**Comments on the Draft: *Assessment Methodology for the Preparation of
The 2014 Integrated Water Quality Monitoring and Assessment Report, and
The 2016 Water Quality Monitoring and Assessment Report, authored by
the Arkansas Department of Environmental Quality (ADEQ)***
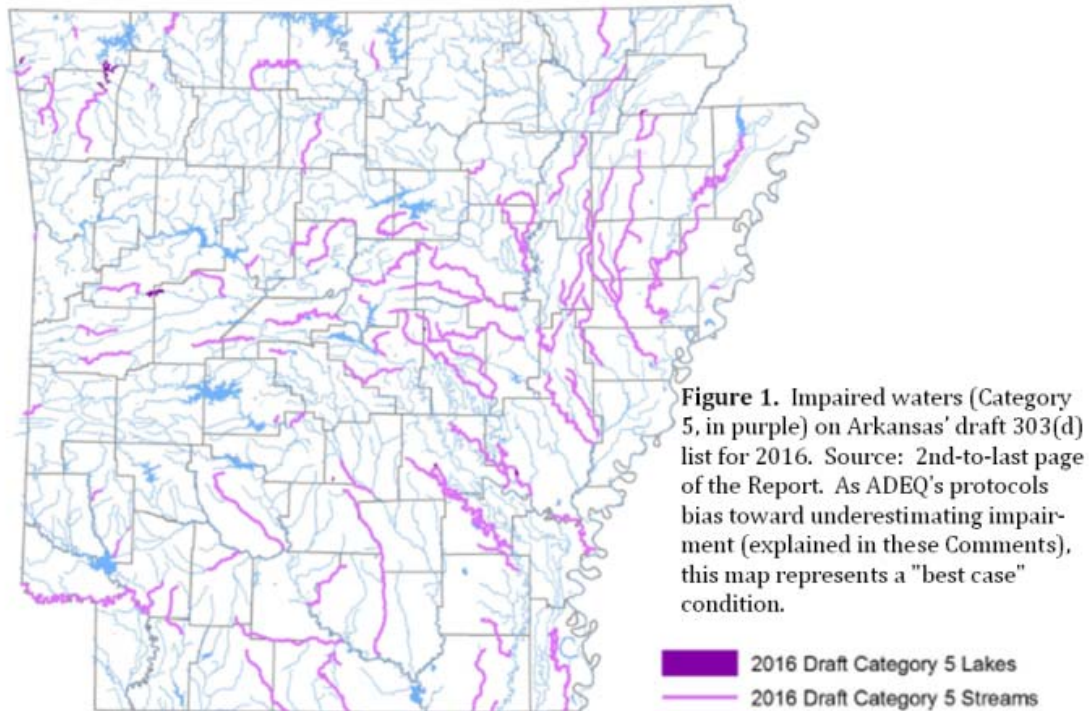
JoAnn M. Burkholder, Ph.D., 15 March 2016

My comments on the draft report, *Assessment Methodology for the Preparation of The 2014 Integrated Water Quality Monitoring and Assessment Report, and The 2016 Water Quality Monitoring and Assessment Report*, hereafter referred to as the Report, were requested by Ms. Anna Weeks, Environmental Policy Associate of the Arkansas Public Policy Panel. These comments represent my professional opinion as a specialist with more than 30 years of experience in water quality analysis and assessment. An updated copy of my curriculum vitae is attached.

Overall Evaluation

The designated uses of Arkansas surface waters include use by Aquatic Life, and uses for Domestic Water Supply; Primary and Secondary Contact; and Agricultural and Industrial Water Supply (Report, p.24). A total of 87, 617 stream and river miles occur in the state (p.20), but only 18% (16,135 miles, p.18) are digitized in the Arkansas Department of Environmental Quality (ADEQ) Water Base Layer, suggesting that only 18% are monitored. It is doubtful, based on the Report, that even 18% are actually monitored, considering that the writing (p.23) states that "Monitoring segments without stations, where data from another segment is used for evaluating attainment, are identified as 'evaluated'….for tracking purposes." Thus, most Arkansas waters are not monitored despite indication, from the relatively few that *are* monitored, that many of the state's surface waters are impaired (see Figure 1 on the next page of these Comments).

The U.S. Environmental Protection Agency (EPA 2005) describes assessments based on larger sample sets as more likely to yield accurate conclusions than assessments based on smaller sample sets, while also recognizing difficulties that can be imposed by expense and logistics (U.S. EPA 2002). Unfortunately, however, Arkansas has taken reliance upon sparse data to an extreme; ADEQ sanctions sampling numbers and frequencies that are seriously inadequate and do not enable accurate assessment. The sparse data deemed acceptable for evaluation of use attainment bias the findings against impairment.

