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Water quality of potential reference lakes in the Arkansas Valley and Ouachita Mountain ecoregions, Arkansas

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Abstract This report describes a study to identify reference lakes in two lake classifications common to parts of two level III ecoregions in western Arkansas—the Arkansas Valley and Ouachita Mountains. Fifty-two lakes were considered. A screening process that relied on land-use data was followed by reconnaissance water-quality sampling, and two lakes from each ecoregion were selected for intensive water-quality sampling. Our data suggest that Spring Lake is a suitable reference lake for the Arkansas Valley and that Hot Springs Lake is a suitable reference lake for the Ouachita Mountains. Concentrations for five nutrient constituents—orthophosphorus, total phosphorus, total kjeldahl nitrogen, total nitrogen, and total organic carbon—were lower at Spring Lake on all nine sampling occasions and transparency measurements at Spring Lake were significantly deeper than measurements at Cove Lake. For the Ouachita Mountains ecoregion, water quality at Hot Springs Lake slightly exceeded that of Lake Winona. The most apparent water-quality differences for the two lakes were related to transparency and total organic carbon concentrations, which were deeper and lower at Hot Springs Lake, respectively. Our results indicate that when nutrient concentrations are low, transparency may be more valuable for differentiating between lake water quality than chemical constituents that have been useful for distinguishing between water-quality conditions in mesotrophic and eutrophic settings. For example, in this oligotrophic setting, concentrations for chlorophyll *a* can be less than 5 μg/L and diurnal variability that is typically associated with dissolved oxygen in more productive settings was not evident.

Keywords Geographic information systems · Nutrient criteria · Water-quality standards · Reference lake

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Introduction

The first water-quality standards (WQSs) for Arkansas lakes were adopted from the surface WQSs for streams, because water-quality data that were necessary to develop appropriate standards and provide adequate protection of designated uses for most Arkansas lakes were not available on an ecoregion basis. However, WQSs for streams often have little relevance to lakes. Notwithstanding the difference in physical characteristics of lakes and streams, Arkansas lakes are highly variable in terms of water quality, morphology, watershed characteristics, operation and management activities, and naturally occurring influences. As a first step to revise lake WQSs, the Arkansas Department of Environmental Quality (ADEQ), in cooperation with the US Geological Survey (USGS), is attempting to identify lakes that have the best obtainable (reference or least impaired) water quality for different lake classifications and ecoregions in Arkansas.

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Lakes identified as having reference conditions typically are associated with the least anthropogenic disturbance and development and have water quality that should be comparable to historical, background conditions. Data collected from reference lakes for a given ecoregion can be used to develop WQSs and criteria needed for evaluating conditions of test lakes that can be expected to have the same native biological, chemical, hydrological, and physical properties. Unfortunately, locating reference lakes can be prohibitively time consuming and expensive for States (US Environmental Protection Agency 2000).

The process of establishing reference conditions is a first step in a common approach used to develop WQSs for all types of waterbodies (US Environmental Protection Agency 2006; Stoddard et al. 2006). WQSs define the goals for a waterbody by designating its uses and setting criteria to protect those uses (US Environmental Protection Agency 2008). This is the second project in Arkansas that evaluated a group of potential reference lakes for nutrient-related conditions (Justus 2009). Excessive nutrients are the most common pollutant responsible for lake impairment in Arkansas (Arkansas Department of Environmental Quality 2008), as well as across the nation (US Environmental Protection Agency 2002).

This report describes the methods and summarizes data collected for a study conducted by the USGS in partnership with ADEQ and the US Environmental Protection Agency (USEPA) to identify reference lakes in two lake classifications common to parts of two level III ecoregions in western Arkansas—the Arkansas Valley and the Ouachita Mountains (Woods et al. 2004). Nutrient concentrations were selected to represent anthropogenic risk because of the relatively large number of Arkansas lakes that USEPA considers to be impaired by nutrients. This project focused on what ADEQ classifies as "type B" lakes within the Arkansas Valley ecoregion (AV) and Ouachita Mountain ecoregion (Ouachita Mountains) in west central Arkansas. The type B classification pertains to lakes that are between approximately 25 and 485 ha, which are located in the AV or in upland areas of the Ozark, Ouachita, and Boston Mountains. Completion of the proposed work will provide ADEQ, USEPA, and USGS with additional water-quality information for reference lakes associated with these lake classifications and ecoregions in Arkansas.

The study involved three phases of study. Two phases of study—screening and reconnaissance—were used to identify and eventually select lakes in the AV and Ouachita Mountains for the third (intensive, heretofore) phase—nine water-quality sampling events over an 11-month period; December 2011 through October 2012. The screening phase utilized Geographical Information System (GIS) methods to characterize land cover and land use in all test lake watersheds (Table 1). During the screening phase, at least six lakes with least-disturbed watersheds (usually greater than 80 % forest land use) were selected for a single water-quality (reconnaissance) sampling event. Water-quality data collected in the reconnaissance phase were considered jointly with other factors that required on-site observation (Table 2) and were compared with GIS land-use data gathered in the screening phase to select (potential reference) lakes for the intensive phase. Two lakes were sampled intensively in the AV but three lakes were sampled for the first three (of nine) intensive sampling events in the Ouachita Mountains, after which, sampling was discontinued at the lake with the least-favorable water quality. Data from the 9 months of intensive water-quality sampling were compared for the two lakes in each ecoregion to determine which lake had the "best" water quality and would be considered as a reference lake for the respective ecoregions.

Materials and methods

Description of the study area

The AV lies between the Boston Mountains to the north and the Ouachita Mountains to the south. Most lakes evaluated in this ecoregion were located in the Scattered

Table 1 Lake characteristics determined with geographic information systems in a lakes screening exercise for a reference lake study in two level III ecoregions in Arkansas, the Arkansas Valley and Ouachita Mountains

Characteristics	Resolution
Watershed cover	Comparison of forest to pasture and developed lands
Anthropogenic sources	Minimal nutrient and sediment sources (wastewater, natural gas drilling, mining, etc.)
Size	Greater than 25 and less than 485 ha
Ecoregion	Watershed totally contained within the ecoregion

Table 2 Considerations evaluated (in addition to water sampling data) during reconnaissance phase of a reference lake study

Consideration	Resolution
Nutrient concentrations	Historic water-quality data
Hydrology	Isolation from riverine backwater and groundwater sources
Wildlife	Moderate waterfowl use (not a roost or resting area)
Fisheries management	Fertilization, not excessive

High Ridges and Mountains (level IV ecoregion), which tends to be more rugged and wooded than the three other subecoregions within the AV (Woods et al. 2004). The AV is largely underlain by interbedded Pennsylvanian sandstone and shale. Prior to the nineteenth century, upland areas surrounding the lakes were predominantly forested with oaks and hickory, or shortleaf pine, with smaller areas of savannas and prairies. Today, the least rugged upland areas and valleys have been cleared for pasture or hay. Water quality in the Scattered High Ridges and Mountains is generally good and influenced more by prominent land uses such as poultry and livestock farming rather than by soils or geology (Woods et al. 2004). The two lakes that were selected for intensive sampling in the AV were located near Mount Magazine, the highest point in Arkansas (839 m).

The Ouachita Mountains are composed of east–west trending ridges, along with hills and valleys formed by the erosion of folded and faulted Paleozoic sandstone, shale, and novaculite (chert). The Ouachita Mountains are a continuation of the Appalachian Mountains and although, physiographically, they are unlike the majority of the AV, parts of the Ouachita Mountains share similarities with the areas of highest elevation in the AV. Rock outcrops, and shallow, stony soils are widespread in the Ouachita Mountains. Perennial springs and seeps are common, and constricted valleys between ridges sometimes have waterfalls and rapids (Woods et al. 2004).

