: Other sources of nutrients in the monitored watershed might be the other non-permitted hayed and grazed pastures receiving mineral fertilizers and poultry litter, residential septic system discharge, and stormwater runoff from Mt. Judea. Statements concerning the uncertainties of the karst setting, which make it difficult to identify sources and provide cause-and-effect interpretations with any degree of reliability, have been added to the Conclusions section.

Objective #3. As mentioned in our comments on Methodology, additional quantitative information on the results of the treatment of the holding pond slurry with lime and hydrated lime are desirable to augment the interpretation by the BCRET that such treatments are likely to be unfeasible as a method of reducing available P prior to slurry application to pastures.

<u>General Comment Regarding the Relevance of Karst Hydrogeology</u>

One limitation in the report, is the lack of a detailed discussion about how specific karst characteristics present at the site were factored into the monitoring/sampling plan design and were considered in analysis and evaluation of the results. Information presented in Appendix D (ground penetrating radar surveys) is particularly relevant, as is information that can be gleaned from a number of previous trace test studies of the karst hydrogeology in the watershed area cited in the references. The paper by Brahana and others (2014), referenced below, is particularly relevant and detailed, and should be very helpful. Finally, there was no specific discussion in the report about water-chemistry and flow characteristics at the spring sampling site (Site 5), even though field and laboratory water-chemistry data from that site is included in Appendix I. An evaluation of the spring's discharge characteristics may provide significant insights about the nature of karst development at the site and its possible impacts on contaminant transport.

<u>Response</u>: We have added text to emphasize more clearly that the spring posed a challenge to sample with any degree of certainty that the water collected was not contaminated from external sources. We found dead frogs and live snakes in the sampling chamber for example, and cows used the access trail as a walk way and the spring as a drinking water source. Thus, the spring water chemistry is not discussed in detail, as we believe the chemistry was influenced by factors beyond our control at this particular site, making the data collected unreliable and not an accurate reflection of spring-water chemistry. We were not given permission to sample other springs close to the animal houses and monitored fields.

This information should be synthesized and discussed in the report in a way that describes a conceptual model of the karst, discusses how the presence of karstic drainage characteristics (both surface and subsurface) affected the choice of groundwater sampling site locations and techniques, and evaluates the possible uncertainties the presence of karst may have on the interpretation of the water-quality analytical results. For example, the report could benefit from inclusion of:

1. A map showing the locations of any identified sinkholes or sinking streams, and given the presence of mantled karst, the thickness of soils, and areas of bare rock outcrop, relative to the locations of potential contaminant source areas, and especially, locations of the spring and well sampling sites. This information would be useful in assessing the adequacy of sampling locations with regard to on-site locations potentially most susceptible to rapid infiltration and/or internal drainage of concentrated surface runoff.

Response: We have added a map showing the locations of any sinkholes or sinking streams identified by USGS in the Big Creek Watershed. This information is provided as "Response 4".

2. A map showing plotted dye flow vectors (inferred from previously reported dye-trace tests) relative to locations of source areas and groundwater (well and spring) sampling sites. This information would be helpful in assessing the effectiveness of sampling site locations and evaluating possible uncertainties relative to existence of preferential karst or fracture flowpaths in the aquifer, possible interbasin water transfer, etc---all which are mentioned and discussed briefly or in general terms in the text.

Response: Summary information of dye-tracing studies conducted by Drs. Kosic and Brahana in the monitored portion of the Big Creek watershed has been added to the new section "Karst Geology and the Big Creek Watershed." This information is provided as "Response 2".

In considering needed additional content and to how to frame the discussion in this section of the report, the following papers would be helpful to consult:

Brahana, Van, Nix, Joe, Bitting, Carol, Bitting, Chuck, Quick, Ray, Murdoch, John, Roland, Victor, West. Amie. Robertson, Sarah, Scarsdale, Grant, and North, Vanya, 2014, CAFOs on karst—Meaningful data collection to adequately define environmental risk, with specific application from the southern Ozarks of northern Arkansas: in Kuniansky, E.L., and Spangler, L.E., eds., U.S. Geological Survey Karst Interest Group Proceedings, Carlsbad, New Mexico, April 29-May 2, 2014, U.S. Geological Survey Scientific Investigations Report 2014-5035, p. 87-96.

Ewers, R.O., 2006, Karst aquifers and the role of assumptions and authority in science: Geological Society of America Special Papers 404, p.235-242 doi: 10.1130/2006.2404(19).

Field, M.S. 1990, Transport of chemical contaminants in karst terranes: outline and summary: in Simpson, E.S., and Sharp, J.M. Jr., International Association of Hydrologists, Selected Papers on Hydrogeology from the 28th International Congress, Washington, DC, USA, July 9-19, 1998, v. 1, p.17-27.

Quinlan, J.F., 1989, Groundwater monitoring in karst terranes: recommended protocols and implicit assumptions. Las Vegas Nevada: U.S. Environmental Protection Agency Report EPA/600/X-89-050.

Conclusions

The review team, based on the findings presented in the draft report, concurs with the conclusions reached by the BCRET. Namely that at present there is no evidence that the operations associated with C&H Farms has significantly impacted the quality of the ground or surface waters associated with the holding ponds or the fields where slurry has been applied. There is a potential, however, that long-term continued application of slurry to pastures in excess of nutrient requirements may contribute to degradation in water quality absence the use of techniques to reduce nutrient availability in the slurry. Acceptance of these findings by the scientific community at large is further evidenced by publication of portions of the report in peer-reviewed journals.

Response 1

Soil and Geologic Description Adjacent to Animal Barns and Slurry Holding Ponds

Soils adjacent to the animal barns and slurry holding ponds on the C&H Farm are classified as Noark very cherty silt loams, ranging from 3 to 40% slopes (Figure S1 and Table S1). The area south of the slurry holding ponds, where the inceptor trenches are (T1 and T2) located, borders between soil map units 42 and 43, which have 3 to 8% slopes identified during trench installation. Pipe was installed in the inceptor trench (i.e., French drain) located just below the BE horizon, a depth of 20 to 30 inches below the soil surface (Table S2). This is the 2Bt1 horizon. From Table S2 it can be seen that the 2Bt1 (i.e., very gravelling clay) horizon has a markedly greater fine clay-sized particles compared to the above BE horizon (i.e., very gravelling silty clay loam). This increase in clay imparts a zone of reduced permeability, such a portion of any seepage from the base of the ponds would move laterally above this transition to the inceptor trench.

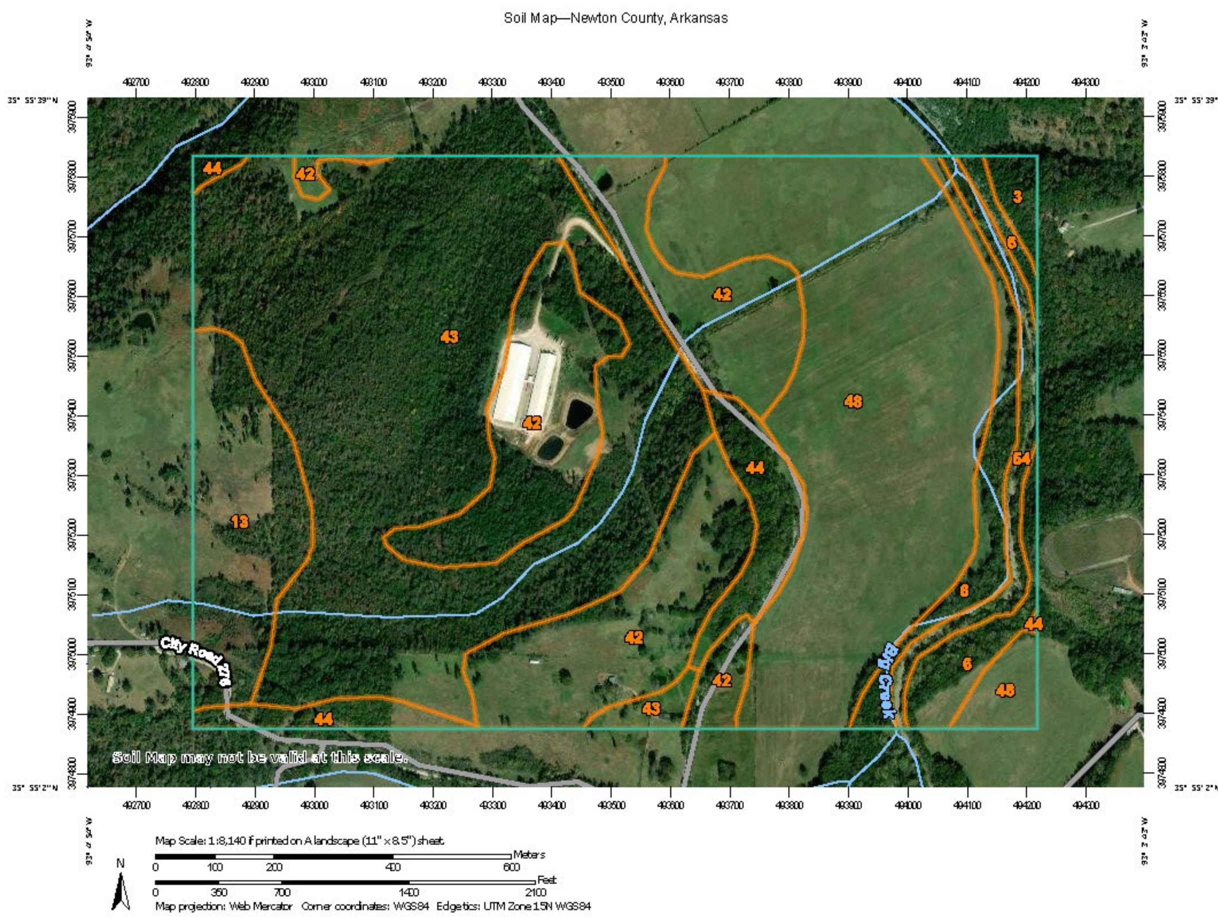

Figure S 1. Soils adjacent to the animal barns and slurry holding ponds at the C&H Farm.

Table S 1. Soil map unit descriptions in the area adjacent to the animal barns and slurry holding ponds at the C&H Farm.

Map unit legend	Map unit name	Acres in area of interest	Percent area of interest
3	Arkana-Moko complex, 20 to 40 percent slopes	2.5	0.7
6	Ceda-Kenn complex, 0 to 3 percent slopes, frequently flooded	18.3	5.4
13	Enders stony loam, 3 to 15 percent slopes	23.1	6.8
42	Noark very cherty silt loam, 3 to 8 percent slopes	68.1	20.1
43	Noark very cherty silt loam, 8 to 20 percent slopes	120.8	36.8
44	Noark very cherty silt loam, 20 to 40 percent slopes	14.2	4.2
48	Razort loam, occasionally flooded	84.0	24.8
54	Water	7.9	2.3

Noark Soil Series Profile Description from Arkansas NRCS

The Noark series consists of very deep, well drained, moderately permeable soils that formed in colluvium and clayey residuum from cherty limestones. These soils are on nearly level to very steep uplands of the Ozarks. Slopes range from 1 to 45%. The mean annual temperature is about 56 ^{o}F, and the mean annual precipitation is about 42 inches.

TAXONOMIC CLASS: Clayey-skeletal, mixed, semiactive, mesic Typic Paleudults

TYPICAL PEDON: Noark very gravelly silt loam, forested. (Colors are for moist soil unless otherwise stated.)

A--0 to 3 inches; dark grayish brown (10YR 4/2) very gravelly silt loam; moderate medium granular structure; friable; many medium roots; about 40% by volume angular chert fragments less than 3 inches in diameter; very strongly acid; abrupt smooth boundary. (1 to 7 inches thick)

E--3 to 12 inches; brown (10YR 5/3) very gravelly silt loam; weak medium subangular blocky structure; friable; many fine roots; about 40% by volume angular chert fragments less than 3 inches in diameter; extremely acid; clear wavy boundary. (6 to 14 inches thick)

BE--12 to 19 inches; yellowish red (5YR 4/6) very gravelly silty clay loam; pockets and streaks of brown (10YR 5/3) silt loam; moderate medium subangular blocky structure; firm; many fine roots; about 40% by volume angular chert fragments less than 3 inches in diameter; very strongly acid; clear wavy boundary. (0 to 11 inches thick)

2Bt1--19 to 26 inches; red (2.5YR 4/6) very gravelly clay; strong medium blocky structure; very firm; common fine roots; common fine pores; many thin patchy clay films on ped faces and chert fragments; about 40% by volume angular chert fragments less than 3 inches in diameter; extremely acid; gradual wavy boundary.