There are numerous other non-science-based steps in ADEQ's evaluation protocols. As examples, some integrated reporting categories, by definition, fail to provide protection to impaired waters and instead can allow them to continue to degrade indefinitely. The Biological Integrity Assessment protocol wrongly "transforms" substantially compromised Partially Supporting communities into a "Fully Supporting" designation. For fish communities, the assessment protocol evaluates substantially decreased taxa richness, the loss of sensitive aquatic life, and increased abundance of pollution-tolerant species as "supporting" designated uses for Aquatic Life, again wrongly resulting in a "Fully Supporting" overall assessment. The dissolved oxygen (DO) standard for reservoirs is applied by ADEQ only to near-surface waters (depth, 1 meter); yet, hypoxia generally occurs first in

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Figure 1. Impaired waters (Category 5, in purple) on Arkansas' draft 303(d) list for 2016. Source: 2nd-to-last page of the Report. As ADEQ's protocols bias toward underestimating impairment (explained in these Comments), this map represents a "best case" condition.

2016 Draft Category 5 Lakes
2016 Draft Category 5 Streams

the bottom waters and then increasingly affects shallower waters as the critical summer season progresses (Wetzel 2001). Thus, nearly the entire water column of a given impoundment ("lake") would have to become hypoxic or anoxic before a violation of the standard would occur – and, because ADEQ has monitored the state's reservoirs only once in five years, such extreme conditions could occur during the summer critical period for four years before any sampling would be conducted.   Streams with small watersheds (defined as having an area less than 10 square miles) anywhere in the state, even in the Ozark Highlands, are evaluated as having "acceptable" water quality during the critical summer season if DO is at an hypoxic level (2 mg/L) which repeatedly has been shown to cause death of many biota. Small headwater streams, known to be extremely important to river ecosystems of Arkansas, have been decreed by ADEQ without scientific basis to have insufficient flow to warrant higher DO criteria during the critical summer period. Despite asserting otherwise, the state has **no** numeric nutrient (quantitative nitrogen and phosphorus) criteria and the Report indicated no plans to develop them.   Moreover, ADEQ's seriously inadequate assessment protocol for nutrient-related impairment will fail to protect many actually-impaired Arkansas surface waters from loss of designated uses due to nutrient pollution.   The analysis in support of this overall evaluation is given below.

Supporting Analysis

1. *Integrated reporting Categories 4b, 5-medium, and 5-low fail to provide protection to impaired waters and instead allow them to continue to degrade indefinitely.*

Arkansas has considered U.S. EPA (2011) guidance in using five "integrated" reporting categories for monitored waterbody segments in that state:

- Category 1 – all designated uses attained, no use threatened;
- Category 2 – available data/information indicate that some, but not all, designated uses are supported;
- Category 3 – insufficient data/information available to evaluate attainment;
- Category 4 – water quality standards are not attained for one or more designated uses, but a total maximum daily load (TMDL) is not required because (a) a TMDL has already been completed; (b) other pollution control requirements are expected to result in attainment; or (c) non-support is not caused by a pollutant; and
- Category 5 – the waterbody is impaired, and one or more water quality standards not attained.

ADEQ then went beyond the above U.S. EPA-recommended categories by devising three subdivisions within Category 5 including:

High – "truly impaired:" a TMDL should be developed or other corrective action(s) taken;

Medium – the waterbody is not presently attaining water quality standards, but it may be delisted if the state revises its water quality standards in the future; and

Low – the waterbody is not attaining one or more water quality standards, but all designated uses are determined to be supporting; or there is insufficient data to assess attainment; or ADEQ assessed the waterbody as not impaired, but the U.S. EPA assessed it as impaired.

The Category 4(b) designation provides no description about the waiting (delay) period that is "acceptable" (months? years?) before actions will be required to improve the impaired waterbody. ADEQ's "medium" subcategory within Category 5 is similarly problematic; it allows no cleanup indefinitely, simply based on the premise that the state *may* revise the water quality standard(s) in violation at some vague future date. Lack of protection for surface waterbodies similarly characterizes subcategory "Low" within Category 5. Waters that are known to be in violation of one or more water quality standards are considered low priority for cleanup if ADEQ assesses all designated uses to be supported. However, the sampling upon which ADEQ's assessment is based is inadequate to enable sound scientific evaluation, and it is biased against finding impairment (see #2 below). Alternatively, waters assessed as impaired by the *U.S. EPA* are prioritized "Low" for cleanup if *ADEQ* considers them unimpaired, with no further explanation as to how/why the state and federal assessments diverged. Thus, ADEQ states here that it can all-but-ignore (that is, prioritize "Low") a federal assessment of "impaired."

