JOURNAL OF THE NACAA

ISSN 2158-9429

VOLUME 17, ISSUE 1 – JUNE, 2024

Editor: Linda Chalker-Scott

Quintero Fonseca, H.[1], Williams, R.[2], Pena Morales, M.[3]

[1]Program Director for Aquaculture Extension, The Ohio State University, Delaware, Ohio, 43015
[2]Production Manager, Keo Fish Farms Inc., Keo, Arkansas, 72083
[3]Assistant Professor , Universidad Surcolombiana, Neiva (Huila, Colombia)

Carbon Dioxide (CO_2) Monitoring in Aquaculture Well Water: A Participatory Research Case Study

Abstract

A participatory research study evaluated the presence of carbon dioxide (CO_2) in two wells that supply water to a fish hatchery. Samples at the well, the aeration tower and holding tanks were taken over a year. Even though the wells were near each other (438 ft or 133.5 m) there were significant differences in the presence of CO_2, with well 1 having an average concentration of 69.1 mg/L and well 2 an average of 48.5 mg/L. CO_2 concentrations in both wells were not consistent throughout the year, and differences in effectiveness of removal CO_2 were observed for both locations. Significance of these findings could relate to potential effects to the environment, human health, wildlife habitats, agricultural land, and surface waters.

Keywords: aquaculture, carbon dioxide (CO_2), groundwater, participatory research study

Introduction

Water use in the United States during 2015 was estimated to be 322 billion gallons per day, with 78% of water used for thermoelectric power and irrigation purposes, 12% for public supply, 5% industrial usage, and the remaining 5% for aquaculture, mining, livestock, and domestic purposes (Dieter et al., 2018). Aquaculture water usage during 2015 reached 7,550 million gallons per day, of which 79% were from surface water, and 21% groundwater (1,600 million gallons per day). Four states, Louisiana, California, Alaska, and Arkansas accounted for 57% of the total groundwater withdrawals, with Arkansas usage reaching about 152 million gallons from groundwater (Dieter et al., 2018).

Groundwater is considered as "one of the largest continental carbon reservoirs and tightly linked to globally important carbon fluxes such as uptake on land, degassing from inland waters and delivery to oceans" (Klaus, 2023). Some studies suggest that dissolved organic carbon will increase due to climate and land use changes, and research in long-term dynamics or large-scale patterns of groundwater dissolved inorganic carbon (i.e. the sum of CO_2, bicarbonate (HCO^{-3}), and carbonate (CO_3^{-2}) are scarce. Klaus (2023) using environmental data (pH, alkalinity, and water temperature) reported significant increases in groundwater dissolved inorganic carbon (DIC) and CO_2 concentrations by 28% and 49%, respectively, across Sweden between 1980-2020. In general, groundwater quality is very variable depending on the geological formation where water is trapped, and typically is depleted of dissolved oxygen, has low pH due to high presence of carbon dioxide, and on occasion has high presence of iron and manganese compounds.

Arkansas has 16 hydrogeologic formations that are considered aquifers and are grouped into the Coastal Plain Province and Interior Highlands physiographic regions. Most of the aquaculture farms are in the Coastal Plain aquifer system, that includes the Mississippi River Valley alluvial aquifer (Kresse et al., 2014). Some aquaculture wells in Chicot County are in the Cockfield aquifer, while some wells in Arkansas and Lonoke County are in the Sparta aquifer. The Sparta aquifer for Lonoke County is considered high quality, except for the presence of elevated concentrations of iron that makes water pre-treatment an essential step before using it in aquaculture facilities. These issues have been addressed by fish farmers by designing aquaculture facilities that include aeration towers as a way of stripping and removing carbon dioxide, as well as sedimentation tanks and filtration units to get rid of iron in the water.