2Bt2--26 to 37 inches; dark red (2.5YR 3/6) very gravelly clay; strong medium blocky structure; very firm; few fine roots; common fine pores; thick continuous clay films on ped faces and chert fragments; about 50% by volume chert fragments less than 3 inches in diameter; extremely acid; gradual wavy boundary.

2Bt3--37 to 80 inches; dark red (2.5YR 3/6) extremely gravelly clay; strong medium blocky structure; very firm; thick continuous clay films on ped faces and chert fragments; about 70% by volume angular chert fragments less than 3 inches in diameter; extremely acid. (Combined thickness of the 2Bt horizon ranges from 31 to 73 inches or more.)

Geologic Description

Below is a summary of the Harbor Environmental and Safety Drilling Study Report submitted to the Arkansas Department of Environmental Quality, December 2016 (available at https://www.adeq.state.ar.us/water/bbri/c-and-h/drilling.aspx#collapseResults). The drilling was conducted adjacent to the C&H animal houses and slurry holding ponds, which was approximately 20 m from the BCRET interceptor trenches.

The uppermost geologic formation below the site is the Mississippian-age Boone Formation, a fossiliferous limestone interbedded with abundant chert, which varies considerably in abundance vertically and horizontally. The chert-free St. Joe Member is observed at the base of the Boone Formation. The Boone Formation is well known for dissolutional features, such as sinkholes, caves, and enlarged fissures. Thickness of the Boone Formation ranges from approximately 90 to 107 m (300 to 350 ft) in most of northern Arkansas. Groundwater below the site is contained within the Springfield Plateau aquifer, comprising the Boone Formation and the St. Joe Member of the Boone Formation.

The ADEQ test boring encountered yellowish red silty clay (CL) with chert and limestone fragments from the surface to a depth of 2.5 m (8 ft) below ground surface. All subsequent depths are stated as below ground surface. This material appeared to be fill soil placed during construction of the hog farm and adjacent waste ponds. Yellowish red fat clay (CH) was encountered from 2.5 to 4 m (8 to 13.5 ft). Fine-grained, fossiliferous, gray limestone was encountered from 13.5 feet to 20 feet with a six-inch seam of fat clay as above occurring from approximately 5.5 to 5.6 m (18 to 18.5 ft). Weathered and fractured, fossiliferous gray to buff limestone was encountered from 6.0 to 8.7 m (20 to 28.5 ft). The driller reported drilling water loss in this zone.

Competent, fossiliferous gray limestone (consistent with the Boone Formation), with some minor fracturing and bedding planes was encountered at 8.7 m (28.5 ft), which generally extended to 37 m (120 ft). Zones of increased fracturing were encountered around 21 and 27 m (70 and 90 ft); however, no karst features such as dissolution features were encountered. Natural gamma logging correlated with the boring log with counts ranging 60 to 100 counts/sec in the upper 4.6 m (15 ft) as would be expected in a clay, but decreasing from 4.6 to 6.1 m (15 to 20 ft; as would be expected in a limestone.

From 6.1 to 36.6 m (20 to 120 ft), natural gamma counts range from approximately 20 to 40 counts/sec, but are typically in the 20 to 30 counts/sec range. Minor spikes of increased counts, which might suggest weathered zones, occur at 20, 24, and 30 m (64, 78, and 115 ft). Neutron logging also correlated well with the boring log. Neutron counts range from approximately 750 to 1,750 counts/sec in the upper 4.6 m (15 ft), as would be expected in a high moisture clay and increased 4.6 to 6.1 m (15 to 20 ft) as the subsurface material becomes more dense (as would be expected in a less porous limestone). From 6.7 to 30.2 m (22 to 99 ft), neutron counts range from approximately 1,750 to 3,000 counts/sec. At 30.2 m (99 ft), a sharp drop in neutron counts occurs. From 30.5 to 36.6 m (100 to 120 ft, neutron counts range from approximately 600 to 1,500 counts/sec, suggesting a porous zone.

Core analysis from 8.5 m to a total depth of 36.6 m (28 to 120 ft), confirmed the Boone Formation, and basal St. Joe Limestone member. Zones of thin bedding that appeared to be mechanically broken by the drilling process were observed, but no significant karst voids were identified in core recovery or by driller observation. The primary karst feature identified was the epikarst zone noted between 4.2 and 8.5 m (13.8 and 28.0 ft).

Response 2

Dye-trace Studies Conducted in Big Creek Watershed

A series of dye-trace studies in the monitored Big Creek Watershed were conducted by Drs. Kosic and Brahana in 2014 after the C&H Farm became operational. As mentioned in our plan of work, in order to conserve resources, we chose not to conducted additional dye-trace studies and refer to Kosic (2019) and Brahana et al. (2016). Additionally, we were not able to devise an appropriate dye-trace study that mimicked the surface application of slurry to our monitored, permitted fields.

A general map of area geology and dye-trace studies conducted in the Big Creek Watershed is shown in Figure 3 (from Brahana et al., 2016). Additionally, we were not able to devise an appropriate dye-trace study that would simulate potential for movement with surface applied slurry.

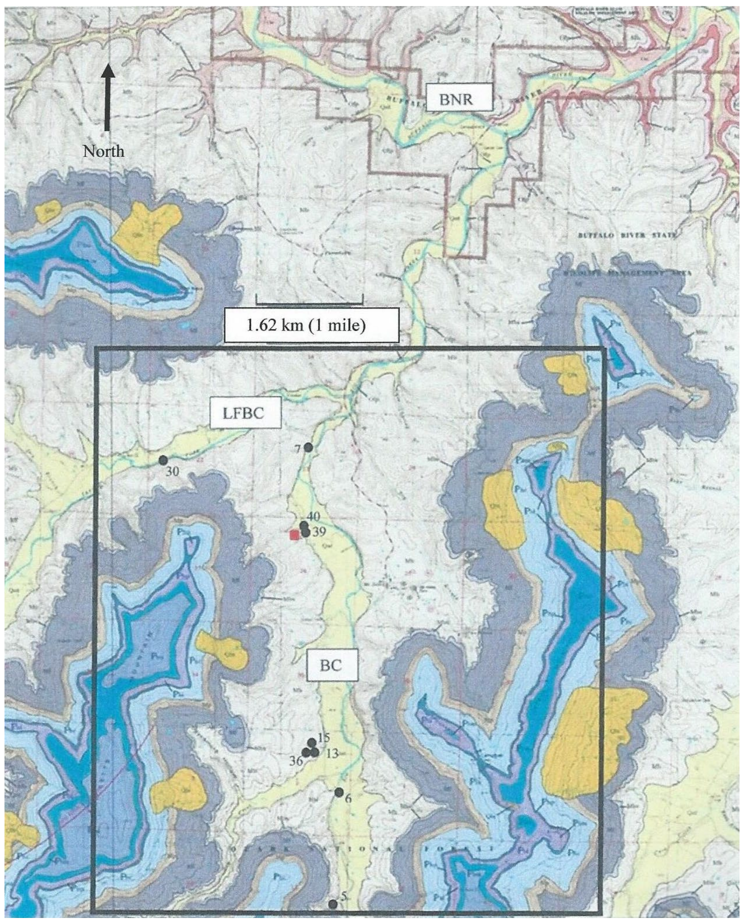

Figure 1. Geologic map of the study area, indicating the extent of karst where the Boone Formation (light grey color) occurs at land surface. BNR is Buffalo National River; BC is Big Creek and LFBC is Left Fork of Big Creek. The CAFO is shown by the red square, and the spreading fields for waste mostly lie between 7 & 6 on the west side of Big Creek. The study area is outlined by the black rectangle. Numbers 5 & 30 are the furthest extent of groundwater tracing in the study area from dye input at 36, which has an altitude greater than any of the dye-receiving sites. Map reproduced from Brahana et al. (2016) with the permission of Dr. Brahana.

Kosic (2019) used three dyes fluorescein, rhodamine, eosin and to trace groundwater flow paths in April and August 2014 at several sites in the Big Creek Watershed (Table 1). Dye injection points were chosen based on the hydrogeological setting of the area, direct accessibility to the aquifer, and proximity to the C&H Farm production area and its spray fields (Kosic, 2019 and Kosic et al., 2015). Dye receptors were placed at selected monitoring points in private or National Park Service springs, wells and caves. Several monitoring points were also located in the stream beds of Big Creek and Buffalo National River.

Sampling utilized active charcoal dye receptors, which enabled the time-integrated monitoring of a large number of locations. For example, the eosin dye was injected in a field adjacent to Field 12 monitored by BCRET. Here 3 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 later an 89 mm rainfall 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. The resulting eluent was analyzed after 5 hours, using a scanning Shimadzu spectrophotoflurimeter at the University of Arkansas. The resulting detects in springs, caves, and creeks in the Big Creek Watershed for fluorescein, rhodamine, and eosin are shown in Figures 4, 5, and 6, respectively. Arrows on these figures assume straight-line groundwater flow directions between injection and detection points.

The dye-trace studies of Kosic (2019) and Kosic et al. (2015) demonstrate the high velocity with which groundwater flows can occur in the Boone karst setting of Big Creek Watershed (Table 1 and Figures 4, 5, and 6). It was evident from the eosin-dye injection that subsurface flows traversed surface drainage basins, with detects from the field adjacent to BC12 occurring in Left Fork sub-watershed (Figure 6). The overall conclusions of the dye-trace studies of Kosic (2019) demonstrate the complexity of subsurface flows can be in the karst system of in this area of the Boone formation.

Table 1 . Qualitative trace tests conducted in 2014 in Big Creek Watershed and adjacent watersheds using three fluorescent dyes; fluorescein (F), rhodamine (R), eosin (E). Information adapted from Kosic (2019) with permission from Dr. K. Kosic.

Injection date	Site	Injection point	Geology	Tracer material	Groundwater flow	Detection comments
April 22	BS-39	Dug well, perched	Lower cherty Boone epikarst	F	Moderate: velocity about 600 m/day	Multiple visual and instrumental confirmation
April 27	BS-78	Sinking stream	Alluvial gravel over middle Boone	R	Low velocity, not calculated	No observable confirmation, likely perched
May 12	BS-36	Dug well, perched on chert	Middle cherty Boone	E	Very high velocity, about 800 m/day	Multiple instrumental confirmation; cross-basin and cross formation flow; radial flow
July 10	BS-71	Swallet, perched	Upper Boone	R	Moderate velocity, about 700 m/day	Visual and instrumental confirmation; surface flow part of the way
August 5	BS-36	Dug well, perched on chert	Middle cherty Boone	F	Very low, no velocity	No observable confirmation; dye sunk to lower reservoir, ,which was stagnant with no flow