A third alternative under Category 5 that results in consideration of an impaired waterbody as "Low" priority for cleanup requires clarification: The waterbody will be so prioritized if there are insufficient data to make a scientifically defensible decision regarding attainment of designated uses. – Yet, why would such waters be evaluated as impaired if the data are insufficient to assess attainment? Why would they not instead be designated as Category 3? One answer may be that such waterbodies are clearly, visually impaired – for example, characterized by high-biomass algal outbreaks ("blooms") and major fish kills – but measurements have not been taken. It would seem important to the people of Arkansas to prioritize waters that are clearly, visually impaired as "High" rather than "Low" for data gathering and cleanup.

2. *The required sample numbers and sampling frequency are inadequate and, thus, do not enable accurate condition assessment.*

    a) Q*uarterly or bimonthly sampling is inadequate to assess attainment of water quality criteria and designated uses.*

Accurate assessment of water quality critically depends upon adequate monitoring (Burkholder et al. 2010, Reed et al. 2010). In its protocols to assess use attainment, ADEQ uses exceedingly sparse data to attempt to assess "average" conditions, compliance with water quality criteria, and use attainment. These exceedingly sparse data are not based in science. The Report (p.13) describes two tiers of data (Tiers III and IV) that are used for assessment of attainment of designated uses in a given waterbody. These tiers allow quarterly (III) or bimonthly (III, IV) sampling during key periods (e.g. the summer season for low DO). However, quarterly or bimonthly sampling is inadequate to assess attainment of water quality criteria and designated uses. Quarterly data are insufficient to assess average conditions in surface waters because they miss many storm events and associated higher nutrient concentrations, as well as drought periods with substantially altered water quality, which would be detected with more frequent sampling (Stansfield 2001, Hollabaugh and Harris 2004).

For determining whether a waterbody is meeting state criteria and attaining its designated uses, a body of science publications has shown that data collected at least monthly during the same growing season of the same year, then repeated the next year, are needed to assess conditions accurately (e.g. Harmeson and Barcelona 1981, Robertson and Roerish 1999; U.S. EPA 2000a,b; Stansfield 2001; Hollabaugh and Harris 2004). Assessment of average conditions should also encompass baseflow, stormflow, and wetflow conditions (Hollabaugh and Harris 2004). Only a few data points over an entire year (ADEQ accepts only 2 per year; see #2b below) are inadequate to accurately assess compliance with criteria or impairment. As Stansfield (2001) noted, if sampling frequency is changed from monthly to quarterly, many statistically significant trends detected from the monthly water quality data "disappear."

For Tier III data, the report (p.13) states that "limited use" of continuous monitoring instruments is sufficient, but provides no information as to the actual amount of sampling that is acceptable to ADEQ. When this point is considered together with what ADEQ views as acceptable temporal coverage ("adequate to monitor for chronic conditions…"), such a vague description translates into waterbodies so inadequately sampled that impairment would easily be missed. For example, consider a waterbody that is actually impaired by low DO, with pre-dawn oxygen sags common over much of the mid- to late summer but not the early summer. Pre-dawn is the time of day when low DO conditions usually are worst, that is, when aquatic organisms are most vulnerable to stress and death from low DO (Hynes 1980, Morgan et al. 2006, Miltner 2010). If ADEQ regards one to a few diel (24-hour) periods to be an acceptable amount of "limited use" of continuous monitoring instruments during the critical summer season, and if the 24-hour periods are selected to be in *early* summer, then severe low DO impairment that occurs throughout much of the summer would be entirely missed (e.g. Morgan et al. 2006). The waterbody would be evaluated as "attaining" its designated uses when, in reality, cryptic early life history stages of beneficial aquatic life would die unnoticed throughout the mid- to late summer from undetected low DO conditions; recruitment failure of many species would occur; and no protective cleanup would be planned.

b) *As few as 10 water quality samples, over as long as 5 years, is inadequate to assess average conditions accurately, or to determine whether a waterbody supports its designated uses..*

ADEQ (Report, p.10) relies upon as few as 10 water quality samples, over as long as 5 years, to assess whether a given waterbody supports its designated uses. This sampling is seriously inadequate to enable accurate assessment (see references cited in comment #2 above), requiring only 2 samples per year. It is not science-based, as it would easily miss stormwater runoff, baseflow conditions, pollutant spills, algal outbreaks, and other stochastic events that strongly control the true "average" conditions. The approach by ADEQ to rely upon extremely sparse data does not enable even "somewhat" realistic assessment of use attainment. ADEQ's approach instead strongly biases the findings against impairment.