Although aquaculture facilities and fish farmers have been dealing with water chemistry changes for a long time, from May through August 2019 several baitfish and sportfish farms experienced direct losses of over $200,000 due to changes in the groundwater, with sudden increases in the carbon dioxide concentration in water used for their hatcheries, holding tanks, and packing units before shipping.

Objective

These water quality changes motivated the Aquaculture Extension Program at the University of Arkansas at Pine Bluff (UAPB) to start a participatory research study to prevent and develop a warning system that help fish farmers avoid deleterious effects of these water quality changes in their fresh groundwater sources of their aquaculture farms.

Methods

Water quality variables that include temperature, pH, alkalinity, and hardness were monitored and used as an indirect method to calculate the presence of carbon dioxide in groundwater. These three parameters are routinely measured by many environmental agencies and are used for most of the published partial pressure of CO_2, considering the dissociation constants of carbonic acid, and the solubility of CO_2, which are temperature dependent (April et al., 2014; Millero, 1979; Park, 1969). These variables were measured using a Hach Fish Farming Water Quality Test Kit FF-1A (243002; Loveland, CO). Once the temperature, pH, and alkalinity variables were found a factor was used to multiply by total alkalinity (mg/L) to get carbon dioxide (mg/L) (Tucker, 1984; Wurts and Durborow, 1992).

The monitoring was performed on a weekly basis for one year, from October 2019 to October 2020, in a commercial fish farm at Keo, Arkansas. This commercial farm has two wells that are separated by 438 feet (133.5 m), and supply water to different sheds (Figure 1). A total of three locations were selected to get water samples and those included: the well (Figure 2a), the aeration tower (pit) (Figure 2b), and the vat, where the fish were held prior shipping (Figure 2c). A repeated measures analysis of variance was performed to determine the effects of the water treatment on water that was pumped from the well.