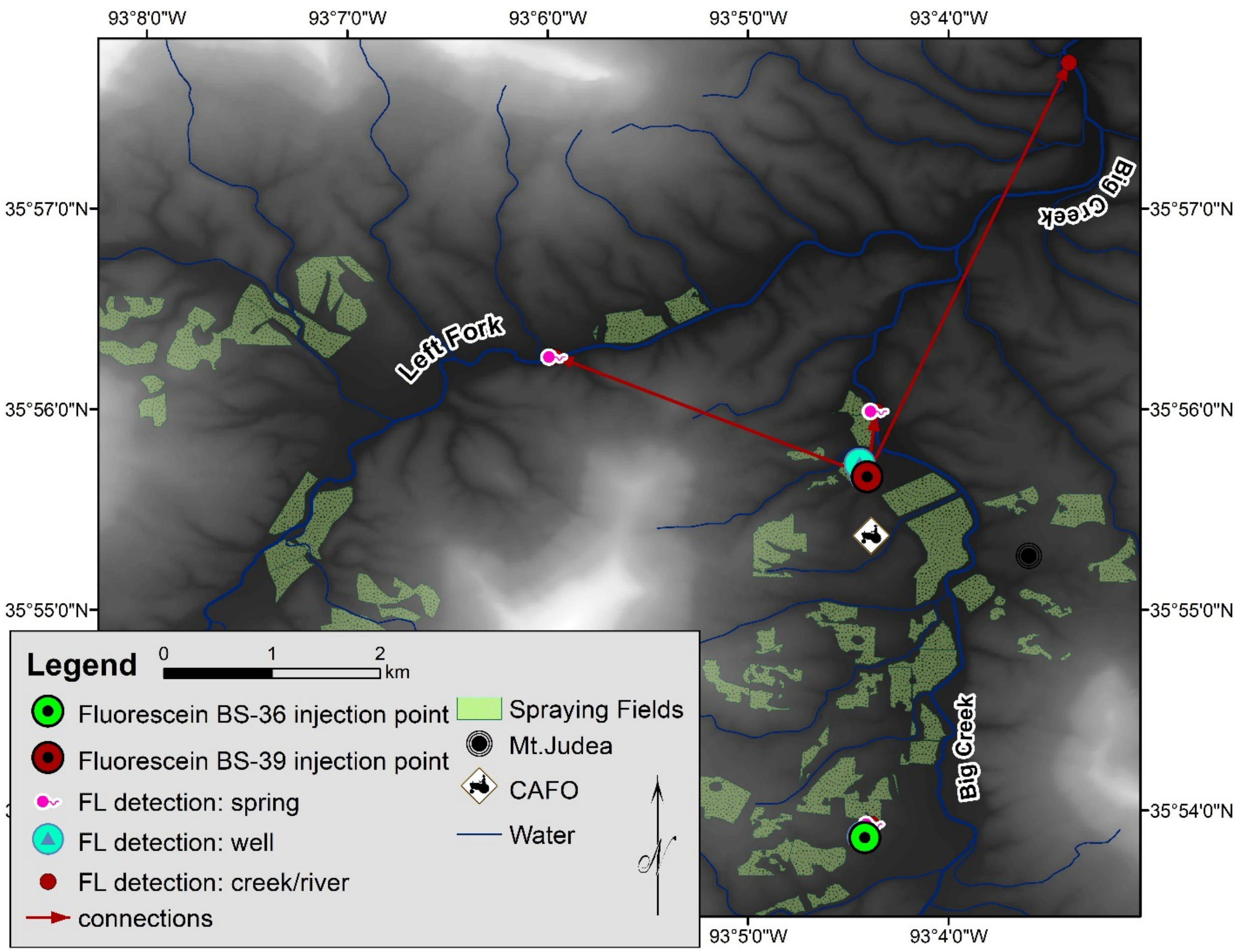

Figure 2. Map of dye-tracing results for fluorescein injections on April 22, 2014. No positive detects were obtained for tracing performed on August 5, 2014. From Kosic (2019) reproduced with permission of Dr. K. Kosic.

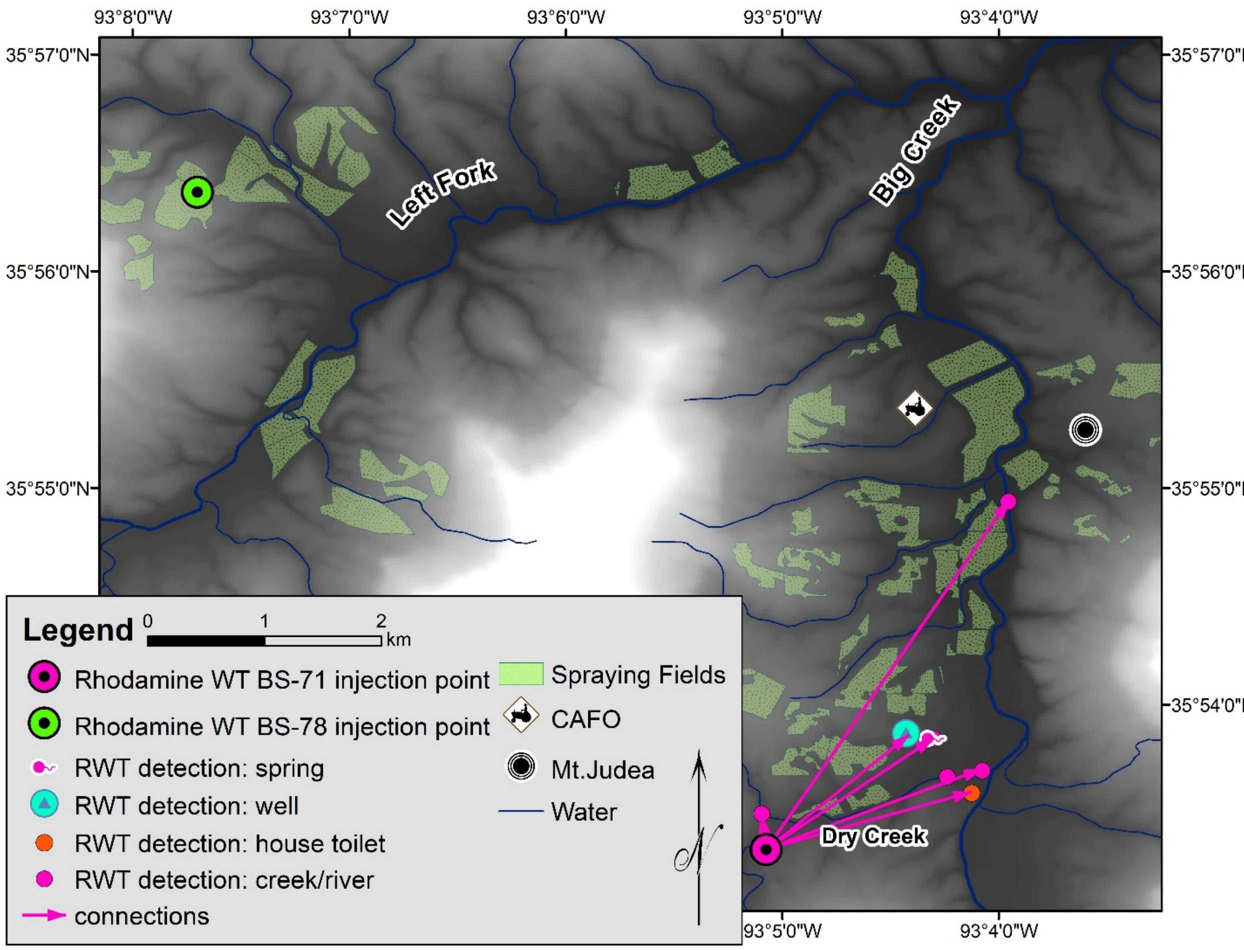

Figure 3. Map of dye-tracing results for rhodamine injections on July 10, 2014. No positive detects were obtained for tracing performed on April 27, 2014. From Kosic (2019) reproduced with permission of Dr. K. Kosic.

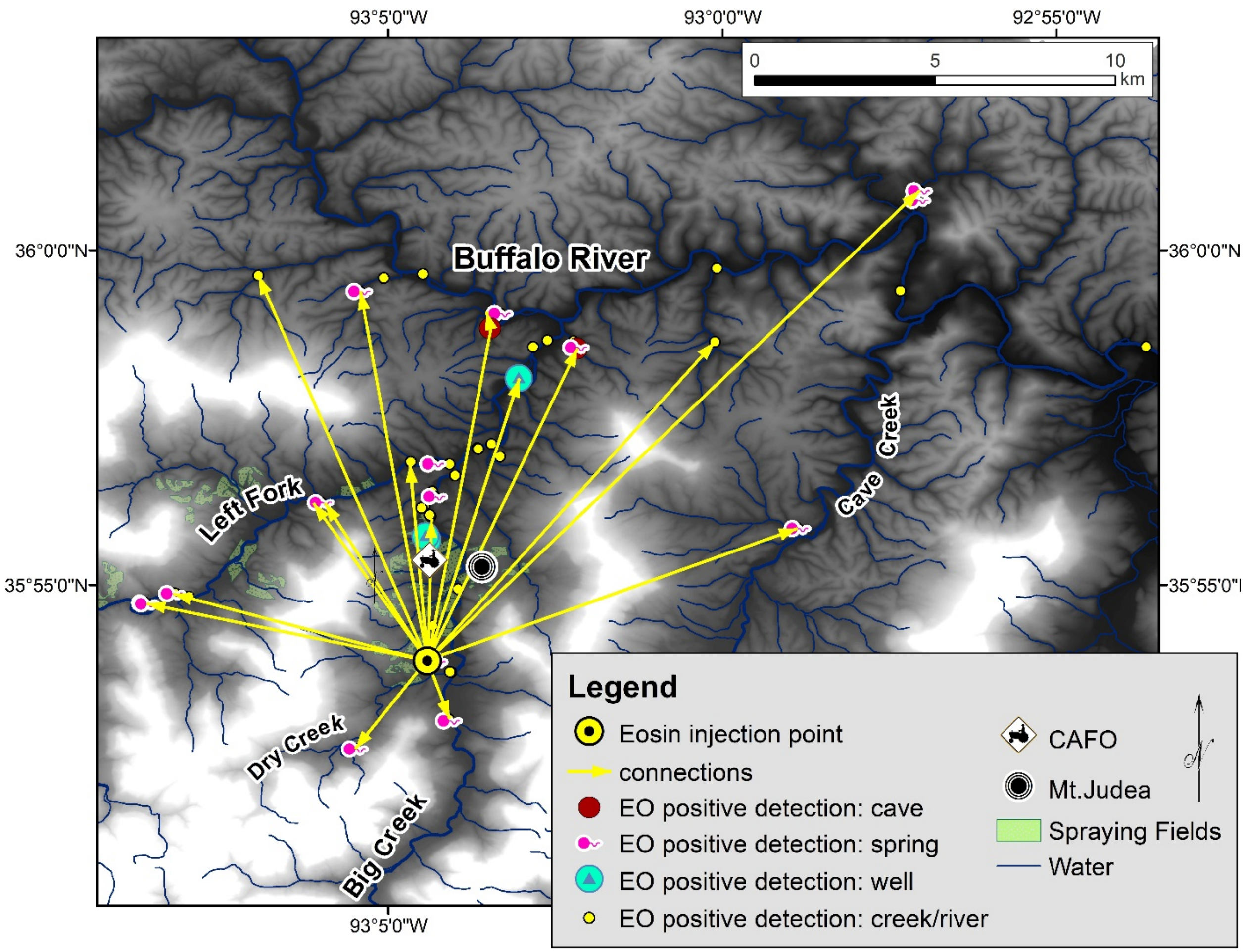

Figure 4. Map of dye-tracing results for eoscin injections on May 12, 2014. From Kosic (2019) reproduced with permission of Dr. K. Kosic.

Response 3

APPENDIX J: MANURE TREATMENT

Calcium Enhanced Precipitation of Swine Manure: Supporting Concepts and Lab Scale Trial Findings

Summary

1. A mixture of locally sourced lime and hydrated lime amendments, decreased water-soluble P concentrations of the liquid and precipitate or solids fraction of holding pond slurry. Use of an off-the-shelf granular agricultural grade lime product, had no consistent effect on water-soluble P concentration.
2. Hydrated lime amendments tended to enhance the effectiveness of separation of solids from liquid in manure slurry, as related to increasing the percent solids and P concentration of the separated solids. In principle, this would be beneficial for transport of P off the generating farm.
3. Hydrated lime amendments appeared to increase manure slurry pH sufficiently to increase N loss via ammonia volatilization. If manure slurry was viewed as a N fertilizer, the increased loss of N would not be desirable. If air quality was a concern, the increased loss of N would not be desirable.
4. Use of granular agricultural grade lime at the rates used, had no consistent effect on the solids separation process for manure slurry from the C&H Farm.
5. Despite certain potential benefits of lime amendment providing options available to the Farm to manage the slurry in compliance with nutrient management planning requirements, all amendments presented economic, logistical, and labor constraints severely limit their viability for adoption.

Background

An important consideration of liquid manure solids separation is the fate and economic value of the resulting liquid and solids fractions. The desired properties of the separated fractions, operator preferences, regulatory considerations, and economics should determine the type and degree of treatment.