3. *The protocol for assessment of Biological Integrity does not stipulate that temperature extremes should be avoided during data collection, and does not account for inter-annual variation which can be substantial, even extreme.*

The report describes assessment of only one biological assemblage (Tier III) – either macro-invertebrates or fish – over at least two seasons as acceptable by ADEQ for assessment of Biological Integrity. There is no requirement that the seasons should be selected so as to avoid temperature extremes (Maxted et al. 2000). Data collection over two years is described as preferable, but it is not required; thus, there is no effort to address or account for inter-annual variation, which can be substantial (Resh and Rosenberg 1989). Acute and chronic toxicity tests of vertebrates (fish) and (macro)invertebrates are considered if available, but they are not required either for use assessment (Report, p.26).

4. *The Biological Integrity Assessment protocol fails to protect already-impaired surface waters because substantially compromised Partially Supporting communities are wrongly "transformed" into a Fully Supporting designation.*

ADEQ (Report, p.28) considers four categories of status in evaluating macroinvertebrate assemblages:

Comparable to Reference (by 90% or more) = expected to support the community structure present at the reference site.

Supporting (75-88% comparable to reference site) = should support a diverse community similar to that at the reference site.

Partially Supporting (60-73% comparable to reference site) = difference in the biological community may be due to poor habitat; comparisons may be difficult.

Non-supporting (< 58% comparable to reference site) = should not be expected to support the community present at the reference site.

Scrutiny of the above descriptions shows that "partially supporting" is poorly described. Readers are informed that 'one cannot be certain' as to why the scores indicate that the macroinvertebrate communities are only 60-73% comparable to the healthy macroinvertebrate community at the reference site. Readers are also informed that 'comparisons [to the reference community] may be

difficult' due to poor habitat. Poor habitat, however, frequently includes poor water quality (Rebich et al. 2004); yet, the strong possibility/probability that the compromised scores at least partly reflect poor water quality is not mentioned here by ADEQ. A macroinvertebrate community that only includes 60% of the species richness and/or abundance of those attributes at the reference site is considerably compromised. After all, Partially Supporting is the same as "Partially Not Supporting."

The Partially Supporting category "suddenly" becomes "Supporting" (S) in the final evaluation, as shown in Table XI (Report, p.30):   The substantially compromised macroinvertebrate community designated as only Partially Supporting "disappears" and the overall evaluation becomes either "Fully Supporting" or Non-Support (see Table XI of the Report, reproduced below as Table 1 of these Comments).

Table 1. Aquatic Life Designated Use Listing Protocol (Table XI in the Report).

Type of Data Present	Evaluation Result		Final Assessment	Listing Category
	Fish Community	Macroinvertebrate Community		
Fish Community and/or Macroinvertebrate Community	S	S	FS	1
	S	NS	NS	5
	NS	S	NS	5
	NS	NS	NS	5
At Least One Biological Community	S	NA	FS	1
	NA	S	FS	1
	S	S	FS	1
	NA	NA	UA	3
	NS	NA	NS	5
	NA	NS	NS	5

S = Support   NS = Non-Support   FS = Fully Supporting   NA = No Available Data   UA = Unassessed

This "sleight of hand" fails to protect already-substantially-compromised communities from further degradation. Instead, it obscures substantially compromised, only-partially-supporting (or, said another equally valid way, partially non-supporting) communities and then artificially "changes" them to "S", "Supporting."   There is no science-based rationale for this step by ADEQ to quietly ignore Partially Supporting macroinvertebrate communities and wrongly evaluate them as "supporting," then as "fully supporting."

5. *The Biological Integrity assessment protocol is not protective of fish communities because it evaluates decreased taxa richness and loss of sensitive aquatic life as wholly "supporting" designated uses.*

The fish community structure indices (Report, p.29) show total score ranges and categories for each of several designated ecoregions. The scores and categories apparently are applied across ecoregions. For example, non-delta scores for watersheds larger than 10 square miles in area are as follows:

mostly similar	25-32	(highest score or healthiest fish community)
generally similar	24-17	
somewhat similar	16-9	
not similar	8-0	

Note that streams draining watersheds smaller than 10 square miles in area, which include ecologically important, perennial headwater streams (as well as ephemeral streams), apparently are not evaluated (and see Comment #6b below).