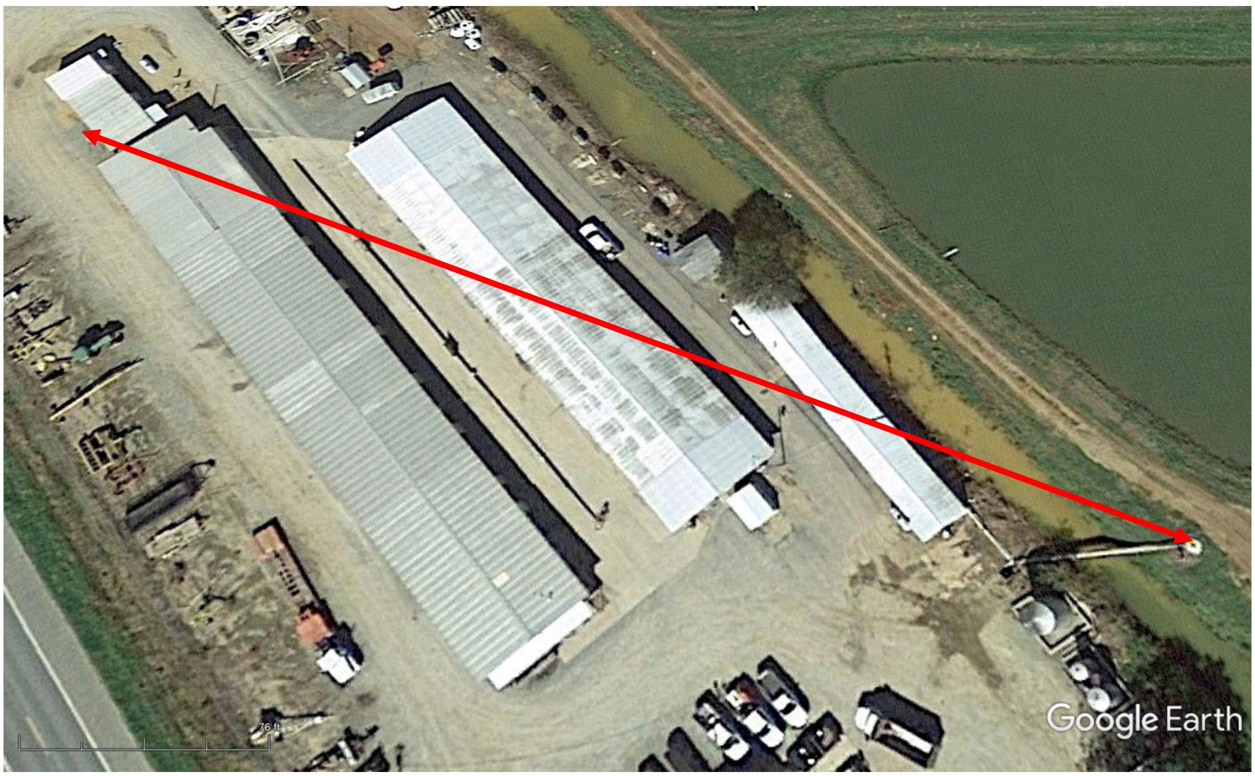

Figure 1. Location of the production units (well, pit and shed) with arrow ends depicting wells (well 1 on the left of the picture, well 2 on the right of the picture) at Keo Fish Farm (Keo, Arkansas).

Figure 2a. Electrical pump located on top of the well.
Figure 2b. Pit or aeration tower for releasing carbon dioxide.

Figure 2c. Holding vats for maintaining baitfish under the shed.

Results

Results from the average water quality monitoring program for temperature, pH, alkalinity, hardness, and carbon dioxide for each production unit, including the well, pit and shed, as well as the statistical analysis using the repeated measures analysis of variance, are presented in Table 1.

Table 1. Average water quality parameter from October 3rd, 2019, to October 30th, 2020, in two production units composed of well, pit and shed at Keo Fish Farm (Keo, Arkansas).

		Temperature (°F)	pH	Alkalinity (mg/L)	Carbon dioxide (mg/L)	Hardness (mg/L)
		Production Unit A				
Well 1		65.57 [b]	6.97 [c]	300.62 [b]	69.12 [a]	276.34 [c]
Pit 1		65.48 [b]	7.45 [a]	282.15 [c]	21.80 [c]	278.05 [c]
Shed 1		65.72 [b]	7.46 [a]	271.89 [d]	20.38 [c]	269.84 [c]
		Production Unit B				
Well 2		66.30 [a]	7.17 [b]	311.66 [a]	48.50 [b]	341.32 [a]
Pit 2		65.81 [b]	7.38 [a]	295.15 [b]	26.96 [c]	327.29 [b]
Shed 2		66.06 [a]	7.39 [a]	286.60 [c]	25.22 [c]	323.87 [b]
Group (sub)	F	36.53	48.68	39.95	46.36	460.71
	p-value	0.0268	0.0202	0.0245	0.0212	0.0022
Week	F	30.32	2.36	6.09	1.53	6.22
	p-value	<0.0001	<0.0001	<0.0001	0.0280	<0.0001
Group*Week	F	5.05	0.95	0.90	0.97	0.59
	p-value	<0.0001	0.5986	0.7108	0.5697	0.9973

Water quality between and within each production unit was significantly different for pH, alkalinity, carbon dioxide (CO_2), and hardness from the well to the shed. This was expected and reflects the release of carbon dioxide by passing water from the well through the aeration tower and ending in the vat (Table 1, Figure 3a to 3d). Well 1 had an average CO_2 concentration of 69.12 mg/L for a total period of 56 weeks, with an average pH of 6.97; while well 2 had a significantly lower CO_2 concentration of 48.50 mg/L and an average pH of 7.17 for the same period (Table 1, Figure 3a and 3c). Alkalinity and hardness were significantly lower for well 1 compared to well 2 (Table 1,

Figure 3b and 3d). Release of CO_2 was more effective in production unit A compared to production unit B, because even though well 1 had higher CO_2 concentration, it was lowered more in pit 1 and shed 1 (68.5%) compared to the levels observed from well 2 in pit 2 and shed 2 (44.4%).