Natural vegetation for much of the Ouachita Mountains is oak–hickory–pine forest; however, logging is the predominant land use for areas too steep and rocky for providing pasture, and loblolly and shortleaf pine are common in replanted areas. Pasture and hay land uses are common in gentle sloping areas and valleys but, despite these practices, water quality is exceptional. Typically, total phosphorus (TP), turbidity, total suspended solids, and biological oxygen demand values are lower, whereas dissolved oxygen (DO) concentrations are higher than in most other Arkansas ecoregions (Woods et al. 2004).

The current ADEQ lake-classification system classifies lakes in Arkansas into five types (A–E) based on characteristics such as size, average depth, and ecoregion (Arkansas Department of Environmental Quality 2000). The primary purpose of most type B lakes is multi-purpose recreation but other designated uses include public water supply and industrial cooling water supply. Depths typically range from 3 to 7.6 m (however, depth for the four lakes that were intensively sampled for this study ranged from 10 to 20 m). Watersheds are predominately forested and hydraulic residence time is normally very short in most type B lakes (Arkansas Department of Environmental Quality 2000). Residence time in the summer of 2012, however, may have been longer than normal due to drought that occurred for the study area and much of Arkansas (US Drought Monitor 2013).

Screening phase

The number of lakes selected for screening was proportional to the total number of lakes in each classification. Land use information obtained with GIS (Homer et al. 2004) was the primary resource used to identify lakes that had reference potential (Wang et al. 2010). Initially, 52 lakes—28 AV lakes and 24 Ouachita Mountain lakes—were selected for screening with GIS (Supplemental Table 1). The percentages of forest, pasture, and urban land use were assumed to be the three land-use metrics that were the strongest indicators of predominant non-point sources of nutrients. Other forms of land use (e.g., shale gas production) were considered; however, a low level of occurrence prevented robust comparisons that were beneficial to the GIS analysis.

Urban development and agriculture land use (pasture, hay, and row crop) generally decreased at higher altitudes, whereas forest generally increased with altitude. Strong relations have been established between stream water quality and forest in the Ozark Mountains of Arkansas (Davis and Bell 1998; Petersen 1998) and an assumption was made the same relation would be true for lakes in adjacent ecoregions. Relatedly, the results of the GIS analysis were interpreted as indication that lakes at higher altitudes likely were to have better water quality than lakes at lower altitudes.

Reconnaissance phase

Data collected in the reconnaissance phase were oriented more toward lake-nutrient water quality than to land-use intensity (the focus of the screening phase). However, we anticipated that, because of recent implementation or because of small scale occurrence, some land-use information might not have been detected with GIS in the screening phase (Table 2). Consequently, a small but important aspect of the reconnaissance phase involved visiting the watershed to look for effects related to forms of land use that might have been overlooked in the screening phase (e.g., construction of natural gas well pads or related road construction).

Some conservative measures were implemented mid-study to ensure that lakes that were eventually selected for intensive sampling included lakes with the "best" water quality in the ecoregion. The initial study plan involved sampling six lakes in the reconnaissance phase, however, the lakes that ranked sixth and seventh in terms of land use in the AV had similar amounts of forest and pasture so both lakes were sampled (for a total of seven lakes). Reconnaissance water-quality sampling was conducted at the 13 lakes during the last week of August and first week of September 2011. Lake profile data for DO, pH, temperature, specific conductivity, and turbidity were recorded at 0.6-m intervals at all lakes. Transparency was measured on each sampling occasion with a Secchi disk. Water-quality samples were collected 0.3 m below the water surface using a Van Dorn sampler. The ADEQ laboratory performed all laboratory analyses using analytical methods approved by USEPA and the American Water Works Association (American Public Health Association et al. 2005; Supplemental Table 2). Water samples were analyzed for dissolved orthophosphorus (OP), total phosphorus (TP), dissolved ammonia nitrogen (NH_3), total Kjeldahl nitrogen (TKN), dissolved nitrite plus nitrate (NO_3+NO_2), chlorophyll *a* (Chl *a*), and total organic carbon (TOC). Total nitrogen (TN) was calculated by adding results for the TKN and NO_3+NO_2.

Analysis of the single round of sampling conducted for the reconnaissance phase involved using a simple water-quality index to compare nutrient constituent data from seven lakes in the AV and six lakes in the Ouachita Mountains. Index values were calculated for each of the 13 lakes by ranking results for selected chemical constituents and transparency measurements and then by summing ranks for all constituent (Table 3).

Lake selection process for intensive sampling

The water-quality index calculated with reconnaissance data, and other historical data or land-use information, were the primary considerations that determined which

Table 3 A demonstration of the ranking process used to score physical and chemical data evaluated in the reconnaissance phase of study

Lake name	PO_4 (mg/L)	PO_4 rank	TKN (mg/L)	TKN rank	TOC (mg/L)	TOC rank	Chl *a* (μg/L)	Chl *a* rank	Secchi (cm)	Secchi rank	Index (sum of ranks)	Condition assessment
Arkansas Valley ecoregion												
Spring	0.011	4	0.322	1	3.34	2	7.81	1	183	1	9	1st best
Cove	0.010	3	0.523	2	4.10	3	13.8	2	140	2	12	2nd best
West Fork Point Remove	<0.01	1	0.667	4	0.59	1	35.2	5	64	5	16	3rd best
Paris	0.011	4	0.591	3	4.96	4	22.8	4	114	3	18	4th best
Rogers Scout	<0.01	1	0.703	5	5.9	5	39.8	6	56	6	23	5th best
Cedar Piney	0.013	6	0.742	6	6.61	6	15.7	3	91	4	25	6th best
Ouachita Mountain ecoregion												
Hot Springs	<0.01	1	0.228	2	3.47	2	2.82	1	305	2	8	1st best
Iron Fork	<0.01	1	0.021	1	3.32	1	4.37	2	206	4	9	2nd best
Winona	<0.01	1	0.233	3	5.21	4	6.06	3	330	1	12	3rd best
Hinkle	<0.01	1	0.377	5	4.65	3	6.85	4	216	3	16	4th best
James Fork	<0.01	1	0.326	4	5.23	5	7.79	5	193	5	20	5th best
Dry Fork	0.010	6	0.383	6	7.42	6	9.41	7	135	7	32	6th best
Rodgers	0.011	7	0.497	7	8.1	7	7.85	6	155	6	33	7th best

PO_4 orthophosphorus as P, *TKN* total Kjeldahl nitrogen as N, *TOC* total organic carbon, *Chl a*, chlorophyll *a*, *Secchi* transparency

lakes were selected for the intensive phase (or the 9 months of water-quality sampling). For the Ouachita Mountains, the water-quality index indicated two lakes were clear candidates for intensive sampling. As a conservative measure, a third lake in the Ouachita Mountains also was sampled for the first 3 months of intensive sampling because historical data indicated the lake had excellent nutrient water quality and GIS analysis revealed a high percentage of forest in the watershed. The water-quality index indicated that one of the six AV lakes that were sampled during the reconnaissance phase consistently had lowest concentrations for most nutrient constituents, whereas concentrations for nutrient constituents at the two "next best" lakes were comparable. Differences observed for some land-use practices during the field reconnaissance resulted in one of those two lakes being dropped from consideration for intensive sampling.