According to Table X (p.30), assessment of use attainment support based on fish communities considers both "mostly similar" and "generally similar" categories (note the vague descriptions) to be acceptable or "supporting." A score as low as 17 out of 32, only a little more than half of the total scale, leads to an overall assessment of "supporting." "Generally similar" is described as:

> "Community structure less than expected. Taxa richness lower than expected. Some intolerant taxa loss. Percent contribution of tolerant forms may increase."

Thus, the approach is not protective because it sanctions loss of species diversity, loss of sensitive species, and an increase in pollution-tolerant forms as "acceptable" or supporting, which the protocol then "translates" to an overall evaluation of "fully" supporting as shown in Table XI.

6. *Certain important features of the Arkansas dissolved oxygen criteria are neither science-based nor protective of the state's surface waters.*

   a) *The reservoir DO criterion applies only to near-surface waters (depth 1 meter) and, thus, fails to protect beneficial aquatic life in lower-water-column and benthic (bottom) habitats.*

Hypoxia/anoxia much more commonly and severely impact aquatic life in benthic and lower-water-column habitats than in near-surface waters (Wetzel 2001). Hypoxic conditions typically begin in deeper waters and sediments, then spread to impact aquatic life in mid-depth waters. Very rarely – even when most of the water column is hypoxic or anoxic – does hypoxia/ anoxia impact near-surface waters, for two reasons. First, those waters are closest to the overlying air, which is an important *source* of oxygen to them (Wetzel 2001). Second, algae and plants usually are most abundant in near-surface waters, and their photosynthesis increases the DO during the day (Wetzel 2001, Burkholder and Glibert 2013) when measurements typically are taken. Thus, a DO criterion applied only to a depth of 1 meter means that nearly the entire reservoir water column would have to become hypoxic/anoxic before the Arkansas DO criterion would indicate impairment.

   b) *A hypoxic DO concentration of 2 mg/L, known to severely stress and kill many aquatic species, is irrationally "acceptable" for ecologically important, small perennial headwater streams throughout the state . This standard is not science-based.*

Headwater streams repeatedly have been shown to be vitally important to entire river ecosystems (Leopold et al. 1964 in Allen and Castillo 2007). As Meyer et al. (2007, pp.86,98) wrote,

> The influence of headwaters on downstream systems emerges from their attributes that meet unique habitat requirements of residents and migrants by: offering a refuge from temperature and flow extremes, competitors, predators,

and introduced species; serving as a source of colonists; providing spawning sites and rearing areas; being a rich source of food; and creating migration corridors throughout the landscape. *Degradation and loss of headwaters and their connectivity to ecosystems downstream threaten the biological integrity of entire river networks* [emphasis added]....Biological connectivity between headwater and downstream ecosystems is considerable and essential for the maintenance of species diversity in downstream ecosystems.

During summer, these small 1st to 3rd order streams in some regions of Arkansas can be reduced to a series of enduring pools as a natural hydrologic progression (Hedman et al. 1987, Taylor and Warren 2001, Woods et al. 2004).

Densities of aquatic insects and fishes have been reported to increase as the pools become more isolated (Williams et al. 2003). Pools in these streams can vary greatly in DO, ranging from well above 5 mg/L to hypoxic at ~3.5 mg/L in summer (e.g. Figure 2). In other areas, however, such as the Ouachita Mountains and Ozark Highlands, small streams remain DO-replete (Woods et al. 2004). Some small streams in Arkansas are perennial, meaning that flow generally is maintained through-out the critical summer period. The natural flows which maintain high biological diversity in DO-replete, shallow waters of these streams can be well below 1 cfs (Hedman et al. 1987, Woods et al. 2004).
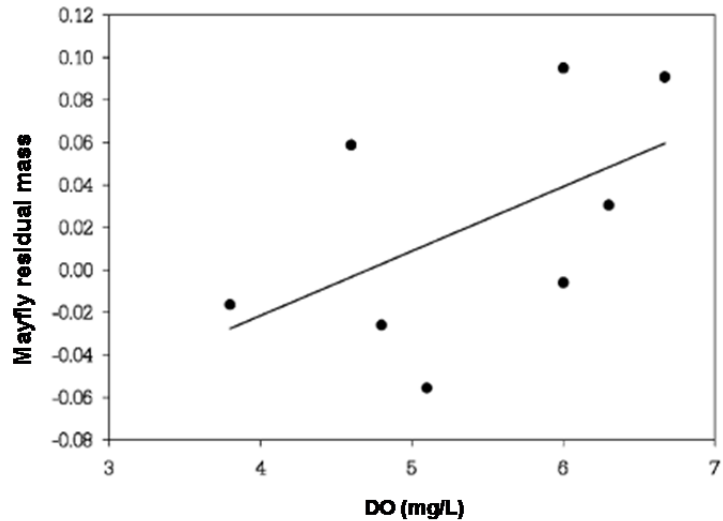

Figure 2. Linear regression between DO and body condition of low-DO-sensitive mayfly larvae from isolated pools in the Alum Fork of the Saline River (summer 2002). Measurements of DO were averaged across months (June-July). From Love et al. (2005).