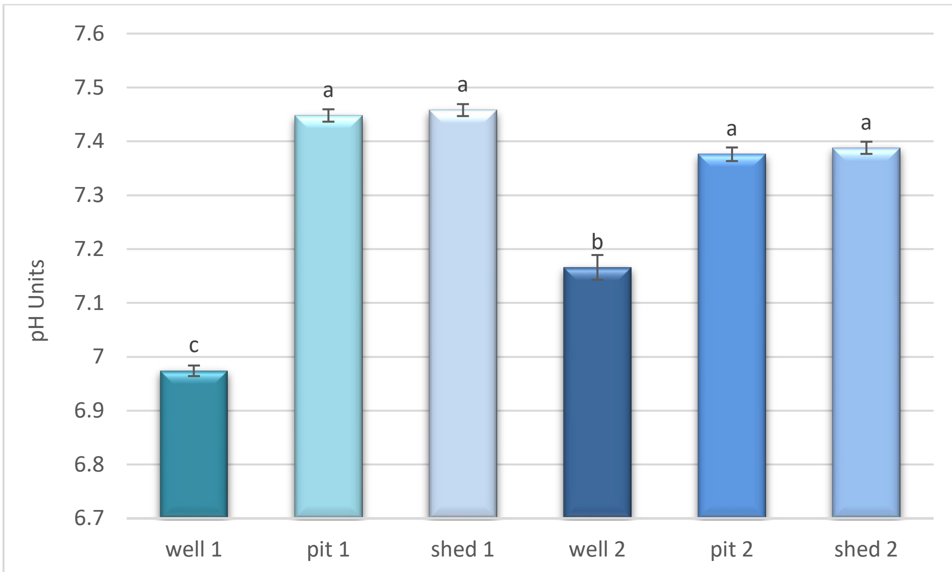

Figure 3a. Average pH from October 3rd, 2019, to October 30th, 2020, in two units consisting of the well, pit and shed at Keo Fish Farm (Keo, Arkansas).

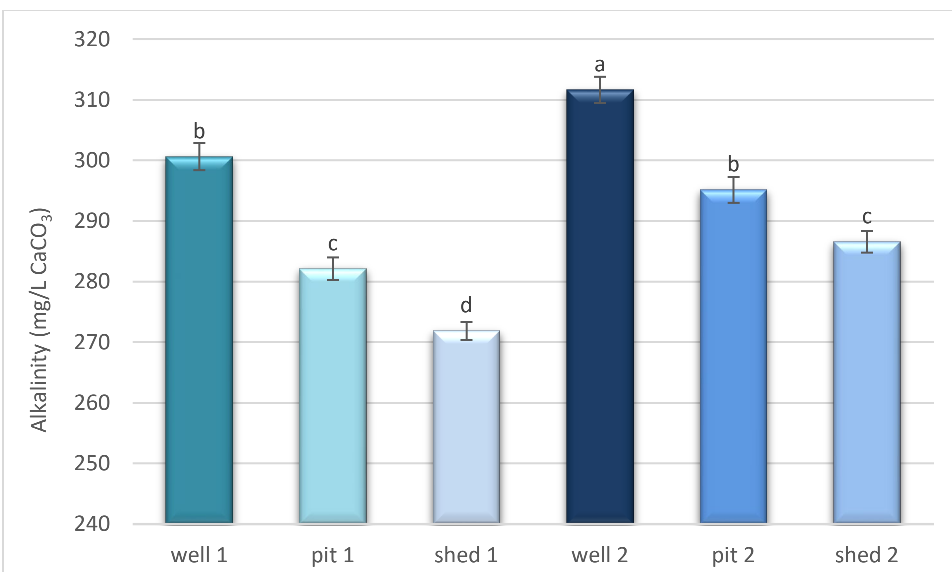

Figure 3b. Average alkalinity (mg/L $CaCO_3$) from October 3rd, 2019, to October 30th, 2020, in two units consisting of the well, pit and shed at Keo Fish Farm (Keo, Arkansas).