Intensive phase

Sampling intensity increased for the five lakes selected for the intensive phase of sampling, but the same water-quality sampling methods used for the reconnaissance phase were used for the intensive phase. While one team member collected water, a second team member used a water-quality monitor (WQM; Yellow Springs Instrument, model 6920) that was calibrated at the beginning of each sampling day to measure field characteristics throughout a depth profile (Wilde and Radtke 1998). Profiling involved measuring water temperature, DO, specific conductance, and pH at 0.3-m below the surface and at 0.6-m depth intervals, thereafter. The second team member also took a transparency (depth measured with a Secchi disk) reading and completed a field data sheet that documented sampling time, environmental conditions (i.e., lake stage, water color, and weather), and general observations. Transparency was measured on the shaded side of the boat, while field personnel wore polarized sun glasses.

One of the five lakes initially sampled in the intensive phase was dropped after the third sampling event but the four remaining lakes (Fig. 1) were sampled on nine occasions from December 2011 through October 2012 (January and March were omitted from sampling during that 11-month period). Monthly samples were collected

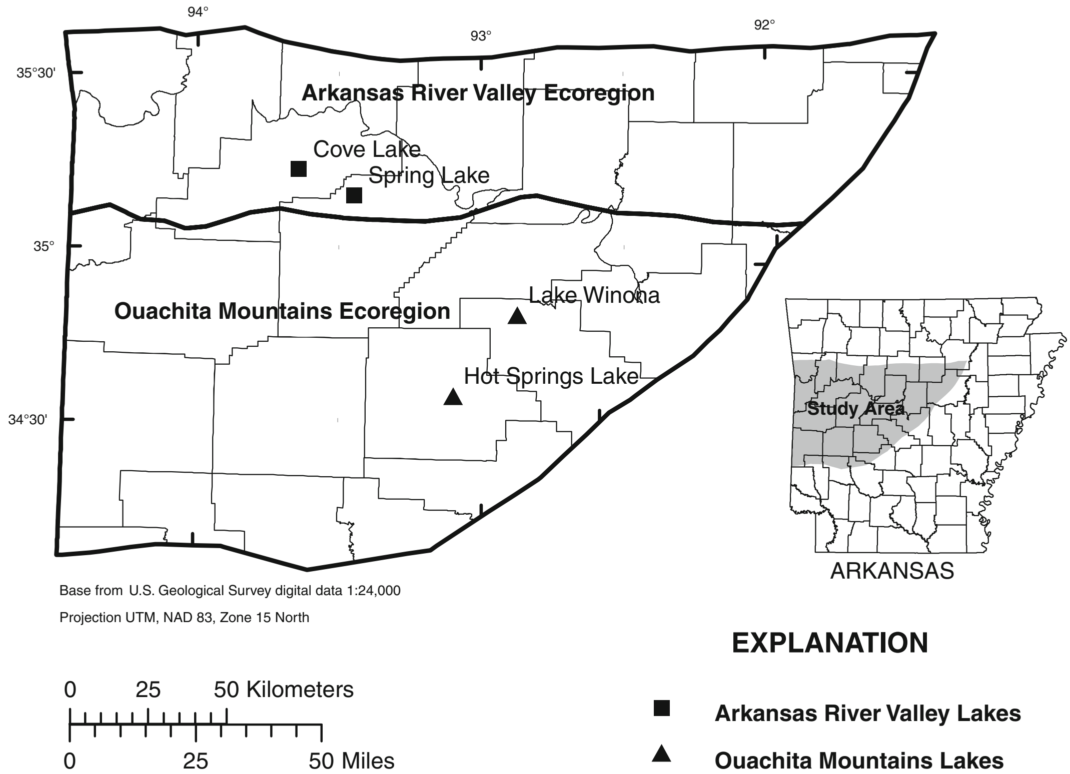

Fig. 1 Loca1ons of four lakes sampled on nine occasions from December 2011 through October 2012

from April 2012 through October 2012 to document water-quality conditions when nutrient response (i.e., lake productivity) should be highest but sampling was conducted every other month from late Fall through early Spring. Water samples were collected from the same general location on each sampling occasion. Samples were filled from a "grab" that was collected 0.3-m below the surface with a Van Dorn sampler. After sampling was completed, sample bottles were sealed and were placed in plastic bags (by lake) and on ice for transport to the ADEQ laboratory. Samples were analyzed for nutrient-related constituents using the same methods used for reconnaissance samples (Supplemental Table 2).

Duplicate water samples were collected in the field as a quality-control measure of the field processing methods and laboratory analyses. Duplicate samples were filled from a second grab collected a few meters away from the location of the original sample. At least one duplicate water sample was collected on each sampling event, and a total of 12 duplicate samples were collected (Supplemental Table 3). Proper chain of custody documentation was completed prior to transferring all water samples to the ADEQ laboratory.

Quality-assurance results indicated that the field-sampling and laboratory methods were acceptable and that data were of good quality (Supplemental Table 3). Of 96 cross comparisons for laboratory analyses (resulting from 12 duplicate samples and 8 constituents), there were only nine occasions when concentrations in the duplicate sample were more than 10 % different from the concentration that was measured in the original sample. In at least some of those nine instances, pairs of results that were more than 10 % different were related to slight differences in extremely low concentrations (e.g., a 12 % difference between TP concentrations of 0.025 and 0.022 mg/L).

Dissolved-oxygen investigation

A 72-h DO study was conducted between 15 and 19 August 2012 at Cove, Spring, and Hot Springs Lakes and at Lake Winona (the four lakes that were eventually selected for intensive water-quality sampling). A WQM (Hydrolab, model MS 5) was deployed at a depth of approximately 0.3 m in each lake and was programmed to collect DO, water temperature, and specific conductivity data at 30-min intervals. WQMs were generally secured to submerged logs along the bank, but at Lake Winona the WQM was secured to a boat dock because there were no submerged logs along the shoreline.

After being retrieved, WQMs were inspected and cleaned and a post-cleaning measurement was taken to determine if data were affected by biofouling. The continuous data collected in the field (also available online at http://waterdata.usgs.gov/ar/nwis/dv/?referred_module=qw) were within 2 % of expected values and well within USGS standards (Wagner et al. 2006); therefore, it was not necessary to shift data to compensate for biofouling or electronic drift at any of the four lakes.

Data analysis

Rather than combining data into an index as was done for the reconnaissance data, the nine months of water-quality data collected during the intensive phase at the two lakes representing each of the two ecoregions were compared by constituent. To determine constituent variability and statistical differences, minimum, maximum, and median concentrations were determined for all laboratory and field constituents and median values were compared to determine if the two potential reference lakes within each ecoregion were statistically different. The first step of this evaluation consisted of testing the data for normality using the Shapiro–Wilk normality test within Sigma Plot software (version 12; Systat Software 2010). For samples that were normally distributed, a paired *t* test was used to determine if laboratory or field values associated with the two potential reference lakes were significantly different. For data that were not normally distributed, results of the Wilcoxon signed rank test (a nonparametric test; Wilcoxon 1945) was used to determine if laboratory or field values associated with the two potential reference lakes were significantly different. A significance level of 0.05 was used in all tests. Trophic state indices (TSIs) were calculated for lakes that were sampled intensively using means for TP and Chl *a* and formulas provided in Carlson (1977).

Results and discussion

Reconnaissance results

Water quality for some lakes in the two ecoregions was very good and very similar. Consequently, when selecting lakes for intensive sampling, it was necessary to consider factors other than the water-quality index that was calculated with data from the one-time sampling event. These other factors included historical water-quality data, the amount of forest cover in the watershed, and recent changes in land use.