The Report contains the following DO criterion for small perennial headwater streams draining watersheds less than 10 square miles in area. These **perennial** (= naturally flowing all year) streams, encompassing both first-order and second-order streams (Table 2) are considered together with ephemeral (intermittent) streams, without scientific basis. Rather than being protected from hypoxia during the critical summer season, they are ***assigned*** a "severe hypoxia" standard:

> In streams with watersheds less than 10 square miles, it is ***assumed*** [emphasis added] that insufficient water exists to support a fishery during the critical season. During this time, a DO standard of ***2 mg/L*** [emphasis added] will apply to prevent nuisance conditions....

ADEQ (Report, p.38) defines "insufficient water" as a stream having less than 1 cubic foot per second (cfs) of flow. Considering the science of small streams as summarized above, the ADEQ definition is not science-based and makes no sense scientifically. Many small streams in Arkansas

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are known to maintain high biological diversity during the critical summer season; many have DO-replete conditions; and most are either perennial with lower average summer flows than 1 cfs, or intermittent but with enduring, DO-sufficient pools. Yet, ADEQ's definition "forces" these streams to either flow at 1 cfs or higher, or be subjected to extreme hypoxia (see U.S. EPA information below) as an assigned minimum criterion.

ADEQ then requires stream-by-stream, individual site-specific "field site verification" to prove that "aquatic life exists at flows below 1 cfs" (although aquatic life is well known to exist in perennial streams with flow less than 1 cfs, worldwide) or that "unique aquatic biota [are supported in] "significant groundwater flows or enduring pools," before the waterbody is afforded protection by a higher DO standard.

Thus, *a priori the DO criterion applied during the critical summer season to small streams draining watersheds less than 10 square miles in area is severely hypoxic* (U.S. EPA, "Hypoxia 101," https://www.epa.gov/ms-htf/hypoxia-101). Exceptions are only made on a site-specific basis, only after field verification. According to "Hypoxia 101" by the U.S. EPA, "Hypoxic waters have dissolved oxygen concentrations of less than 2-3 ppm [mg/L]." Another U.S. EPA publication defines hypoxia as 3 mg DO/L or less (see http://omp.gso.uri.edu/ompweb/doee/science/physical/choxy1.htm), in close agreement with "Hypoxia 101."

Most temperate fishes begin to exhibit respiratory distress at dissolved oxygen levels of ~2.3 mg/L or less (Davis 1975, and references therein; also see Friedrich et al. 2014, Jenny et al. 2015). This DO criterion of 2 mg/L would be expected to stress or kill sensitive life history stages of all but the most tolerant species in small perennial streams. For example, based on an investigation of fish assemblages at 35 sites in lowland streams near Arkansas (southwestern Louisiana), a DO minimum of 2.5 mg/L was needed to maintain all but the most low-oxygen-tolerant species (Justus et al. 2012).

7. *Arkansas criteria for* Escherichia coli *in surface waters sanction **much** higher fecal bacteria densities than the threshold criteria recommended by the U.S. EPA (2012) to protect human health safety. Moreover, the Arkansas criteria allow violations of those criteria in up to 25% of samples as "acceptable"*

The Report (Table XIII, p.42, excerpted on the next page of these Comments) indicates that "acceptable" criteria for *E. coli* densities in Arkansas waters for primary contact range from a geometric mean (GM) of 126 colonies (col, or colony-forming units) per 100 mL in ERWs, ESWs, and NSWs, to 298-410 col per 100 mL during the May-Sept. recreational period.   In secondary contact waters, the "allowable" criteria for *E. coli* densities include a GM of 630 col per 100 mL in ERWs, ESWs, and NSWs; 1,490 col per 100 mL throughout the year in reservoirs; and 2,050 col/100 mL throughout the year in all other waters (rivers, streams, etc.). As the table also shows, up to 25% of the GMs, or up to 25% of the samples, can exceed these remarkably high standards and the waterbody is still evaluated as "acceptable."