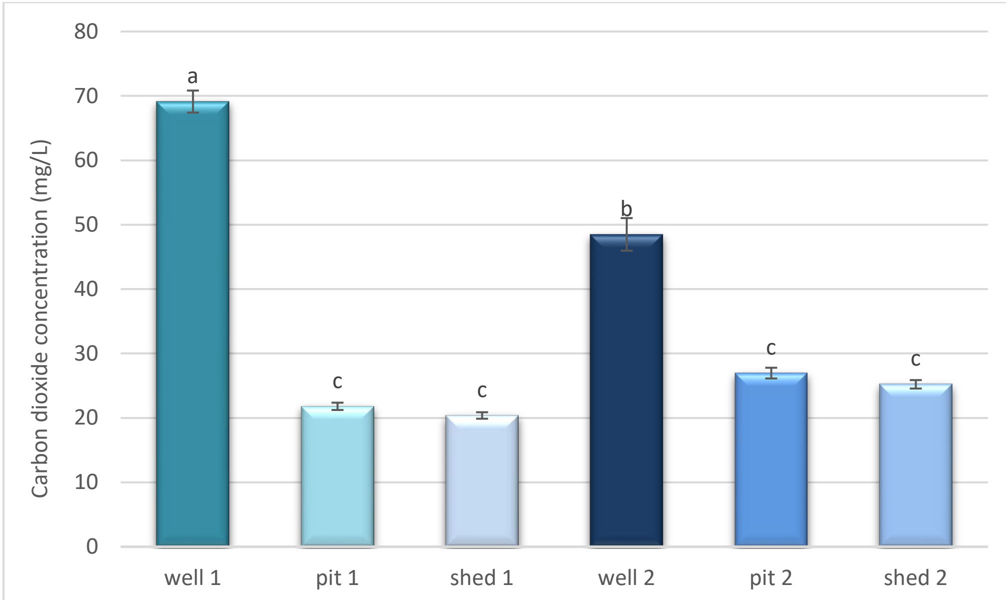

Figure 3c. Average carbon dioxide concentration (mg/L) from October 3rd, 2019, to October 30th, 2020, in two units consisting of the well, pit and shed at Keo Fish Farm (Keo, Arkansas).