Results of the water-quality index clearly indicated that Spring Lake had the “best” water quality of the six lakes that were sampled in the AV during the reconnaissance phase (Table 3). For the two “next-best” lakes, Cove Lake scored only slightly better than West Fork Point Remove Lake, indication that there was little difference in water quality of the two lakes (Table 3). Evidence of recent changes in land use in the West Fork Point Remove watershed (i.e., numerous shale gas drilling pads observed during the reconnaissance phase) resulted in the selection of Cove Lake for intensive sampling over West Fork Point Remove.

Regarding lakes in the Ouachita Mountains, the water-quality index indicated Hot Springs Lake and Iron Fork Lake were clear candidates for intensive sampling; however, the decision was made to also include Lake Winona in the first three sampling events, and then to reevaluate data from the three lakes to determine which lakes would continue to be intensively sampled. Lake Winona was selected as the third test lake for two primary reasons: (1) a review of historical USGS data indicated that Lake Winona had excellent nutrient water quality, and (2) its watershed had the same amount (92 %) of forest as the Iron Fork Lake watershed. That decision was crucial to the study because an extreme storm event that occurred at Iron Fork Lake days before the February 2012 water-quality sample (lake stage increased by 5 m) resulted in dramatic and persistent changes to water quality. Turbidity and TP concentrations in Iron Fork Lake for the February and April sampling events were much higher than in previous samples, and sampling was discontinued in Iron Fork Lake after April, 2012. Locations and basic characteristics of the four lakes indicate that Lake Winona was much larger than the three remaining lakes selected for intensive sampling (Table 4).

Reference lake quality in the Arkansas Valley ecoregion

Much of the data collected between December 2011 and October 2012 at the two lakes located in the AV clearly indicate that water quality at Spring Lake exceeded that of Cove Lake. Concentrations for five of the seven chemical constituents—OP, TP, TKN, TN, and TOC—were lower at Spring Lake on eight of nine sampling occasions (Table 5), and concentrations of those five constituents were significantly lower at Spring Lake than at Cove Lake (Table 6). Nitrate plus nitrite was detected in Spring and Cove Lakes in December 2011 and February 2012, but concentrations at Cove Lake were higher than at Spring Lake on both occasions. Similarly, dissolved ammonia was only detected above the minimum laboratory detection limit (MDL) at Cove Lake and only in one sample (Table 5).

One of the most notable differences between the two AV lakes was that Spring Lake was clearer than Cove Lake. Transparency measurements at Spring Lake (a mean of 190 cm) were deeper than measurements at Cove Lake for eight of nine sampling occasions (Table 5), and transparency also was significantly greater at Spring Lake compare to Cove Lake (Table 6; Fig. 2).

In contrast to the constituents above, Chl *a* (or TSI Chl *a* values) and N/P ratios were not useful for

Table 4 Lakes selected for intensive water-quality sampling for a reference lake study in two level III ecoregions in Arkansas, the Arkansas Valley and the Ouachita Mountains

Level III ecoregion	Lake name	USGS station	County	Latitude[b]	Longitude[2]	Perimeter (km) identifier	Size (ha)	Lake depth (m)
Arkansas Valley	Cove Lake	7256010	Logan	35° 13′ 53.4″	93° 37′ 40.1″	4.4	51.0	11.2
	Spring Lake	7260530	Yell	35° 08′ 59.7″	93° 25′ 33.9″	4.1	32.9	10.4
Ouachita Mountains[a]	Hot Springs Lake	7357840	Garland	34° 34′ 2.13″	93° 05′ 44.3″	10.1	59.4	16.4
	Lake Winona	73625895	Saline	34° 47′ 52.2″	92° 51′ 02.0″	38.2	474.0	20.8

[a] Iron Fork Lake was dropped after the April sampling session because nitrate plus nitrite concentrations and turbidity increased dramatically after an extreme storm event

[b] The horizontal datum for latitude and longitude was North America Datum of 1983 (NAD83)

[c] Depths were estimated using mean depth from profile data

Table 5 A comparison of results for selected constituents and transparency for two pairs of lakes selected as potential reference lakes in two level III ecoregions in Arkansas, the Arkansas Valley and Ouachita Mountains, December 2011–October 2012

Sampling date	OP (mg/L as P)	TP (mg/L as P)	NH_3 dissolved (mg/L as N)	NO_3+NO_2 (mg/L as N)	TKN (mg/L as N)	TN (mg/L)	Chl *a* (μg/L)	TOC (mg/L)	Transparency (cm)
Arkansas Valley ecoregion									
Cove lake									
13 Dec 2011	0.015	0.058	0.039	0.158	0.180	0.338	5.76	8.73	97
7 Feb 2012	0.016	0.029	<0.03	0.119	0.176	0.295	3.31	2.39	97
3 Apr 2012	0.013	0.032	<0.03	<0.03	0.168	0.183	3.97	2.54	168
7 May 2012	0.011	0.027	<0.03	<0.03	0.193	0.208	2.32	2.52	236
4 Jun 2012	0.014	0.047	<0.03	<0.03	0.329	0.344	8.72	3.09	109
9 Jul 2012	0.016	0.040	<0.03	<0.03	0.378	0.393	8.73	4.47	94
6 Aug 2012	0.014	0.040	<0.03	<0.03	0.334	0.349	7.99	3.81	107
10 Sep 2012	0.018	0.049	<0.03	<0.03	0.344	0.359	8.17	3.74	112
1 Oct 2012	0.019	0.053	<0.03	<0.03	0.404	0.419	16.20	3.87	112
Minimum	0.011	0.027	0.015	0.015	0.168	0.183	2.32	2.39	94
Maximum	0.019	0.058	0.039	0.158	0.404	0.419	*16.20*	8.73	236
Median	0.015	0.040	0.015	0.015	0.329	0.344	7.99	3.74	109
Mean	0.015	0.042	0.018	0.042	0.278	0.321	7.24	3.91	126
Spring Lake									
13 Dec 2011	0.012	0.032	<0.03	0.141	<0.05	0.166	1.41	2.26	158
7 Feb 2012	0.014	0.024	<0.03	0.056	0.117	0.173	2.59	1.46	165
3 Apr 2012	0.012	0.024	<0.03	<0.03	0.121	0.136	2.45	1.76	257
7 May2012	<0.01	0.022	<0.03	<0.03	0.145	0.160	2.26	2.03	303
4 Jun 2012	0.011	0.025	<0.03	<0.03	0.199	0.214	3.92	2.60	236
10 Oct 2012	0.012	0.027	<0.03	<0.03	0.290	0.305	9.84	2.91	183
6 Aug 2012	0.012	0.026	<0.03	<0.03	0.286	0.301	8.64	3.18	188
10 Sep 2012	0.017	0.037	<0.03	<0.03	0.331	0.346	10.50	3.56	102
1 Oct 2012	0.019	0.031	<0.03	<0.03	0.366	0.381	22.60	3.56	117
Minimum	*0.005*	*0.022*	0.015	0.015	*0.025*	*0.136*	*1.41*	*1.46*	*102*
Maximum	0.019	*0.037*	*0.015*	*0.141*	*0.366*	*0.381*	22.60	*3.56*	*303*
Median	*0.012*	*0.026*	0.015	0.015	*0.199*	*0.214*	*3.92*	*2.60*	*183*
Mean	*0.013*	*0.028*	*0.015*	*0.034*	*0.209*	*0.242*	*7.13*	*2.59*	*190*
Ouachita Mountain ecoregion									
Lake Winona									
12 Dec 2011	0.013	0.033	0.058	<0.03	0.085	0.100	0.80	5.86	178
6 Feb 2012	0.013	0.015	0.043	<0.03	0.193	0.208	1.95	3.65	269
2 Apr 2012	0.011	0.014	<0.03	<0.03	0.174	0.189	2.25	3.91	226
7 May 2012	0.010	<0.01	<0.03	<0.03	0.195	0.210	1.76	3.60	300
5 Jun 2012	0.011	<0.02	<0.03	<0.03	0.166	0.181	1.96	3.58	302
10 Jul 2012	<0.01	<0.02	<0.03	<0.03	0.153	0.168	1.72	3.70	401
6 Aug 2012	0.010	<0.02	<0.03	<0.03	0.171	0.186	2.29	3.56	290
10 Sep 2012	0.016	<0.02	<0.03	<0.03	0.188	0.203	2.82	3.71	259
2 Oct 2012	0.016	<0.02	<0.03	<0.03	0.196	0.211	6.17	3.76	244
Minimum	0.005	0.005	0.015	0.015	*0.085*	*0.100*	*0.80*	3.56	*178*
Maximum	0.016	0.033	*0.058*	*0.015*	*0.196*	*0.211*	6.17	5.86	401
Median	0.011	0.010	0.015	0.015	*0.174*	*0.189*	*1.96*	3.70	269