Research has shown that amendment with aluminum, iron, and calcium compounds can increase the concentration of phosphorus (P) and manure solids into a lower moisture manure product. Such chemical amendment, preferentially separates the manure into a P-rich portion for transport to more distant locations for utilization, and a P-poor portion for use closer to the farm. In contrast to aluminum and iron, calcium in the form of $CaCO_3$ (Ag lime) or $Ca(OH)_2$ (Hydrated Lime) are often uses as soil amendments for beneficial soil pH modification. In addition, manure amendment with calcium compounds should result in calcium phosphate compounds, which are a common source of P fertilizers.

In addition, due to the fact that P is a finite resource, it is desirable to retain P availability in manure solids for beneficial use, where P is needed for optimal crop production. In the area of alternative manure solids usage via thermal energy conversion (gasification), there is interest on the effects of calcium on energy conversion and bio-char production.

For this reason, we investigated the effectiveness of calcium (Ca) binding with manure P to enhanced natural settling of manure solids. Depending on the chemical and physical properties of the settled solids, the necessary mechanical and structural components of a manure separation system could be designed to meet the nutrient and transportation needs, and hopefully economic constraints of the farm enterprise.

A guiding concept any manure treatment technology is to generate a by-product that has value as a fertilizer, can be transported large distances (in this case, out of the Buffalo River Watershed), or provides a farmer with options to match manure applications to pasture needs and nutrient offtake. A direct benefit of such treatment technology would be to minimize nutrient accumulations in soil beyond optimal levels for pasture / crop production and thereby reducing the potential for nutrient runoff. In addition, because P is a finite resource, it is desirable to retain P in manure for beneficial use, where needed for optimal pasture / crop production.

For this reason, we investigated the effectiveness of calcium (Ca) binding with manure P enhanced by natural settling of manure solids. In principal, after addition of Ca to manure various Ca phosphate compounds are formed, which settle out with manure solids. Depending on the chemical and physical properties of the settled solids, the necessary mechanical and structural components of a manure separation system could be designed to meet the transportation needs and hopefully economic constraints of the farm enterprise.

Methods

Overview

This research treated liquid swine manure with hydrated lime, $Ca(OH)_2$, and agricultural lime, $CaCO_3$. The hydrated lime was added to manure slurry in either a liquid slurry form (30% by weight) or as a dry powder. The agricultural lime was added in the dry fine granular form. The three calcium sources were added to the manure at 3 amendment levels with 3 replicates. A non-amendment control for each chemical source and additional final non-amendment control were also processed. The resulting 31 mixtures were sampled prior to separation via gravity settling in containers lined with 150 micron filter bags. After allowing time for settling, the filter bags were lifted from the containers and allowed to drain prior to collecting leachate from the containers and precipitate from the filter bags. The remaining material was left in the containers and filter bags for storage under ambient conditions but protected from precipitation for 10 days before being sampled again.

Setting Amendment Rates

Due to the variability of swine manure, it was appropriate to set the amendment chemical addition rates on the day of the trail using the manure to be treated in the trail. The 30% (gm/gm) hydrated lime slurry was added at the rate of 0, 10, 20, 30, 40, 60, 80, and 100 ml/l to manure in clear bottles. After mixing and allowing the solids to settle, it was determined via visual inspection to set the base line full Ca amendment rate at 50 mL/L of 30% hydrated lime slurry per liter of manure (Figure 1). The corresponding 1/2X rate and 2X rates would be 25 mL/L and 100 mL/L. Stoichiometric calculations determined the equivalent elemental Ca amendment rates for the dry hydrated and agricultural lime as 1/2X, 1X, and 2X rates (Table 1).

Figure 5. Clear test bottles after 30 % (wt/wt) $Ca(OH)_2$ slurry was added to 500 ml of manure at the rates of 0, 10, 20, 30, 40, 60, 80, and 100 mL/L and allowed to settle. Based on both the clarity of the top liquid and settled solids a target rate of 50 mg/L (5%) was select for the chemical amendment trial.

Table 2. Chemical amendment rates based a 5% (mL/mL) target mixture rate of Ca hydroxide to manure slurry and 17 liters of manure slurry.

Chemical and form	Amendment rate			
	O x Target rate	½ x Target rate	1 x Target rate	2 x Target rate
Ca Hydroxide, 30% (gm/gm) slurry	0 mL	425 mL	850 mL	1700 mL
Ca Hydroxide, dry powder	O gm	154 gm	307 gm	614 gm
Ca Carbonate, dry fine granular	O gm	207 gm	415 gm	830 gm

Collection of Manure Slurry

An on-farm system to chemically and physically treat manure slurry would likely take place the manure slurry as it is discharged from the barns and before it enters holding Pond 1. Thus, a manure slurry collection and mixing system was designed for this chemical trial (Supplemental Figure S1). On the day of the trial (September 4, 2014), a pump was used to capture a portion of the manure discharged from the barns into holding Pond 1 as one of the manure pits was being drained. The captured manure was pumped into a 360-gallon tank (i.e., 1,363 L) via two mixing nozzles to ensure uniform mixing of the manure slurry in the tank (see Figure S2 for nozzle configuration).

Once this tank was filled, a discharge valve was opened to drain a portion of the collected manure into holding Pond 1. By adjusting the discharge valve and pump throttle, the manure flow rate into and out of the tank were balanced resulting in the tank manure volume remaining fixed (Figure S1). This balanced-flow process continued until the manure pit in the barn had been drained and a composite sample of all the manure slurry from the drained pit was collected. After manure was collected was completed, valves were closed so that the pump continually mixed manure slurry in the tank for the remainder of the trial (Figure S1).

Amendment of Manure Slurry

Using one of the tank's valves, manure was drained from the tank into 5-gallon buckets in 17-liter volumes as needed for the chemical amendment. For each chemical amendment, rate, and replication combination 17 L of manure slurry was drained from the tank into a bucket (Table 2). The desired amount of chemical was added and mixed into the manure using a battery-powered drill with attached stirring paddle. Before any settling could occur, the mixture was poured into a second bucket lined with a 150 micron filter bag (see Figure S3). A subsample was collected as it was poured into the lined bucket. At this time, the lined bucket was set aside and the suspended solids allowed time to settle.

After settling each filter bag was lifted from its bucket and allowed to drain into the bucket for 3 minutes. Samples of the concentrated manure slurry (precipitate) in the filter bag and the leachate from the bucket were sampled for analysis. This process was repeated until three replicates of each chemical/rate combination in Supplemental Table S1 had been prepared.

Table 3. Chemical additions associated with the various amendment rates.

Chemical addition per liter of liquid manure					
Amendment	Rate	Water mass [1]	Wet mass [1]	Dry mass [2]	Ca mass [3]
		mL/L	gm/L	gm/L	gm/L
Manure only[4]	0.0	-	1000	-	-
$Ca(OH)_2$ slurry	1/2X	25	30.10	9.03	4.89

(LS)	1X	50	60.21	18.06	9.77
	2X	100	120.42	36.13	19.55
$Ca(OH)_2$ (HL)	1/2X	-	9.03	9.03	4.89
	1X	-	18.06	18.06	9.77
	2X	-	36.13	36.13	19.55
$CaCO_3$ (AL)	1/2X	-	12.20	12.20	4.89
	1X	-	24.40	24.40	9.77
	2X	-	48.80	48.80	19.55

[1] Includes mass of water in Lime Slurry. Assumes Hydrated Lime and Ag. Lime Moisture content to be 0% when it might have been in <3% range.

[2] Mass of Ca(OH)2 and CaCO3 only added assuming chemicals 100% pure when there where likely slight levels of impurities.

[3] Mass of Ca added assuming chemicals 100% pure when there where likely various forms of Ca compounds and impurities within the Ag lime used.

[4] In calculations Liquid manure density assumed equal to water as this is standard assumption and assumed %TS would be <5%. The measured %TS was just under 2%.

Once the manure from the filter bags were sampled, tripods were used to suspend them above their respective bucket (Figure S4). The combination of buckets and tripods were placed under a fenced in awning, which allowed for full air movement while protecting them from rainfall and damage from animals.

After 5 days, the filter bags were dry enough that they were placed on tables to reduce the potential for wind damage and rewetting of the bags. On September 15, 2014, a total of 10 days after treatment, the manure slurry mixture in the filter bags and leachate in the 5-gallon buckets was mixed and sampled for analysis. The remaining precipitate from the filter bags was delivered for energy content analysis.

A total of 93 samples were collected the day the manure was treated, with an additional 62 samples collected after storage for 10 days. Each sample was analyzed for total solids (TS), pH, total N (N), ammonium-N (NH_4-N), nitrate-N (NO_3-N), total P (P), total potassium (K), total Ca (Ca), and water extractable P (WEP)

Preliminary Findings

Preliminary assessment of the three lime products to act as a flocculation agent to enhance precipitation of slurry solids and to sequester P in a less available form are detailed in Supplementary Figures S5 through S16. With the exception of nitrate-N, the coefficient of variation associated with the control samples prior to filtering was 6% or less. These low values, coupled with the fact that the control samples were collected over the course of the sampling day, indicate that a homogenous manure mixture was maintained.

Amendment of manure slurry with each of the three lime products increased flocculation of solids (Figure 2). Hydrated lime was most effective, followed by Ag lime and locally sourced lime.

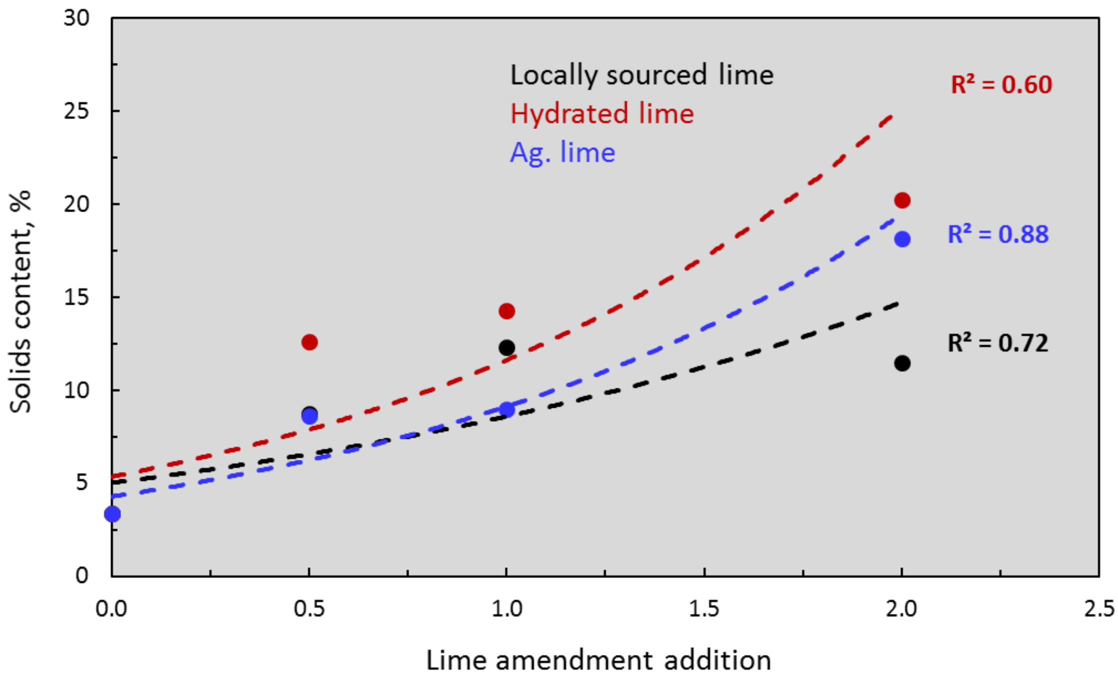

Figure 6. Relationship between solids content of the precipitate three hours after addition of three lime amendments, where the target amendment (i.e., 1.0) is equivalent to 5% volume basis (i.e., 50 mL lime to 1000 mL slurry). Values are average of four replicates.

Addition hydrated lime amendment increased pH of the manure mixture. Higher amendment levels resulted in higher pH levels (Table S2). Addition of the pre-mixed lime slurry was more effective than the same Ca addition of dry lime powder. At the rates added, the Ag lime did not influence the pH of amendment mixture. This may be due in part to the Ag lime rate calculation procedures likely overestimated the Ca concentration in the lime. With increasing amendment rates, total N concentration decreased. In addition to the mass addition-dilution effect mentioned above, the elevated pH levels suggest that ammonia volatilization may be occurring.