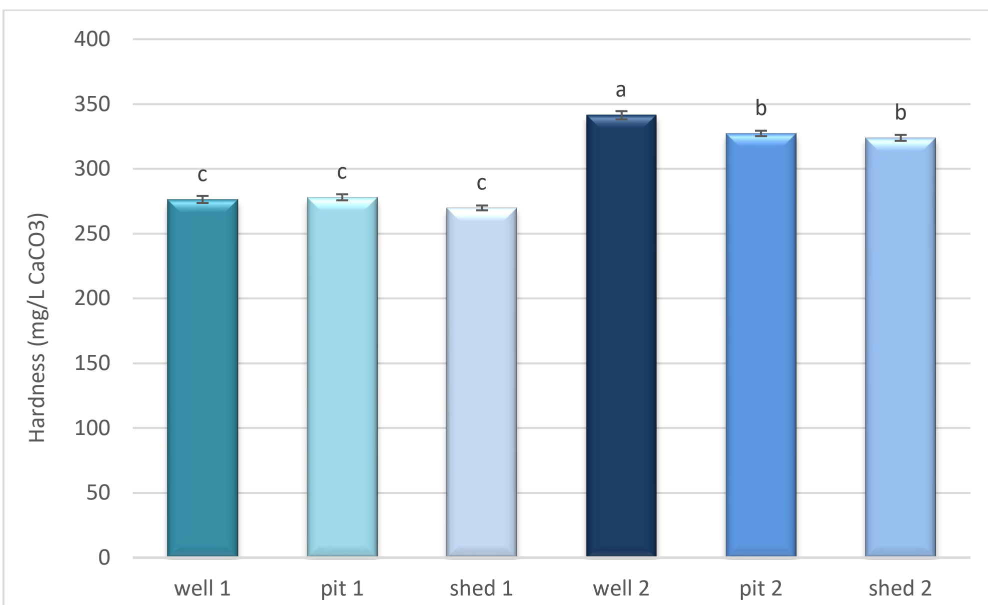

Figure 3d. Average hardness (mg/L $CaCO_3$) from October 3rd, 2019, to October 30th, 2020, in two units consisting of the well, pit and shed at Keo Fish Farm (Keo, Arkansas).

Although the wells were relatively close to each other, and we would expect a uniform water quality, this was not the case. Moreover, carbon dioxide (CO_2) concentration was not consistent throughout the year, observing changes from week to week as shown in Figure 4, and those changes were significantly different for each variable (Table 1). The reason for those changes is unknown. However, Stets et al. (2014) indicate that increase of agricultural and urban areas may enhance organic carbon decomposition, and Klaus (2023) added that air pollution may also change carbonate equilibrium reactions by adding acids that if not neutralized may shift the carbonate equilibrium towards more CO_2.

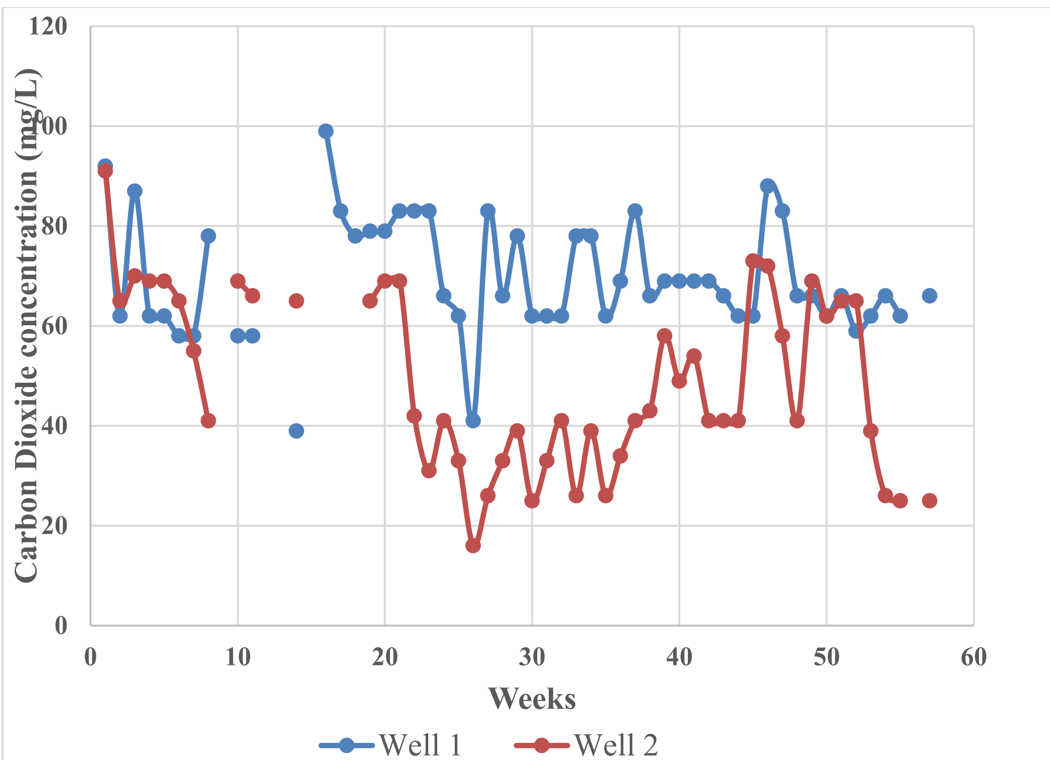

Figure 4. Carbon dioxide (CO_2) concentration from October 3rd, 2019, to October 30th, 2020, in two wells at Keo Fish Farm (Keo, Arkansas).