Table 5 (continued)

Sampling date	OP (mg/L as P)	TP (mg/L as P)	NH_3 dissolved (mg/L as N)	NO_3+NO_2 (mg/L as N)	TKN (mg/L as N)	TN (mg/L)	Chl *a* (μg/L)	TOC (mg/L)	Transparency (cm)
Mean	0.012	0.013	*0.023*	*0.015*	*0.169*	*0.184*	*2.41*	3.93	274
Hot Springs Lake									
12 Dec 2011	0.012	0.026	0.102	0.046	0.256	0.302	3.58	NR	165
6 Feb 2012	<0.01	0.014	0.062	0.065	0.233	0.298	2.01	2.96	343
2 Apr 2012	<0.01	<0.01	<0.03	<0.03	0.156	0.171	3.15	3.25	366
7 May 2012	<0.01	<0.01	<0.03	<0.03	0.170	0.185	2.88	3.28	457
5 Jun 2012	<0.01	<0.02	<0.03	<0.03	0.175	0.190	0.93	3.13	500
10 Jul 2012	<0.01	<0.02	<0.03	<0.03	0.191	0.206	4.89	3.11	391
6 Aug 2012	<0.01	<0.02	<0.03	<0.03	0.195	0.210	1.93	3.14	409
11 Sep 2012	0.015	<0.02	<0.03	<0.03	0.218	0.233	3.42	3.28	305
2 Oct 2012	0.016	<0.02	<0.03	<0.03	0.214	0.229	6.10	2.99	404
Minimum	0.005	0.005	0.015	0.015	0.156	0.171	0.93	*2.96*	165
Maximum	0.016	*0.026*	0.102	0.065	0.256	0.302	*6.10*	*3.28*	*500*
Median	*0.005*	0.010	0.015	0.015	0.195	0.210	3.15	*3.14*	*391*
Mean	*0.008*	*0.011*	0.030	0.024	0.201	0.225	3.21	*3.14*	*371*

Values set in italics indicate the lowest concentration or greatest transparency comparing paired lakes. Total nitrogen was calculated by adding TKN to NO_2 and NO_3 concentrations; when concentrations were less than the laboratory reporting limit, one half of the laboratory reporting limit was substituted with lesser values to calculate TN concentrations and descriptive statistics

N nitrogen, *P* phosphorus, *OP* orthophosphorus, *TP* total phosphorus, *NH_3* ammonia, *TKN* total Kjeldahl nitrogen, *NO_3* nitrate, *NO_2* nitrite, *TN* total nitrogen, Chl *a*, chlorophyll *a*, *TOC* total organic carbon, *Secchi* transparency, *NR* results not reported because of quality-assurance concerns

indicating water-quality differences between Spring Lake and Cove Lake. Median Chl *a* values were slightly more than 4 μg/L lower at Spring Lake than at Cove Lake (3.92 compared with 7.99 μg/L; Table 5), but mean Chl *a* values were only 0.11 μg/L different (7.13 compared with 7.24 μg/L; Table 5). Consequently, TSI Chl *a* results were the same for both lakes (Table 7).

Table 6 Wilcoxon signed rank test results indicating the probability that concentrations or field measures for the listed constituents were different

Constituent	Arkansas Valley ecoregion Cove and Spring	Ouachita Mountain ecoregion Hot Springs and Winona
Orthophosphorus	0.004*	0.008*
Total phosphorus	<0.001*	0.250
Total Kjeldahl nitrogen	0.002*	0.074
Total nitrogen	0.002*	0.074
Chlorophyll *a*	0.927	0.126
Total organic carbon	0.004*	<0.001*
Transparency	0.002*	0.005*

*$p \leq 0.05$, significant difference of concentrations measured at the two lakes. Total nitrogen was calculated by adding TKN to NO_2 and NO_3 concentrations and by using one half of the laboratory reporting level for censored values

Low N/P ratios (about 8:1 and 9:1, respectively) for Spring Lake and Cove Lake (Table 7), contradict most of the nutrient constituent data and reflect eutrophic conditions by most limnological standards (Wetzel 2001; Kalff 2002; Quirós 2002). The N/P ratios could be low because the lakes are fertilized to stimulate fish production. Ammonium phosphate (10–34–0) was applied in solution on three occasions in 2010 and 2011 (typically in June, July, and August) at a rate of one gallon per surface acre. Fertilizer was not applied in 2012 in Spring Lake and was only applied in August 2012 in Cove Lake. Both lakes are owned by the US Forest Service and are associated with campgrounds. Fishing is the primary recreational lake use and, with consultation from the Arkansas Game and Fish Commission, both lakes are fertilized in an effort to enhance fish production.

Profile data for the two AV lakes indicated normal patterns typical of thermal responses to seasonal changes. Both lakes were stratified from May through October. The thermocline varied from approximately 3 m in May

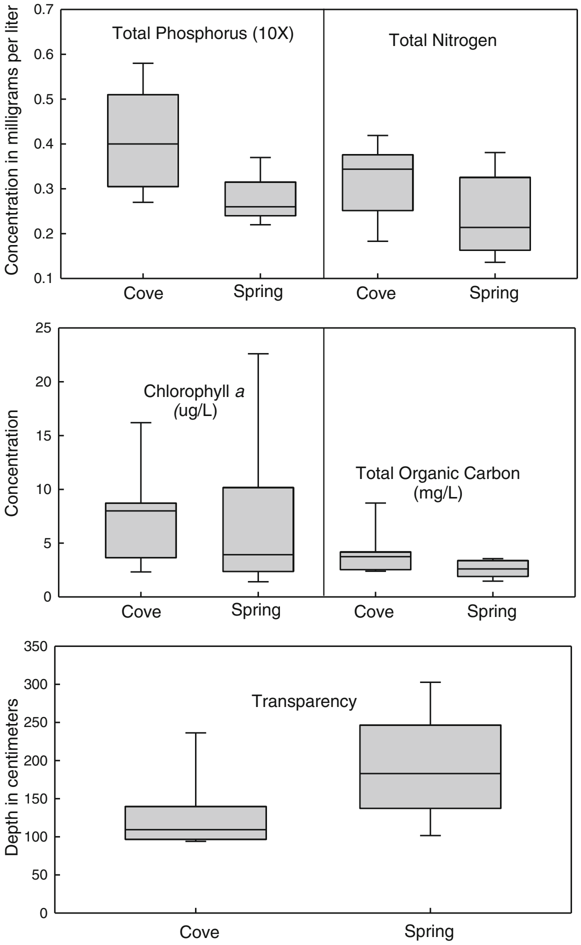

Fig. 2 A comparison of selected water-quality variables at two lakes within the Arkansas Valley, Cove and Spring Lakes, December 2011–October 2012