Amended Slurry Leachate

Locally sourced lime and hydrated lime were appreciably more efficient at decreasing the water-soluble P concentration of amended slurry leachate, where samples were collected three hours after slurry amendment (Figure 3). In fact, the water-soluble concentration of slurry leachate amended with target levels of locally sourced and hydrated lime (i.e., 5% by volume) were just a respective 7 and 33% of control concentrations. The agricultural grade lime amendment only decreased water-soluble P concentration 41% compared to the control (Figure 3 and Table S2).

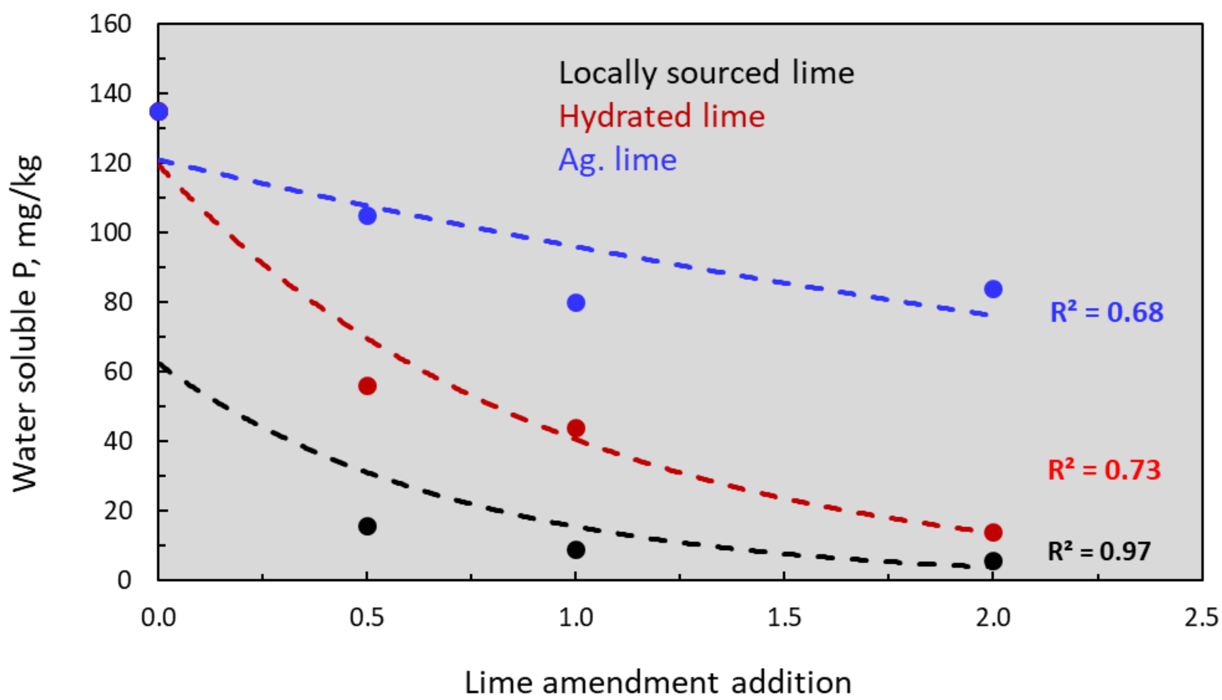

Figure 7. Relationship between water extractable P concentrations of leachate three hours after addition of three lime amendments, where the target amendment (i.e., 1.0) is equivalent to 5% volume basis (i.e., 50 mL lime to 1000 mL slurry). Values are average of four replicates.

Amended Slurry Precipitate

The precipitated material remaining after liquid removal by filtration, were also affected differentially by lime amendments. Figure 4 shows locally sourced and hydrated lime decreased water soluble P concentration of the precipitate material (target amendment was 6 and 4% of the control, respectively), while agricultural grade lime actually increased water soluble P concentration nearly three-fold. Why agricultural lime increased water soluble P concentration is unknown at the present time and further research is needed.

The separation process resulted in higher total P concentrations in separated slurry solids than original pre-treatment mixture and separated leachate. There was a statistically significant decrease in total P concentration as hydrated lime amendment rates increased (Table S2). Because of the total P increase, leachate had the highest water-soluble to total P ratio, with the separated solids the lowest. This effect is likely partially the result of increasing mass additions associated with increasing amendment rates.

Separation increase the total N to total P ratio in the leachate, while decreasing the ratio in the solids, with the hydrated lime amendments enhancing this trend (Table S2). However, the total N to total P ratios also decreased during storage, being more pronounced with the hydrated lime amendment. This is likely the result in ammonium-N loss during storage.

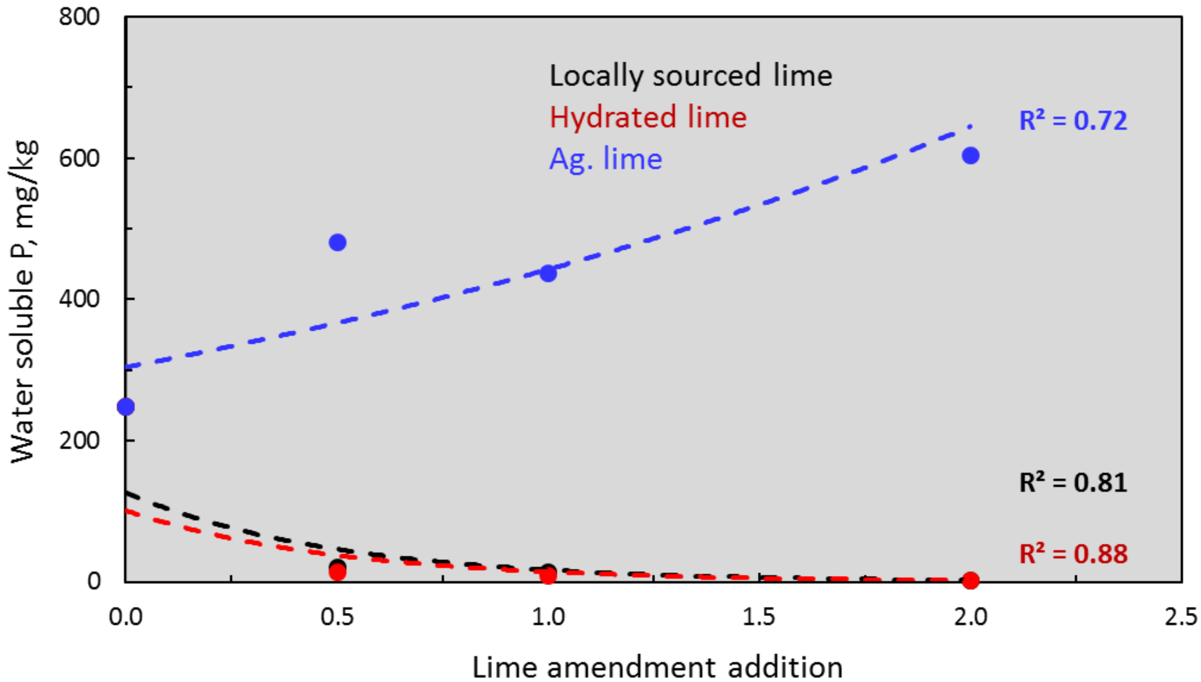

Figure 8. Relationship between water extractable P concentrations of the precipitate three hours after addition of three lime amendments, where the target amendment (i.e., 1.0) is equivalent to 5% volume basis (i.e., 50 mL lime to 1000 mL slurry). Values are average of four replicates.

Conclusions

The general findings were:

1. Hydrated lime amendments tended to enhance the manure solids separation effectiveness as related to increasing the % Solids and P concentration of the separated solids. In principle, this would be beneficial for transport of P off the generating farm.
2. Hydrated lime amendments also increased the manure pH enough that N losses via ammonia volatilization seemed to be increased. If the manure were viewed as a desirable N fertilizer, the increased losses would not be desirable. If air quality were, it atmospheric ammonia emissions would not be desirable.

3. Use of granular agricultural grade lime at the rates used, had no consistent effect on the solids separation process.

In addition to these findings, there are several considerations in the design, financing, and operation of a chemically enhanced gravity separation system. The first is the legal implications. It is generally understood that in Arkansas liquid manures must be applied to land permitted by ADEQ for that purpose. Currently ADEQ's Regulation No 5 provides the only method to remove this requirement is the manure to be composted. Manure solids separation may enable composting but it will not meet the requirements by itself. As a result, unless the regulations are revised or reinterpreted, solids separation may facilitate off farm transportation, the manure destination would still be a permitted site. This would likely restrict the potential for off farm sale of the separated manure solids that could conceptually offset increase manure management costs.

The second consideration relates to the procurement and management of the chemical amendments. In addition to the purchase of the chemicals delivery to, storage on, and metering to the manure must be accomplished. While a formal cost analysis of infrastructure, procurement, and labor cost was not made, it is anticipated that the costs would be greater than the current approach of land application on land within reasonable transport distance to the farm.

The increased N losses due to ammonia valorization would also reduce the fertilizer value of the remaining liquids that would be land applied on the generating farm. It would also increase concerns regarding atmospheric ammonia emissions. Addressing these concerns would require additional expenditures related to infrastructure and management costs.

Given these considerations, it is more practical and sustainable from an individual farm perspective to not invest in enhanced gravity separation via hydrated lime amendments. Rather the practice of local land application of some combination of manure top water, higher solids content bottom water, or an agitated mixture is more sustainable. However, with this approach sufficient land needs to be available to allow manure to be applied at rates that maintain soil test P levels near agronomic levels.

Despite the potential benefits of lime treatment providing options to manage slurry in compliance with nutrient management planning requirements, all presented economic, logistical, labor, and legal constraints severely limit their viability for adoption.

Response 4

Karst Features in the Buffalo River and Big Creek Watersheds

Turner et al. (2016) recently mapped karst features of the Ozark Physiographic Province, northern Arkansas. Those features mapped in the Buffalo River and Big Creek Watersheds are presented in Figure 7. The level of resolution of mapped features is too coarse to identify known observed surficial karst features on fields permitted to receive slurry from the C&H Farm.

Although on-farm nutrient management planning occurs at the field scale, there is a lack of consistent and well-maintained GIS databases of karst features and geologic mapping at this scale. As an example, in Arkansas, the AGS topographic-scale geologic mapping (which includes an inventory of karst features), usually maps 1- 3 quads a year; other states map at a similar rate. Thus, NMP development and risk assessment at a State level (where policy is made) would be greatly aided by consistent karst feature databases and geologic mapping.