As shown, the U.S. EPA (2012)- recommended *E. coli* densities to protect human health safety are significantly lower (that is, significantly more protective of human health safety) than the

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Arkansas values. The available information indicates that the Arkansas criteria allow, as "acceptable," a much higher estimated human illness rate than that of the U.S. EPA, i.e., much higher than 32 people becoming sick per 1000 exposed. Moreover, with exception of ERWs, ESWs, and NSWs, the Arkansas criteria allow even those high *E. coli* densities to be exceeded up to 25% of the time for GMs, or for up to 25% of the samples taken. This stipulation makes the criteria considerably weaker. Human health safety for primary or secondary contact recreation is ***not*** being protected by the Arkansas criteria for *E. coli*.

Table 2. Arkansas water quality standards for *Escherichia coli*:

	Escherichia coli	STANDARD	SUPPORT	NON-SUPPORT
PRIMARY CONTACT	ERW, ESW, and NSW Waters	GM 126 col/100 mL*	≤ standard	> standard
	Lakes, Reservoirs	298 col/100 mL (May-Sept)	≤ 25% exceedance	>25% exceedance
	All other waters	410 col/100 mL (May-Sept)	≤ 25% exceedance	>25% exceedance
SECONDARY CONTACT	ERW, ESW, and NSW Waters	GM 630 col/100 mL*	≤ standard	> standard
	Lakes, Reservoirs	1490 col/100 mL (anytime)	≤ 25% exceedance	>25% exceedance
	All other waters	2050 col/100 mL (anytime)	≤ 25% exceedance	>25% exceedance

ERW: Extraordinary Resource Water NSW: Natural and Scenic Waterway ESW: Ecologically Sensitive Water
*Geometric mean can be calculated for any 30-day period within a season (primary season May 1 through September 30; secondary season October 1 through April 30).

Table 3. Two sets of threshold criteria recommended by the U.S. EPA (2012) for *Escherichia coli* fecal bacteria to protect human health safety in waters used for primary contact recreation. (Note: gm (GM) = geometric mean; STV = statistical threshold value.) The waterbody GM should not be greater than the selected GM magnitude in any 30-day interval; and there should be no greater than a 10% excursion frequency of the selected STV magnitude in the same 30-day interval.

Criteria Elements	Recommendation 1 Estimated Illness Rate 36 / 1000		Recommendation 2 Estimated Illness Rate 32 / 1000	
Indicator	gm (cfu / 100 mL)	STV (cfu / 100 mL)	gm (cfu / 100 mL)	STV (cfu / 100 mL)
Escherichia coli (fresh)	126	410	100	320

8. *Arkansas has no numeric nutrient criteria. The Report describes an inadequate approach for assessing nutrient-related impairment, which biases against finding nutrient-related impairment and fails to protect Arkansas surface waters from loss of designated uses due to nutrient pollution.*

Nutrient pollution is among the most important sources of impairment to the nation's waters (National Research Council 2000). In addition to impairment of Arkansas surface waters by nutrient and associated pollutants, the state adds about 7% of the total nitrogen and 10% of the total phosphorus to the Gulf of Mexico via the Mississippi River and, thus, is a significant

contributor to the nutrient pollution that feeds the major Dead Zone at the river mouth (Barvenik et al. 2009). The U.S EPA (2000a,b) mandated states to adopt ambient nutrient criteria for total phosphorus (TP) and total nitrogen (TN) that EPA had developed, or to develop their own scientifically defensible numerical criteria for nutrients that protect the designated uses of waterways.

ADEQ has included various waterbodies impaired by nutrient pollution on its 303(d) list. The Report (p.25) accurately describes numeric criteria as values that provide a quantitative basis for evaluating designated use support and for managing point and nonpoint loads to surface waters. Unfortunately, ADEQ has not followed through on this rhetoric regarding numeric nutrient criteria. A decade after U.S. EPA's mandate, the U.S. EPA/Office of Inspector General (Barvenik 2009) expressed concerns about the progress made by Arkansas to protect its waters from nutrient pollution. More than 15 years later, Arkansas still has not developed any numeric nutrient [N and P] criteria.   Instead, ADEQ has developed numeric criteria for what are generally regarded as direct (chlorophyll *a*, indicator of suspended microalgal biomass) or indirect response variables (DO concentrations, diel DO changes or DO flux [change] over a 24-hour period) to nutrient enrichment. Moreover, the numeric criteria for the response variables are based on a sampling approach that is inadequate to reliably assess whether waters are nutrient-impaired.