Table 7 Nitrogen:phosphorus ratios and trophic state indices for four potential reference lakes in Arkansas

Ecoregion	Lake name	N/P (median)	TP TSI	Chl *a* TSI
Arkansas Valley	Cove Lake	*9:1*	58	*50*
	Spring Lake	8:1	*52*	*50*
Ouachita Mountains	Hot Springs	*21:1*	*39*	42
	Lake Winona	18:1	41	*39*

Values in italics indicate the ratio of N/P or TSI value that represents the best water quality when comparing the two lakes; TSI values were calculated using mean concentrations; total nitrogen was calculated by adding TKN to NO_2 and NO_3 concentrations and by using one half of the laboratory reporting level for censored values

N/P nitrogen to phosphorus ratio, *TP* total phosphorus, *Chl a* chlorophyll a, *TSI* trophic state index

to 6 m in October. With the possible exception of the area immediately above the thermocline (profiles were measured at 0.6-m intervals), DO was not measured below the State standard of 5 mg/L in the epilimnion of either lake. In December and February, pH at Spring Lake fell slightly below the State WQS of 6 throughout all depths. In this case, however, deviations below the Arkansas WQSs are probably the result of natural variance rather than anthropogenic influence. Low pH is to be expected in this ecoregion because of slightly acidic rainfall (pH averages about 5.2 for the surrounding area, National Atmospheric Deposition Program 2011) and the low buffering capacity of minerals in the Boston Mountain area (Kresse and Hays 2009).

Continuous monitoring data collected over the 72-h monitoring period at the two AV lakes were more characteristic of oligotrophic lake conditions than eutrophic lake conditions (Table 8), (Wetzel 2001). However, constituents measured continuously for the 72-h monitoring period at Spring Lake and Cove Lake were so similar that they were not useful for distinguishing between the overall water-quality conditions of the two lakes. DO concentrations measured during the 72-h continuous monitoring effort were slightly lower and variation was slightly more at Spring Lake than at Cove Lake. For the 72-h monitoring period, mean DO concentrations were 7.42 mg/L and 8.38 and the range in concentration varied 2.61and 1.99 mg/L for Spring Lake and Cove Lake, respectively. These relatively slight differences could reflect physical or climatic variation (e.g., location of the monitoring site relative to wind direction or cloud cover) rather than productivity differences. Specific conductivity was stable at both lakes and varied less than 3 μS/cm for the 72-h monitoring period. The maximum specific conductivity measured at the two lakes was low (32.7 μS/cm) but is to be expected given the nature of the soils and geology in the area (Woods et al. 2004; Kresse and Hays 2009).

Reference lake quality for the Ouachita mountains

Results for several variables indicate that water quality of Hot Springs Lake may be slightly better than water quality of Lake Winona. However, all constituent concentrations were extremely low in both lakes indicating that water quality of these two lakes was very good and comparable (Table 5; Fig. 3). The most apparent water-quality differences for the two lakes were related to transparency and TOC concentrations. Transparency

Table 8 Descriptive statistics for DO and specific conductance and change per hour for DO data collected for 72 h at four potential reference lakes in Arkansas, August 2012

	Arkansas River Valley ecoregion		Ouachita Mountain ecoregion	
	Spring	Cove	Hot Springs	Winona
Descriptive statistics				
Date/time of deployment	15 Aug 2012	15 Aug 2012	15 Aug 2012	15 Aug 2012
Date/time of retrieval	19 Aug 2012	19 Aug 2012	19 Aug 2012	19 Aug 2012
Temperature (mean (°C))	29.22	27.82	28.65	28.48
Temperature change (°C)	3.21	3.07	2.62	3.57
DO percent saturation (min)	71.70	92.70	92.70	98.00
DO percent sat (max)	110.60	122.90	107.90	108.90
DO percent sat (variation)	38.90	30.20	15.20	10.90
DO percent sat (mean)	96.36	106.43	97.63	102.56
DO percent sat (median)	98.10	106.90	97.10	102.30
DO conc (min (mg/L))	5.64	7.43	7.35	7.77
DO conc (max (mg/L))	8.25	9.42	8.32	8.16
DO conc (variation (mg/L))	2.61	1.99	0.97	0.39
DO conc (mean (mg/L))	7.42	8.38	7.59	7.96
DO conc (median (mg/L))	7.57	8.42	7.54	7.96
SpCond (min (μS/cm))	27.10	30.40	49.30	20.80
SpCond (max (μS/cm))	28.10	32.70	50.70	21.40
SpCond (variation (μS/cm))	1.00	2.30	1.40	0.60
SpCond (mean (μS/cm))	27.71	31.98	50.00	21.02
SpCond (median (μS/cm))	27.70	32.00	50.00	21.00
Change per hour in DO for selected typical daytime monitoring periods				
Date/time calculation began	16 Aug 2012/12:00	16 Aug 2012/12:00	16 Aug 2012/12:00	16 Aug 2012/12:00
Date/time calculation ended	19 Aug 2012/12:00	19 Aug 2012/12:00	19 Aug 2012/12:00	19 Aug 2012/12:00
Hours used for calculation	72	72	72	72
DO sat change (total)	38.90	30.20	15.20	10.90
DO sat change (average/h)	0.54	0.42	0.21	0.15
DO conc change (total)	2.61	1.99	0.97	0.39
DO conc change (average/h)	0.04	0.03	0.01	0.01

DO dissolved oxygen, *SpCond* specific conductance, *conc* concentration, *max* maximum concentration, *min*, minimum concentration, *sat* saturation

was deeper at Hot Springs Lake on seven of the nine sampling occasions and TOC concentrations were lower at Hot Springs Lake than at Lake Winona for all eight samples (one result was not reported by the laboratory because of quality-assurance concerns, Table 5). Both transparency and TOC also were significantly different between the two lakes (Table 6). TOC concentrations often reflect the amount of material suspended in the water column, particularly phytoplankton, which can be directly related to TP and Chl *a* concentrations, as well at transparency (Justus 2009).

Concentrations of OP and TP also indicated that water-quality conditions at Hot Springs Lake exceeded those of Lake Winona. OP concentrations were above the MDL at Hot Springs Lake only on three of nine occasions but were above the MDL at Lake Winona on eight of nine occasions; OP data also were significantly different between the two lakes (Table 6). Differences for TP were even less obvious than differences in OP concentration. TP concentrations only exceeded the MDL at Hot Springs Lake in December 2011 and February 2012 but were above the MDL at Lake