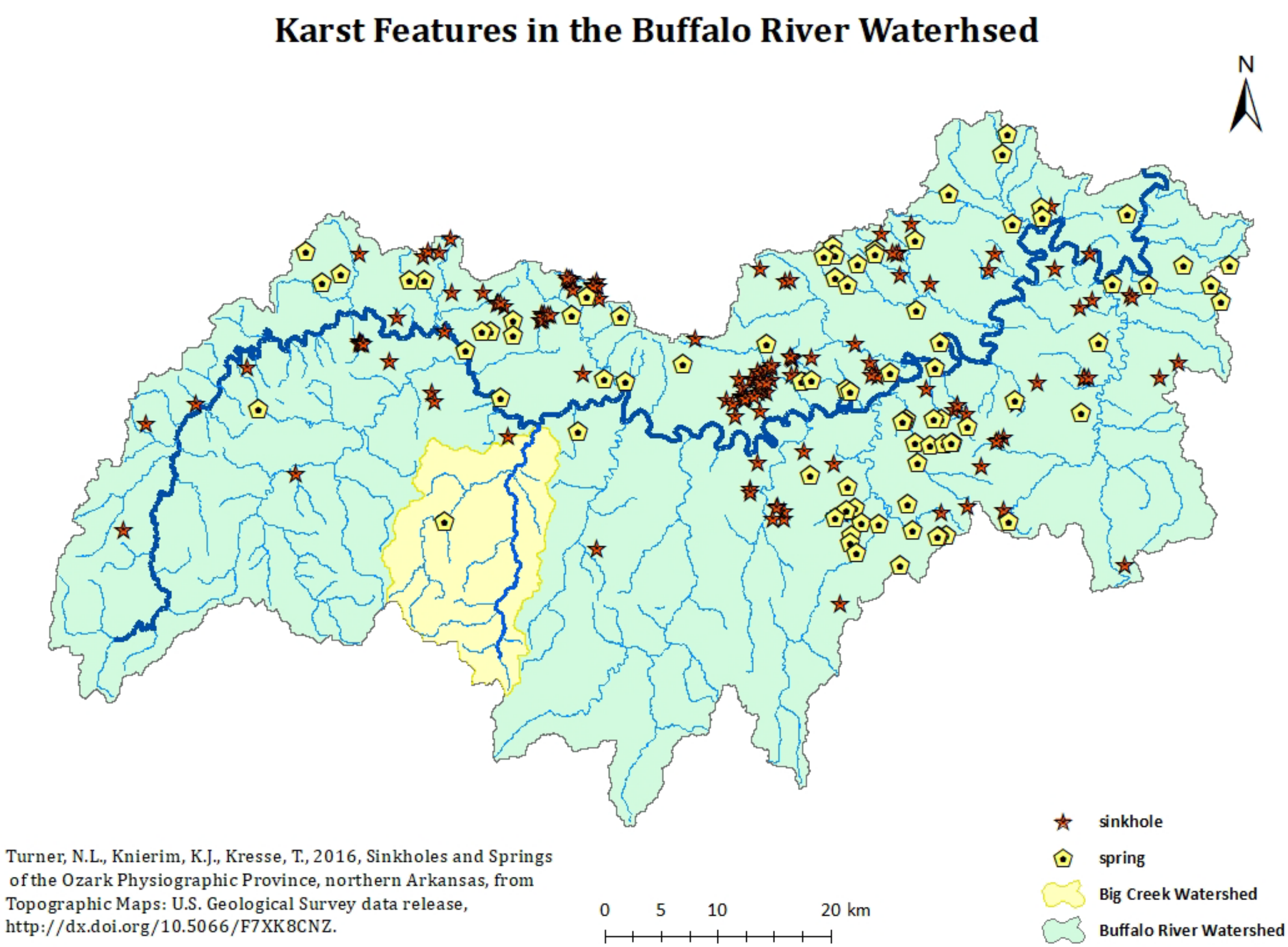

Figure 7. Karst features in the Buffalo River Watershed, derived from Turner et al. (2016).

REVIEW PANEL CURRICULUM VITAE

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EDUCATION:

2000 Ph.D., Environmental Science, University of Virginia, Charlottesville, VA

1994 B.S., Environmental Studies, State University of New York at Buffalo

PROFESSIONAL EXPERIENCE

2004-present Research Hydrologist (GS-15), USDA-Agricultural Research Service, Bowling Green, KY 42101.

2014-present Adjunct Faculty, Department of Plant and Soil Sciences, University of Kentucky, Lexington, KY 40546

2013-present Adjunct Faculty, Department of Biosystems and Agricultural Engineering, University of Kentucky, Lexington, KY 40546

2012-present Adjunct Faculty, Department of Geology and Geography, Western Kentucky University, Bowling Green, KY 42101

2001-2004 Assistant Professor of Watershed Hydrology, Department of Natural Resources,

University of New Hampshire, Durham, NH 03824

1999-2000 Post-Doctoral Research Associate, School of Forestry and Environmental Studies, Yale University, New Haven, CT 06511

HONORS AND AWARDS:

Elected Fellow of the American Society of Agronomy (2017), Elected Fellow of the Soil Science Society of America (2016), Outstanding Associate Editor - Journal of Environmental Quality (2013), Certificate of Merit Research Award (USDA, 2007-2015), Faculty Summer Fellowship (UNH, 2003), Maury Environmental Sciences Prize (1999), Graduate Year Dissertation Fellowship (1998-1999), DuPont Fellowship (1997-1998), Governor's Fellowship (1997-1998), Academic Enhancement Fellowship (1996-1998), Outstanding First Year Graduate Student in

Hydrology (1995), Awarded Student Research Participant Fellowship by the Oak Ridge Institute for Science and Education (1993)

PROFESSIONAL ACTIVITIES

Committees

Member, Fellows Committee, Soil Science Society of America (2018).

Invited Member, Scientific Advisory Committee (SAC) for the 4th International Interdisciplinary Conference on Land Use and Water Quality (Aarhus, Denmark), 2018.

Invited Member, Scientific Advisory Committee (SAC) for the 3rd and 4th International Interdisciplinary Conference on Land Use and Water Quality (The Hague, the Netherlands; Aarhus, Denmark), 2017 and 2019.

Invited Member, Scientific Advisory Committee (SAC) for the 4th International Interdisciplinary Conference on Land Use and Water Quality (The Hague, the Netherlands), 2017.

Invited Member, Review panel for the NRCS Stewardship Tool for Environmental Performance (2015).

Elected Vice-Chair and Chair, Southern Research Extension-Research Activity Group 17 (SERA17; 2014-2015).

Elected Vice-leader and Leader, Biochar Community of the American Society of Agronomy (2014-2015).

Member, Methods of Soil Analysis Subcommittee of the Soil Science Society of America (2014-present).

Invited Member, Expert Review Panel for the University of Arkansas Division of Agriculture regarding monitoring efforts on the Buffalo River (2014).

Member and Chair, Environmental Quality Research Award Committee (A447) of the American Society of Agronomy (2012-2015).

Member, Presentation Contest Committee (A449.6) of the American Society of Agronomy (2012-2015).

Member, Emil Truog Soil Science Award Committee of the Soil Science Society of America (2012-2015).

Invited Member, SERA-17 Workgroup to establish recommendations for USDA-NRCS on how to properly evaluate phosphorus indices (2011-2013).

Invited Member, Kentucky 590 Nutrient Management Standard revision committee (2012-2013).

Invited Member, Pathogen Team for Livestock Poultry Extension Website (2011-present).

Invited Member, SERA-17 Working Group for making recommendations to USDA-NRCS on revising their 590 Nutrient Management Standard (2010-2011).

Publication and proposal reviewer

Associate Editor, *Journal of Environmental Quality* (2009-2015)

Guest Associate Editor for Special Section of *Journal of Environmental Quality* entitled “Phosphorus Fate, Management, and Modeling in Artificially Drained Systems” (2014- 2015).

Guest Associate Editor for Special Section of *Journal of Environmental Quality* entitled “Phosphorus Fate, Management, and Modeling in Artificially Drained Systems” (2014- 2015).

Ad hoc journal reviewer for: *Water Resources Research, Environmental Science and Technology, Applied and Environmental Microbiology, Ground Water, Journal of Environmental Quality, Advances in Water*

Resources, Journal of Contaminant Hydrology, Journal of Hydrologic Engineering, Vadose Zone Journal, Soil Science, Soil Science Society of America Journal. (2001-present)

Review panel member for AFRI Renewable Energy Natural Resources and Environment (2013).

Reviewer of research proposals submitted to the New Hampshire Water Resources Research Center (2007) and the Wisconsin Water Resources Research Center (2012).

Reviewed research proposals for the National Science Foundation (2002, 2003, and 2009).

Served as a member of USDA-ARS research position evaluation system (RPES) panel; reviewer for OSQR Proposals, CRIS, and NP 216 project plans.

Reviewed online course on watershed modeling for the American Water Resources Association (2002).

Memberships

American Society of Agronomy (ASA), Soil Science Society of America (SSSA), Southern Extension Research Activity-17 (SERA-17), Kentucky Agricultural Water Authority.

Sessions Organized at Professional Meetings

Co-organized and co-presided over the following sessions and symposia at the 2015 Tri-Societies Annual Meeting: Novel and Value-Added Uses of Biochar (symposium); A Critical Assessment of Phosphorus Reduction Goals and Mitigation Strategies (symposium); Fate and Transport of Agrochemicals, Microbes, and Nutrients in Biochar-Amended Soils; and Agronomic, Environmental, and Industrial Uses of Biochar: I & II (2015)

Co-organized and co-presided over symposium on the fate and transport of phosphorus in artificially-drained fields at the annual ASA/SSSA meeting (2013).

Invited moderator of symposium entitled **"100th Anniversary of the Langmuir Equation, 1916-2016"** at the Soil Science Society of America annual meeting, Phoenix, AZ, 2016.

Invited session chair 3rd International Interdisciplinary Conference on Land Use and Water Quality (The Hague, the Netherlands), 2017.

Invited session chair 4th International Interdisciplinary Conference on Land Use and Water Quality (Aarhus, Denmark), 2019.

University Activities

Undergraduate Coordinator of Water Resource Management Program at University of New Hampshire (2002-2004).

Program Coordinator for Water Resource Management minor at University of New Hampshire (2001-2004).

Taught a general education course entitled Freshwater Resources and developed three new courses entitled Watershed Hydrology (undergraduate), Contaminant Hydrology (graduate), and Watershed Modeling (graduate) (2001-2004).

Developed online course in forest hydrology for the University of Massachusetts (2004).

Guest Lecturer on transport processes for hydrology courses at Western Kentucky University (2012-present).

Graduate Student Theses Advised

Vanderhoff, S. 2011. Multiple Storm Event Impacts on Epikarst Storage and Transport of Organic Soil Amendments in South-central Kentucky. Masters Thesis, Western Kentucky University, Bowling Green, KY.

Ham, B. 2009. Using conservative and biological tracers to better understand the transport of agricultural contaminants from soil water through the epikarstic zone. Masters Thesis, Western Kentucky University, Bowling Green, KY.

Clarner, P. 2004. Masters Thesis, University of New Hampshire, Durham, NH.

*Strauss, J. 2004. Biological effects on tailing of bacteria from laboratory columns. Masters Thesis, University of New Hampshire, Durham, NH.

Bjerklie, D. 2004. An approach to estimating river discharge from space. PhD Thesis, University of New Hampshire, Durham, NH.

Faivre, E. 2004. Geomorphic and biological index for assessing health of forest streams. Masters Thesis, University of New Hampshire, Durham, NH.

Blumberg, J.E. 2002. Instream nutrient dynamics in five first order tributaries in the Lamprey River watershed, New Hampshire. Masters Thesis, University of New Hampshire, Durham, NH.

O'Neill, D.T. 2003. Bench-level study of MTBE remediation in soils by chemical oxidation as measured by a convenient headspace analysis method. Masters Thesis, University of New Hampshire, Durham, NH.

*Bromley, J.M. 2003. Evidence for the resuscitation of chlorine-induced viable but nonculturable *Escherichia coli* in estuarine environments. Masters Thesis, University of New Hampshire, Durham, NH.

*Served as major advisor

FUNDING:

2017-2019. August T Larsson Guest Researcher Programme, Swedish University of Agricultural Sciences. Field scale modeling of phosphorus fate and transport in soils. Travel and per diem expenses for annual (3 years) 2-month visit to Sweden. $ 30,000.

2016. Organization of Economic and Co-operation and Development, Co-operative Research Programme Research Fellowship. Improving models for describing phosphorus cycling in manure-amended soils. $ 5,500. (PI)

2013-2016. USDA-NRCS Conservation Innovation Grants. Refine and Regionalize Southern Phosphorous Assessment Tools Based on Validation and State Priorities. $563,000 (Co-PI)

2013-2014. National Pork Board. Effect of manure application rate and timing on the leaching and runoff potential of antibiotic resistant bacteria and their associated genes. $34,500. (PI)

2010-2012. USDA-ARS Headquarters Funded Post-Doc. $100,000. (PI)

2003-2005. National Oceanic Atmospheric Association: New methods for estimating evapotranspiration. $65,000. (PI)

2001-2004. US Department of Agriculture, Agricultural Experiment Station: Transport Behavior of E. coli in New Hampshire Aquifer Sediments. $27,000 (PI)

2002-2004. New Hampshire Estuaries Project: Evaluation of Effects of Wastewater Treatment Discharges on Estuarine Water Quality. $35,990 (PI)

2001-2002. New Hampshire Water Resources Research Center: Effect of Surface Coatings and Ionic Strength on Bacterial Removal Rates in Porous Media. $16,335. (PI)

PEER-REVIEWED SCIENTIFIC PUBLICATIONS:

(h-index, 24; number of citations, >1600; source, Scopus)

Bolster, C.H., Baffaut, C., Nelson, N.O., Osmond, D.L., Cabrera, M.L., Ramirez-Avila, J., Sharpley, A.N., Veith, T.L., McFarland, A.M.S., Senaviratne, A.G.M.M.M., Udawatta, R.P., and G.M. Pierzynski. 2019. Development of PLEAD: A database containing event-based runoff phosphorus loadings from agricultural fields. Journal of Environmental Quality. 48: 510-517. 2019.