Conclusions

The water quality monitoring program allowed us identification of variability in the carbon dioxide concentrations from a temporal (weekly differences) and spatial basis (well water even from wells located close by). It also identified differences in the carbon dioxide removal efficiency from well water after passing through the aeration tower and sediment tanks for each production unit. Updates in the aeration tower and sediment tanks from this facility as well as other facilities were performed as a result of this study.

Future Research

A groundwater quality monitoring program could provide some useful information regarding long-term effects of anthropogenic activity, as well as spatial patterns that could predict deleterious effects on agriculture and/or aquaculture activities.

Acknowledgments

The authors would like to acknowledge the University of Arkansas at Pine Bluff (UAPB) Cooperative Extension Service for the support of this study, as well as Mr. Mike Freeze for allowing us to conduct this participatory research study on his farm, Keo Fish Farm, Inc.

Literature Cited

Abril, G., S. Bouillon, F. Darchambeau, C.R. Teodoru, T.R. Marwick, F. Tamooh, F.O. Omengo, N. Geeraert, L. Deirmendjian, P. Polsenaere, and A.V. Borges. 2014. Technical note: large overestimation of pCO_2 calculated from pH and alkalinity in acidic, organic-rich freshwaters. *Biogeosciences Discuss* 11: 11701-11725. https://doi.org/10.5194/bgd-11-11701-2014

Dieter, C.A., M.A. Maupin, R.R. Caldwell, M.A. Harris, T.I. Ivahnenko, J.K. Lovelace, N.L. Barber, and K.S. Linsey. 2018. Estimated use of water in the United States in

2015. U*.S. Geological Survey Circular 1441, 65 p*., https://doi.org/10.3133/cir1441. [Supersedes USGS Open-File Report 2017–1131.]

Klaus, M. 2023. Decadal increase in groundwater inorganic carbon concentrations across Sweden. *Communications Earth and Environment*, *4*:221. https://doi.org/10.1038/s43247-023-00885-4

Kresse, T.M., P.D. Hays, K.R. Merriman, J.A. Gillip, D.T. Fugitt, J.L. Spellman, A.M. Nottmeier, D.A. Westerman, J.M. Blackstock, and J.L. Battreal. 2014. Aquifers of Arkansas—Protection, management, and hydrologic and geochemical characteristics of groundwater resources in Arkansas. *U.S. Geological Survey Scientific Investigations Report 2014–5149, 334 p*., http://dx.doi.org/10.3133/sir20145149

Millero, F.J. 1979. The thermodynamics of the carbonic acid system in seawater, *Geochimica et Cosmochimica Acta* 43:1651–1661. https://doi.org/10.1016/0016-7037(79)90184-4

Park, P.K. 1969. Oceanic CO_2 system: an evaluation of ten methods of investigation. *Limnology and Oceanography* 14(2):179-316. https://doi.org/10.4319/lo.1969.14.2.0179

Stets, E.G., V.J. Kelly, and C.G. Crawford. 2014. Long-term trends in alkalinity in large rivers of the conterminous US in relation to acidification, agriculture, and hydrologic modification. *Science of the Total Environment* 488–489: 280–289. https://doi.org/10.1016/j.scitotenv.2014.04.054

Tucker, C.S. 1984. Carbon dioxide. In: (T.L. Wellborn, Jr., and J.R. MacMillan, eds.) *For Fish Farmers 84-2*. *Mississippi Cooperative Extension Service*.

Wurts, W.A., and R.M. Durborow. 1992. Interactions of pH, Carbon dioxide, alkalinity and hardness in fish ponds. *Southern Regional Aquaculture Center*, *Publication No. 464.*