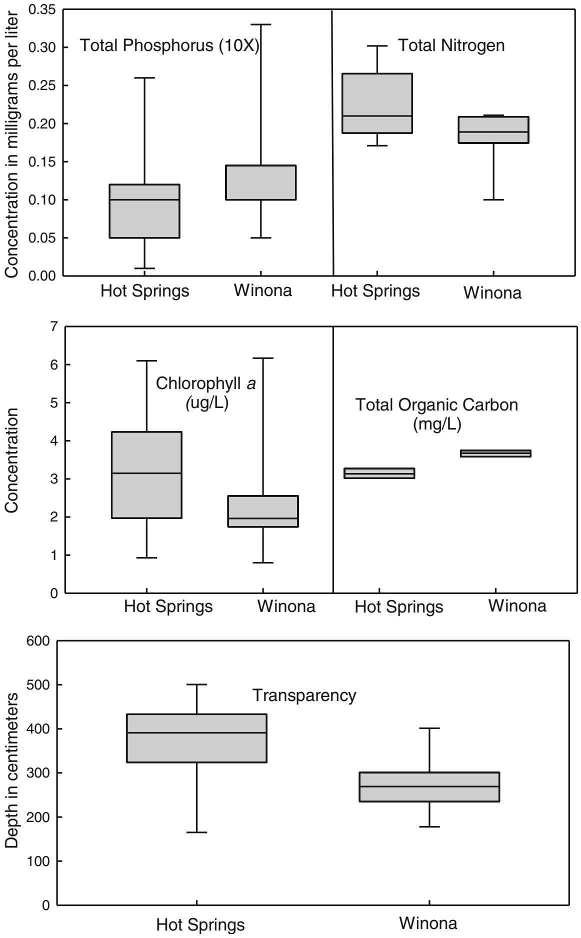

Fig. 3 A comparison of selected water-quality variables at two lakes within the Ouachita Mountains, Hot Springs Lake and Lake Winona, December 2011–October 2012

Winona in both those months and in April. Concentrations of TP were slightly higher at Lake Winona and, relatedly, TP TSI were slightly lower at Hot Springs Lake compared with Lake Winona (Table 7).

In contrast to phosphorus constituents, nitrogen constituents and Chl *a* generally were slightly higher at Hot Springs Lake compared with Lake Winona. At both lakes, NH_3 was only detected in December 2011 and February 2012 but detected concentrations were slightly higher at Hot Springs Lake compared with Lake Winona (Table 5). Nitrate plus nitrite was detected in two samples at Hot Springs Lake (December 2011 and February 2012) but was not detected in any samples at Lake Winona. Concentrations for TKN and TN were slightly higher at Hot Springs Lake compared with Lake Winona for seven of nine samples. Given that TP and OP concentrations were lower at Hot Springs Lake compared with Lake Winona, slightly higher and more frequent detections of nitrogen constituents at Lake Winona in the months of December and February may be related to differences in the two lakes regarding the ratio of lake surface area to forest buffer or, perhaps, to differences in precipitation rates and atmospheric deposition rates. At such low concentrations, sources of nitrogen could include organic nitrogen from decomposing leaves, as well as inorganic nitrogen from atmospheric deposition and snow. For these two lakes, differences in TP concentrations (which were lower at Hot Springs Lake) may be of more trophic significance than concentrations of nitrogen constituents.

The relation between Chl *a* and nutrients has been understood for mesotrophic and eutrophic lakes for some time (Jones and Bachmann 1976; Dillon and Riger 1974; McCauley et al. 1989), but the data collected in this study indicates that Chl *a* concentrations may not be as useful for indicating productivity of oligotrophic lakes. Chl *a* concentrations were slightly higher at Hot Springs Lake compared with Lake Winona for six of nine samples (Table 5); however, mean concentrations at both lakes were less than 3.5 μg/L and were less than 1 μg/L different. It seems likely, that at the low concentrations inherent to true reference lakes in the oligotrophic setting, variability associated with laboratory analysis may negate the use of Chl *a* and other chemical constituents for detecting water-quality differences.

Similar to the two lakes evaluated in the AV, lake profile data collected from Hot Springs Lake and Lake Winona (not shown) did not indicate these lakes were influenced by nutrient enrichment or anthropogenic effects. Profile data for the two lakes indicated stratification patterns that were typical of seasonal changes and data were not useful for indicating if either lakes was more or less productive than the other. A DO concentration of 5 mg/L is the Arkansas WQS and also was used in this study to indicate the depths at which the lakes begin to stratify. Concentrations for DO decreased below 5 mg/L at approximately the same depth in late summer (e.g., August was 7.6 m and September was 5.8 m) for both lakes.

In December 2011, pH at Lake Winona fell slightly below the State WQS of 6 throughout all depths. Similar to Spring lake (described above), and in this particular situation, low pH is likely unrelated to anthropogenic disturbance in the watershed, but rather, to the combined effects of slightly acidic rainfall and the low buffering capacity of minerals throughout the Ouachita Mountains (Kresse and Hays 2006).

Consistent with the profile data and similar to the situation for the two AV lakes, continuous monitoring data collected at the two Ouachita Mountain lakes for the 72-h period in August 2012 were of limited value for water-quality comparisons. Mean DO concentrations for Lake Winona and Hot Springs Lake were relatively high; 7.96 and 7.59 mg/L, respectively (Table 8). Rates of change for DO concentration during the continuous 72-h monitoring period were 0.01 mg L^{-1} h^{-1} for both lakes indicating that concentrations also were very stable. Specific conductivity was stable at both lakes for the 72-h monitoring period but values at Hot Springs Lake were slightly more than twice that of Lake Winona. Specific conductivity can indicate anthropogenic sources; however, given the low concentrations at both lakes (medians were 50 and 21 μS/cm), higher specific conductance at Hot Springs Lake compared with Lake Winona, is likely related more to differences in soils or geology at the two lakes than to anthropogenic sources (Woods et al. 2004).

Overall constituent value for differentiating between lakes in low productivity situations and comparisons to state criteria

Results for this study indicate that when nutrient concentrations are low, transparency may be more valuable for differentiating between lake water quality than chemical constituents and other studies have arrived at this conclusion (Peeters et al. 2009). Some advantages of transparency over chemical constituent analysis are that measurements are very simple, no expensive analytical or sampling equipment is required, variability associated with the determination does not exceed natural constituent differences, particularly when concentrations are extremely low, and much of the public associates water clarity to favorable water quality.

By contrast, some constituents that have been useful for distinguishing between water-quality conditions in mesotrophic and eutrophic settings, such as Chl *a* and DO (Wetzel 2001; Justus 2009), were not useful for distinguishing between water-quality conditions in this oligotrophic setting (Table 7). Concentrations for Chl *a* are generally very low (less than 5 μg/L) in pristine lakes in the ecoregions that were studied and Chl *a* analysis may be susceptible to more variability than dissolved constituents when concentrations are near zero (Ficek and Wielgat-Rychert 2009). Furthermore, Chl *a* concentrations would not be expected to be as uniformly distributed as concentrations of dissolved constituents.

DO data that were measured during profiling and during the continuous monitoring effort also were not useful for indicating whether any of the four lakes that were monitored were more or less productive. Although DO concentrations varied slightly among lakes, concentrations were relatively high and stable for both pairs of lakes. In this oligotrophic setting, the diurnal variability that is typically associated with DO in more productive settings was not evident.

For all four lakes that were sampled intensively, some constituents that were detected in the months of December and February were not detected in other months. In the case of nitrogen constituents, detections may have resulted from organic nitrogen in leaves that fall (or are washed) into the lake in late fall, or from snow fall. Whereas, for phosphorus constituents, winter concentrations may be related to destratification that generally occurs in late fall. As lakes were mixed during the fall turnover period, phosphorus released from sediments on the lake bottom during stratification could have been mixed throughout the water column (Wetzel 2001; Cooke et al. 1993).

Arkansas WQSs (Arkansas Department of Environmental Quality 2007) state that lake pH should not decline below 6.0 or exceed 9.0. None of the four lakes that were monitored in the intensive phase had values that exceeded a pH of 9; however, pH declined below 6 in the hypolimnion of all lakes and declined below 6 in the epilimnion of Spring Lake and Lake Winona in December and in Spring Lake in February (Table 9). Given that all other indications were that these two lakes had excellent water quality, this standard may not be applicable to lakes in this ecoregion.