Bolster, C.H., Brooks, J.P., Cook, K.L. Effect of manure application rate and rainfall timing on the leaching of antibiotic-resistant bacteria and their associated genes. Water, Air, & Soil Pollution. 229:130. 2018.

Bolster, C.H. and Vadas, P.A. Comparison of two methods for calculating the P sorption capacity parameter in soils. Soil Science Society of America Journal. 82: 493-501. 2018.

Ramirez-Avila, J., Radcliffe, D.E., Osmond, D, **Bolster, C.H.**, Sharpley, A.N. Ortega-Achury, S. L., Forsberg, A., and Oldham, J.L. Evaluation of the APEX model to simulate runoff quality from agricultural fields in the southern region of the United States. Journal of Environmental Quality. 46: 1357-1364. 2017.

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Fiorellino, N.M., McGrath, J.M., Vadas, P.A., **Bolster, C.H.**, and Coale, F.J. 2017. Use of annual phosphorus loss estimator (APLE) model to evaluate a phosphorus index. Journal of Environmental Quality. doi:10.2134/jeq2016.05.0203

Forsberg, T.A., D.E. Radcliffe, **C.H. Bolster**, A. Mittelstet, D.E. Storm, and D.L. Osmond. 2017. Evaluation of a quantitative phosphorus transport model for potential improvement of southern phosphorus indices. Journal of Environmental Quality. doi:10.2134/jeq2016.06.0210.

Bolster, C.H., Forsberg, A., Mittelstet, A., Radcliffe, D.E., Storm, D., Ramirez-Avila, J., Sharpley, A.N., and Osmond, D. 2017. Comparing an annual and daily time-step model for predicting field-scale phosphorus loss. Journal of Environmental Quality. DOI:10.2134/jeq2016.04.0159

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Novak, J.M., Ippolito, J.A., Lentz, R.D., Spokas, K.A., **Bolster**, **C. H.,** Sistani, K., Trippe, K.M., Phillips, C.L., and Johnson, M.G. 2016. Scientific investigations of biochars impact on soil health, crop

productivity, microbial transport, and mine spoil reclamation. Bioenergy Research. DOI 10.1007/s12155-016-9720-8

Cook, K.L., Ritchey, E.L., Loughrin, J.H., Haley, M., Sistani, K.R., and **C.H. Bolster**. 2015. Effect of turning frequency and season on composting materials from swine high-rise facilities. Waste Management 39:86-95.

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Kleinman, P.J.A., Smith, D.R., **Bolster, C.H.**, and Z.M. Easton. 2015. Phosphorus fate, management, and modeling in artificially drained systems. Journal of Environmental Quality. 44:460-466.

Bolster, C.H., Horvath, T., Lee, B.D., Mehlhope, S., Higgins, S., and J.A. Delgado. 2014. Development and testing of a new phosphorus index for Kentucky. Journal of Soil and Water Conservation. 69:183-196.

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Osmond, D., Sharpley, A., **Bolster, C.H.**, Cabrera, M., Feagley, S., Lee, B., Mitchell, C., Mylavarapu, R., Oldham, L., Walker, F., and H. Zhang. 2012. Comparing phosphorus indices from twelve southern studies. Journal of Environmental Quality 41:1741-1749.

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Bolster, C.H. A critical evaluation of the Kentucky phosphorus index. 2011. Journal of the Kentucky Academy of Sciences. 72(1):46-58.

Cook, K.L., **Bolster, C.H.**, Ayers, K., and Reynolds, D. 2011. *Escherichia coli* diversity in livestock manures and agriculturally impacted stream waters. Current Microbiology. 63(5):439-449.

Tellinghuisen, J. and **Bolster, C.H.** 2011. Using R^2 to compare least-squares models: When it must fail. Chemometr. Intell. Lab. Syst. 105: 220-222.

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INVITED PRESENTATIONS:

How Much Model Complexity is Needed for Predicting Phosphorus Loss from Agricultural Fields? Department of Plant and Soil Science, University of Kentucky, Lexington, KY, 2018.

Using proper regression methods for fitting the Langmuir model to sorption data. Annual Meeting of the Soil Science Society of America, Phoenix, AZ, 2016.

Two invited presentations and sponsored travel, "Effect of Biochar on the transport of *E. coli* through soil" and "The importance of model uncertainty in predicting field-scale P loss." Department of Soil and Environment, Swedish University of Agricultural Sciences, Uppsala, Sweden, 2015.

Four invited presentations and sponsored travel: "Model Parameter Uncertainty Analysis for an Annual Field-Scale P Loss Model"; "Is *Escherichia Coli* a Good Indicator of the Transport Behavior of *Campylobacter Jejuni* in Groundwater Environments?"; "Diversity in Cell Properties and Transport Behavior among Different Environmental *Escherichia coli* Isolates"; and "Factors affecting transport of bacteria through biochar-amended soils." State Key Laboratory of Agricultural Microbiology, Huazhong Agricultural University Wuhan, China, 2015.

Modifying the Kentucky phosphorus index using published P loss data. Annual meeting of the Southern Extension Research Activity Group-6, Lexington, KY, 2014.

The Kentucky Phosphorus Index: Past, Present, and Future. Plant and Soil Sciences Department, University of Kentucky, 2014.

Factors Controlling the Transport of Bacteria through Soil. Vanderbilt University, Nashville, TN, 2013.

Evaluation of the Kentucky phosphorus index. Department of Geography and Geology, Western Kentucky University, 2011.

Investigations into the transport behavior of *E. coli* and the sorption of phosphorus to soil. Department of Chemical and Environmental Engineering, University of California at Riverside, 2011.

Improving our ability to assess risk of phosphorus from agricultural fields. Department of Agriculture, Western Kentucky University, 2011.

Comparing the Kentucky Phosphorus Index with P loss Calculated with a Process-Based Model. Annual Meeting of the Kentucky Water Resources Research Institute, Lexington, KY, 2011.

Using a Process-Based Model to Evaluate P Indices: An Example Approach. Annual Meeting of the Heartland Regional Water Coordination, Nebraska, NE, 2011.

Methods to Evaluate and Update Current Phosphorus Indices. Annual Meeting of the Southern Extension-Research Activity 17 (SERA-17), Delray Beach, FL., 2011.

Attenuation of *Escherichia Coli* In a Biochar-Amended Soil. 56th Midwest Groundwater Conference, Lexington, KY, 2011.

Using A P Loss Model to Evaluate and Improve P Indices. Annual Meeting of the American Society of Agronomy, San Antonio, TX, 2011.

Revisiting how we determine risk of phosphorus loss from agricultural fields: An evaluation of the KY phosphorus index. Plant and Soil Sciences Department, University of Kentucky, 2011.

E. coli transport variability among twelve isolates. EPA Symposium on Ground Water-borne Infectious Disease Epidemiology, Etiologic Agents and Indicators, Washington, DC, 2009.

Case Study 3: Research at Cave Springs Cavern. Department of Geography and Geology, Western Kentucky University. 2006.

Using numerical approaches in hydrologic studies. USDA-ARS, Bowling Green, KY. 2004.

Effects of Wastewater Discharge on Estuarine Water Quality. New Hampshire Estuaries Conference. New Hampshire Department of Environmental Services. 2003.

Use of a canal-drawdown test to calculate the specific yield of the Biscayne aquifer. Spring Meeting Am. Geophys. Union. 2002.

Hydrological Studies of the Florida Everglades. Department of Earth Sciences, University of New Hampshire. 2002.

Effect of Heterogeneity of Bacterial Transport and Deposition. Department of Natural Resources, University of New Hampshire. 2001.

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Education:

1988 B.S., North Carolina State University, Biological and Agricultural Engineering

Experience:

2019-Present Private Consulting

2018-2019 Interim Director, Animal and Poultry Waste Management Center, North Carolina State University.

Coordinate with faculty, staff, and external partners to carry out the mission and goals of the Center through research and extension programs.

2005-2018 Extension Specialist, Animal Waste Management, Department of Biological and Agricultural Engineering and the Animal and Poultry Waste Management Center, North Carolina State University.

Serve as principal investigator/project manager for externally funded projects related to alternative animal waste management system and nutrient recovery. Provide technical, administrative and outreach support for the College of Agriculture and Life Science's - Animal and Poultry Waste Management Center. Provide Extension and outreach programs to share research based information with swine and poultry producers in North Carolina as well as nationally through participation with the eXtenion, Animal Manure Management Community of Practice.

2000-2005 Assistant Director, National Center for Manure and Animal Waste Management, North Carolina State University.

Planned and coordinated the annual meetings for the multi-state effort as well as managed research and demonstration projects to reduce the environmental impacts of manure management practices. Served as co-editor for a book, "Animal Agriculture and the Environment, National Center for Manure and Animal Waste Management White Papers" which summarized the research and knowledge gaps discovered through the National Center effort. Supervised the on-farm installation, demonstration and evaluation of 3 alternative swine waste treatment technology projects funded under the agreement between the North Carolina Attorney General and Smithfield Foods [Belt System for Manure Removal, "ReCip"-Reciprocating Wetland, and Constructed Wetland for Swine Waste Water Treatment.

1990-2000 Extension Specialist, NC State University

Worked in the area of water quality and animal waste management. Served as project manager and principal investigator for 2 USDA funded water quality demonstration projects to increase producer implementation of best management practices.

1988-1990 Production Superintendent, Plant Engineer, Archer Daniels Midland, Augusta, GA

Memberships in Professional Societies:

American Society of Agricultural Engineers

North Carolina Irrigation Society – President 2004-2005, 2011-2013

Certified – Spray Irrigation Water Pollution Control System Operator, North Carolina

Animal Waste Technical Specialist – Waste Utilization Planning/Nutrient Management

Publication Summary:

Refereed journal Articles	8
Extension publications	4
Conference proceedings, papers, abstracts	64
Book editor	1

Referred Journal Articles

Rice, Mark, Craig Baird, Larry Stikeleather, W. E. Morgan Morrow, Robert Meyer. Carbon dioxide system for on-farm euthanasia of pigs in small groups. *Journal of Swine Health and Production.* 2014; Volume 22, Number 5.

Meyer, R.E., Whitley J.T., Morrow W.E.M., Stikeleather, L.F., Baird, C.L., **Rice, J.M.,** Halbert, B.V., Styles, D.K., Whisnant, C.S. Effect of physical and inhaled euthanasia methods on hormonal measures of stress in pigs. *J Swine Health Prod.* 2013;21(5):261–269.

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Rice, J.M., Caldwell, D.F., Humenik, F.J. Co-Editors "Animal Agriculture and the Environment, National Center for Manure & Animal Waste Management White Papers" ASABE, 776 pp., 2006.

Extension Publications

Rice, J.M., Small-Scale Farmers and the Environment: How to be a Good Steward, Livestock and Poultry Environmental Stewardship Curriculum, 2005.

Westerman, P.W., Shaffer, K.A., **Rice, J.M**. Sludge Survey Methods for Anaerobic Lagoons, North

Carolina Cooperative Extension Service, AGW-639. 2003.

Published Proceedings, Chapters and Abstracts

Rice, J. Mark, M.E. Deerhake, P.R. Peterson, N. Ubaka-Blackmore, A. Wesley. An Air Emissions Assessment Tool for CLEANEAST^{TM} Volunteer Livestock and Poultry Operations. Written for presentation at the 2011 ASABE Annual International Meeting. Louisville, KY. August 9, 2011.

Schaffner, Karen, M. Deerhake, **M. Rice**, N. Ubaka-Blackmore, A. Wesley, P.R. Peterson and R. Nuelicht. CLEANEAST^{TM} Project: Performance of a Voluntary Approach to Environmental Protection at Livestock and Poultry Operations Written for presentation at the 2011 ASABE Annual International Meeting, Louisville, KY. August 9, 2011.