Water-quality comparison to other reference lakes

Data collected in this study suggest that Spring Lake is a suitable reference lake for the AV and that Hot Springs Lake is a suitable reference lake for the Ouachita Mountains. It may be necessary, however, to conduct additional monitoring before numeric nutrient criteria are established for the two lake classifications. Intensive sampling was conducted only through an 11-month period, and lake conditions can be susceptible to change in response to biological, hydrological, and physical

Table 9 Violations of Arkansas water-quality standards for DO and pH values measured at four potential reference lakes on nine occasions between December 2011 and October 2012

Profile data	Arkansas Valley ecoregion		Ouachita Mountain ecoregion	
	Cove Lake	Spring Lake	Hot Springs Reservoir	Lake Winona
Times when DO concentration was <5.0 mg/L[a,b]	0	0	0	0
Number of sampling months when pH was <6.0[b]	*2*	*2*	*1*	*2*
Number of sampling months when pH was >9.0	0	0	0	0
First month of DO stratification[a]	May	May	Jun	May
Continuous monitoring data				
Minimum DO concentration (mg L^{-1})	7.43	5.64	7.35	7.77

Values in italics indicate a state water-quality standard violation

DO dissolved oxygen

[a] DO profile data from the hypolimnion were not included when lakes were stratified but data from all depths were included when lakes were not stratified. Stratification is defined as the point where the temperature changed more than 3 °C over a depth of 0.6 m

[b] The Arkansas water-quality standard for DO is 5.0 mg/L. Water-quality standards for pH state that pH should not be less than 6 or be greater than 9 and should not change more than one unit in a 24-h period (Arkansas Department of Environmental Quality 2007).

[c] Continuous data were collected 0.3 m below the lake surface at 30-min intervals for a 72-h period

alterations even when nutrient sources are relatively stable (Cooke et al. 1993).

Median values of TP, TN, Chl *a*, and transparency for Spring Lake and for Hot Springs Lake were compared with four reference lakes identified in four other Arkansas ecoregions (Justus 2009), including 28 lakes in three Missouri ecoregions (Mark Osborn, Missouri Department of Natural Resources, written communication,

Table 10 Median values for selected constituents and transparency at two potential reference lakes in Arkansas compared with median values for those same measures at reference lakes in Missouri and Kansas and at least-impaired lakes in Texas and Arkansas

State	Lake location/characterization	Number of lakes sampled	Total phosphorus (mg/L as P)	Total nitrogen (mg/L as N)	Chlorophyll *a* (μg/L)	Secchi depth (cm)
Arkansas	Spring Lake	1	0.026	0.214	3.9	183
Arkansas	Hot Springs Lake	1	0.010[d]	0.210	3.2	391
Missouri	Lakes in the Ozark Highlands[a]	14	0.009	0.270	3.0	257
Missouri	Central Irregular Plains[b]	7	0.030	0.670	9.2	101
Missouri	Lakes bordering the Ozark Highlands[b]	9	0.035	0.580	14.1	99
Missouri	Disconnected Big River Lake[b]	1	0.067	1.020	36.1	79
Texas	South Central Plain Lakes and Reservoirs[b]	9	0.029	NA	5.6	NA
Kansas	Six ecoregions[bc]	47–58	0.023	0.625	8.0	129
Arkansas	Crowleys Ridge Reservoir[b]	1	0.026	0.556	7.6	109
Arkansas	Mississippi Alluvial Plain Oxbow Lake[b]	1	0.034	0.616	21.3	175
Arkansas	South Central Plains Reservoir[b]	1	0.046	0.476	15.1	69
Arkansas	Mississippi Alluvial Plain Reservoir[b]	1	0.086	0.900	23.7	86

N nitrogen, *P* phosphorus, *Secchi depth* transparency, *Plains* Central Irregular Plains ecoregion, *Ozark border* lakes bordering the Ozark Highlands, *NA* data unavailable

[a] Data for lakes in the Ozark Highlands were provided courtesy of Mark Osborn with the Missouri Department of Natural Resources

[b] Data originally compiled from various sources in Justus (2009)

[c] Data were compiled using best professional judgement regarding reference quality and from 47 to 58 lakes depending on the measurement.

[d] Calculated using one half of the laboratory reporting limit for less than values

February 2013), and 47–58 Kansas lakes (depending on the measurement) identified for six Kansas ecoregions (Dodds et al. 2006) (Table 10). Median concentrations measured at Hot Springs Lake for Chl *a* were very similar to Chl *a* concentrations measured in lakes in the Ozark Highlands that were sampled in Missouri (i.e., 3.2 compared with 3.0 μg/L) but all other median concentrations calculated for Hot Springs Lake were lower than median concentrations calculated for reference lakes in the other ecoregions in Arkansas, Missouri and Kansas (adjacent states). With the exception of median TP concentrations at lakes in the Ozark Highlands that were sampled in Missouri, median values for Spring Lake generally were comparable or lower than median values of TP, TN, Chl *a*, and transparency measured at most reference lakes identified in other ecoregions in Arkansas, Missouri, and Kansas.

Conclusions

The process of locating reference lakes can be prohibitively time consuming and expensive for States, but it is a first step in a common approach used to develop water-quality standards for all types of waterbodies. This report describes the methods used and data collected to identify reference lakes in two lake classifications common to parts of two level III ecoregions in western Arkansas—the Arkansas Valley and the Ouachita Mountains. Nutrients were selected as a water-quality surrogate to represent anthropogenic risk because of the relatively large number of Arkansas lakes that USEPA considers to be impaired by nutrients.

Two phases of study—screening and reconnaissance—were used to identify and eventually select four lakes for intensive water-quality sampling (the third phase of study). The four lakes were sampled for nine sampling events over an 11-month period. The screening phase utilized GIS methods to characterize land cover and land use in all test lake watersheds, which was used to identify lakes for a one-time water-quality sampling event in the reconnaissance phase. For the Arkansas Valley, intensive sampling was conducted at Spring Lake and Cove Lake. For the Ouachita Mountains, intensive sampling was conducted at Hot Springs Lake and Lake Winona. Our data suggest that Spring Lake is a suitable reference lake for the Arkansas Valley and that Hot Springs Lake is a suitable reference lake for the Ouachita Mountains. Median values of TP, TN, Chl *a*, and transparency for Spring Lake and Hot Springs were comparable or lower than median values of TP, TN, Chl *a*, and transparency measured at most reference lakes identified in other ecoregions in Arkansas, Kansas, and Missouri (adjacent states).

Arkansas WQSs state that lake pH should not decline below 6.0 or exceed 9.0. No lakes had pH values that exceeded the latter two criteria, however, pH declined below 6 in the hypolimnion of all lakes and declined below 6 in the epilimnion of two of the four lakes in December. In this case, however, deviations below the Arkansas WQSs are probably the result of natural variance rather than anthropogenic influence. Low pH is to be expected in these ecoregions because of slightly acidic rainfall (pH averages about 5.2 for the surrounding area) and the low buffering capacity of minerals in the Boston Mountain area.

Our results indicate that when nutrient concentrations are low, transparency may be more valuable for differentiating between lake water quality than chemical constituents that have been useful for detecting water-quality differences in mesotrophic and eutrophic settings. For example, in this oligotrophic setting, concentrations for Chl *a* can be very low (less than 5 μg/L) and diurnal variability that is typically associated with DO in more productive settings was not evident. Some advantages of transparency over chemical constituent analysis are that measurements are very simple, no expensive analytical or sampling equipment is required, variability associated with the determination does not exceed natural constituent differences when concentrations are extremely low, and much of the public associates water clarity to favorable water quality.

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