Liehr, S.K. J.J. Classen, J.J. Humenik, C Baird**, J.M. Rice**. Ammonia Recovery from Swine Belt Separated Liquid. Written for presentation at the 2006 ASABE Annual International Meeting Sponsored by ASABE Portland Convention Center Portland, Oregon 9 - 12 July 2006.

Boyette, M.D., T. Bilderback, S.L. Warren, J. Macialek, C. Baird, **J.M. Rice**, S. Liehr and F.J. Humenik. Composting anaerobic swine lagoon sludge and cotton field residue to produce a value-added product. Proc. CD 2005 Animal Waste Management Symposium: The Development of Alternative Technologies for the Processing and Use of Animal Waste, N.C. State Univ. Raleigh, NC. Poster No. 11. 2005.

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Rice, J.M., W.G. Eddins, P.G. Hunt, J.S. Hill, D.M. Rashash. Design and implementation of a full-scale, on-farm constructed wetland for treating swine wastewater. Int. Proceedings 7th International Conference on Wetland Systems for Water Pollution Control Univ. of Florida, p. 1484. 2001.

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EDUCATION

The Ohio State University	Agronomy	B.Sc.	1977
The Ohio State University	Soil Science	M.Sc.	1980
The University of Guelph	Soil Science	Ph.D.	1986 (With Distinction)

PROFESSIONAL EXPERIENCE

2012-2018 Research Soil Scientist USDA - Agricultural Research Service, National Laboratory for Agriculture and the Environment, Ames, IA

1986-2012 Research Soil Scientist, USDA - Agricultural Research Service, North Appalachian Experimental Watershed, Coshocton. OH

PROFESSIONAL ACTIVITIES AND AWARDS

- Editorial Board – *Journal of Applied Soil Ecology* 2003-2018
- Associate Editor – *Journal of Environmental Quality* 1996-2001
- Fellow – *American Society of Agronomy* (2012), *Soil Science Society of America* (2012)
- Conservation Research Award – *Soil and Water Conservation Society* (2011)
- No-Till Researcher-Educator Award – *Ohio No-Till Council* 2011.

PEER-REVIEWED PUBLICATIONS - 2013 to 2018 (from 98 total)

Alvarez , D.A., Shappell, N.W., Billey, L.O., Bermudez, D.S., Wilson, V.S., Kolpin, D.W., Perkins, S.D., Evans, N., Foreman, W.T., Gray, J.L., **Shipitalo, M.J**., and Meyer, M.T. 2013. Bioassay of estrogenicity and chemical analysis of estrogens in streams across the United States associated with livestock operations. *Water Research* 47(10):3347-3363.

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Shipitalo, M.J., Malone, R.W., Ma, L., Nolan, B.T., Kanwar, R.S., Shaner, D.L., and Pederson, C.H. 2015. Corn stover harvest increases herbicide movement to subsurface drains – Root Zone Water Quality Model simulations. *Pest Management Science* DOI 10.1002/ps.4087

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Gonzalez, J.M, **Shipitalo, M.J.**, Smith, D.R., Warnemuende-Pappas, E., and Livingston, S.J. 2016. Atrazine sorption by biochar, tire chips, and steel slag as media for blind inlets: A kinetic and isotherm sorption approach. *Journal of Water Resource and Protection* 8:1266-1282.

Burke, R.H., Moore, K.J., **Shipitalo, M.J**., Miguez, F.E., Heaton, E.A. 2017. All washed out? Foliar nutrient resorption and leaching in senescing switchgrass. *BioEnergy Research.* 12:22-23. doi: 10.1007/s12155-017-9819-6.

Logsdon, S.D., Sauer, P.A., and **Shipitalo, M.J.** 2017. Compost improves water quality. *Journal of Water Resource and Protection* 9:345-357.

Ashworth, A.J., Allen, F.L., Tyler, D.D., Pote, D.H., and **Shipitalo, M.J.** 2017. Earthworm populations are affected from long-term crop sequences and bio-covers under no-tillage. *Pedobiologia* 60:27-33.

Korucu, T., **Shipitalo, M.J.** and Kaspar, T.C. 2018. Rye cover crop increases earthworm populations and reduces losses of broadcast, fall-applied, fertilizers in surface runoff. *Soil & Tillage Research* 180:99-106.

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A. Education

1992 **M.S., Geological Sciences**, Applied Hydrogeology and Karst, University of Kentucky, Lexington, KY
1984 **B.S., Geological Sciences,** Hydrogeology, University of Kentucky, Lexington, KY

B. Appointments

2013 – present **Groundwater Hydrologist and Section Head**, Water Resources Section, Kentucky Geological Survey, University of Kentucky, Lexington, KY
1994 – 2013 **Groundwater Hydrologist and Center Groundwater Specialist**, U.S. Geological Survey, Kentucky Water Science Center, Louisville, KY
1991 – 1994 **Groundwater Hydrologist**, U.S. Geological Survey, Kentucky Water Science Center, Louisville, KY
1989 – 1991 **Geologist Chief and Supervisor**, Technical Services Section, Groundwater Branch, Cabinet for Natural Resources and Environmental Protection, Kentucky Division of Water, Frankfort, KY

C. Publications

1. Zhu, J., Parris, T.M., **Taylor, C.J.,** and seven others, 2017, Assessing methane in shallow groundwater in unconventional oil and gas play areas, eastern Kentucky: Groundwater, v. 56, no. 3, p. 413-424.
2. Husic, A., Fox, J., Ford, W., Agouridis, C., Currens, J., and **Taylor, C.J.,** 2017, Sediment carbon fate in phreatic karst (Part 2): numerical model development and application: Journal of Hydrology, v. 549, p. 208-219.
3. Husic, A., Fox, J., Agouridis, C., Currens, J., Ford, W., and **Taylor, C.J.**, 2017, Sediment carbon fate in phreatic karst (Part 1): conceptual model development: Journal of Hydrology, v. 549, p. 179-193.
4. **Taylor, C.J.,** 2017, Karst aquifer characteristics in a public-supply well field near Elizabethtown, Kentucky, *in* Kuniansky, E.L., and Spangler, L.E., eds., U.S. Geological Survey Karst Interest Group Proceedings, San Antonio, Texas, May 16–18, 2017: U.S. Geological Survey Scientific Investigations Report 2017–5023, 245 p., https://doi.org/10.3133/sir20175023.
5. **Taylor, C.J.,** and Doctor, D.H., 2016, Karst: Chapter 89, *in* Handbook of Applied Hydrology, Second Edition, Singh, V.P. (ed.): McGraw-Hill Education.

6. Bayless, E.R., Cinotto, P., Ulery, R.L., **Taylor, C.J.,** McCombs, G.K., Kim, M.H., Nelson, H.L., Jr., 2014, Surface-water and karst groundwater interactions and streamflow-response simulations of the karst-influenced Upper Lost River watershed, Orange County, Indiana: U.S. Geological Survey Scientific Investigations Report 2014-5028, 52 p.
7. Williamson, T.N., **Taylor, C.J.**, and Newson, J.K., 2013, Significance of exchanging SSURGO and STATSGO data when modeling hydrology in diverse physiographic terranes: Soil Science Society of America Journal, v. 77, no. 3, p. 877-889.
8. **Taylor, C.J.,** Williamson, T.N., Newson, J.K., Ulery, R.L., Nelson, H.L., Jr., and Cinotto, P.J., 2012, Phase II modification of the Water Availability Tool for Environmental Resources (WATER) for Kentucky: The sinkhole-drainage process, point-and-click basin delineation, and results of karst test-basin simulations: U.S. Geological Survey Scientific Investigations Report 2012-5071, 19 p., plus appendixes.
9. Lindgren, R.J., **Taylor, C.J.,** and Houston, N.A., 2009, Description and evaluation of numerical groundwater flow models for the Edwards aquifer, south-central Texas, U.S. Geological Survey Scientific Investigations Report 2009-5183, 25 p.
10. **Taylor, C.J.,** and Greene, E.A., 2008, Hydrogeologic characterization and methods used in the investigation of karst hydrology, *in* Rosenberry, D.O., and LaBaugh, J.W., (editors), Field Techniques for Estimating Water Fluxes Between Surface Water and Ground Water, U.S. Geological Survey Techniques and Methods Report 4-D2, Chapter 3, p. 71-114. (Accessible at http://pubs.usgs.gov/tm/04d02/pdf/TM4-D2-chap3.pdf).
11. **Taylor, C.J.,** and Nelson, H.L., Jr., 2008, A compilation of provisional karst geospatial data for the Interior Low Plateaus physiographic region, central United States, U.S. Geological Survey Data Series Report 339, 26 p. (Accessible at http://pubs.usgs.gov/ds/339/).
12. **Taylor, C.J.,** Kaiser, W.P., and Nelson, H.L., Jr., 2008, Application of Geographic Information System (GIS) hydrologic data models to karst terrain, in Sinkholes and the Engineering and Environmental Impacts of Karst, Proceedings of the Eleventh Multidisciplinary Conference, Tallahassee, Florida, September 22-26, 2008, American Society of Civil Engineers Geotechnical Special Publication No. 183, p. 146-155.
13. **Taylor, C.J.,** Nelson, H.L., Jr., Hileman, G., and Kaiser, W.P., 2005, Hydrogeologic framework mapping of shallow, conduit-dominated karst—components of a regional GIS-based approach, *in* Kuniansky, E.L., (editor), 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.103-113.
14. **Taylor, C.J.,** and Hostettler, F.D., 2002, Hydrogeologic framework and geochemistry of groundwater and petroleum in the Silurian-Devonian carbonate aquifer, south-central Louisville, Kentucky, U.S. Geological Survey Water-Resources Investigations Report 02-4123, 3 map sheets.
15. **Taylor, C.J.,** and Alley, W.M., 2001, Ground-water-level monitoring and the importance of long-term water-level data, U.S. Geological Survey Circular 1217, 68 p. (Accessible at http://pubs.usgs.gov/circ/circ1217/).
16. Alley, W.M., and **Taylor, C.J.,** 2001, The value of long-term ground-water-level monitoring, Ground Water, v. 39, no. 6, p. 801.

17. **Taylor, C.J.,** and Greene, E.A., 2001, Quantitative approaches in characterizing karst aquifers, *in* Kuniansky, E.L., (editor), U.S. Geological Survey Karst Interest Group Proceedings, St. Petersburg, Florida, February 13-16, 2001, U.S. Geological Survey Water-Resources Investigations Report 01-4011, p. 164-166.
18. **Taylor, C.J.,** and McCombs, G.K., 1998, Recharge-area delineation and hydrology, McCraken Springs, Fort Knox Military Reservation, Meade County, Kentucky, U.S. Geological Survey Water-Resources Investigations Report 98-4196, 12 p., 1 plate with text.
19. Bayless, E.R., **Taylor, C.J.,** and Hopkins, M.S., 1994, Directions of ground-water flow and locations of ground-water divides in the Lost River watershed near Orleans, Indiana, U.S. Geological Survey Water-Resources Investigations Report 94-4195, 25 p., 2 plates.

D. Recent Synergistic Activities

1. Position description: I presently lead the research program and data-collection activities of the KGS Water Resources Section and serve as the supervisor of seven professional staff scientists conducting various hydrogeologic and water-quality investigations. I provide scientific technical assistance to various state and federal agencies, and collaborate regularly on hydrogeologic, water, and environmental research projects conducted by University of Kentucky faculty members from the Colleges of Agriculture Food and Environment, Agricultural Extension, Earth and Environmental Sciences, Civil Engineering, and Forestry.
2. University service: I presently serve as an advisory board member for the Kentucky Water Resources Research Institute, University of Kentucky, and have served as member of the Alumni Advisory Board, Department of Earth and Environmental Sciences, University of Kentucky [2005-2007].
3. Professional Societies and Service: Member, Geological Society of America, Hydrogeology Division [1994-present]; Member, National Ground Water Association, Association of Ground Water Scientists and Engineers [1992-present]; Member, National Speleological Society; Appointed board member to the Kentucky Agriculture Water Quality Authority [2013-present]; Member of the Kentucky Interagency Technical Advisory Committee on Groundwater [1991-present]; was recently appointed to the Technical Data Subcommittee of the Kentucky Water Resources Board [2017-present]. I served as co-convener of Technical Session No. 73-T10, “Comprehensive monitoring approaches at regional and statewide levels—advantages and limitations”, 2004 GSA Annual Meeting.