As part of its Nutrient Criteria Development Plan, thus far ADEQ (2005) has designed one set of *lake-specific* water quality criteria (= specific for one impoundment, the Beaver Reservoir). *Although these water quality criteria were called "numeric nutrient criteria" by ADEQ (Report, p.22), they are not.* Nitrogen and phosphorus are the two major nutrients that, when over-supplied, cause noxious algal outbreaks (Wetzel 2001, Burkholder 2009). Chlorophyll *a* is not a nutrient; it is an algal pigment. Turbidity is not a nutrient; it is a measure of water-column 'cloudiness.'   The Report describes the same approach, lacking entirely in numeric nutrient criteria, being planned for application to other significant impoundments in the state as of a decade ago (ADEQ 2006).

a) *The ADEQ protocol design sets thresholds for excess TN and TP at a much higher, much less protective level than would be set from use of U.S. EPA's recommended protocols.*
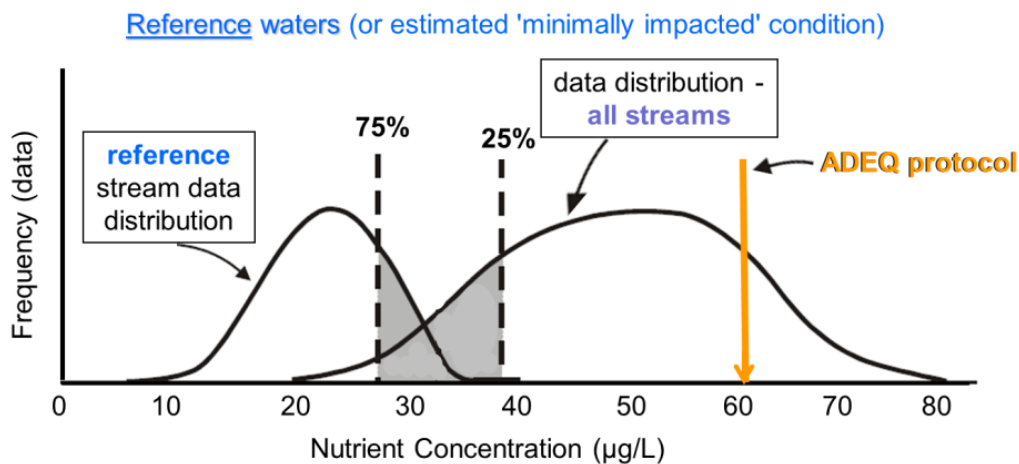
The Report (p.46) states,

> Because nutrient water column concentrations do not always correlate directly with stream impairments, impairments will be assessed by a combination of factors such as water clarity, periphyton or phytoplankton production, dissolved oxygen values, dissolved oxygen saturation, diurnal [diel] dissolved oxygen fluctuations, pH values, aquatic-life community structure and possibly others. However, when **excess nutrients** [emphasis added] result in an impairment, based upon Department assessment methodology, by any Arkansas established numeric water quality standard, the waterbody will be determined to be impaired by nutrients.

ADEQ has established a protocol which sets levels of excess TN and TP. Its protocol sets these thresholds much higher (that is, the thresholds are much less protective) than the procedure

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recommended by U.S. EPA's (2000a,b). The U.S. EPA (200a,b) recommends that if true reference (pristine) sites are available for a given ecoregion within a state, the state should use the 75th percentile of data collected in the past ~decade from the reference sites as the threshold numeric nutrient (TN, TP) criteria. If true reference waters can no longer be found in the ecoregion, the U.S. EPA recommends that to prevent deviation from "minimally impacted" water quality, the state should use the 25th percentile of all data, that is, data available (past ~decade) from all streams in the ecoregion within the state in setting numeric nutrient (TN, TP) criteria:

Figure 3. Comparison of U.S. EPA-recommended protocols for setting numeric thresholds for nutrients (TN, TP – U.S. EPA 2000a,b), versus ADEQ's in the Report.

Thus, scrutiny of ADEQ's "Assessment Methodology for Nutrients" shows that, rather than following U.S. EPA's (2000a,b) protective recommendations, ADEQ designed a protocol for wadeable streams and rivers which begins by assuming that **much higher** TN and TP concentrations are "acceptable:" Moreover, if these high concentrations are not exceeded, then ADEQ simply assumes that there is no nutrient-related impairment.   If the high concentrations ADEQ has selected are exceeded, however, the agency does not evaluate the waterbody as impaired. Rather, ADEQ follows a set of steps that are biased against finding impairment.

b) *The ADEQ protocol flow chart for evaluating whether wadeable streams within a given ecoregion have nutrient-related impairment requires "paired data" that are not paired.*

ADEQ defines paired data/collections as "combined physical, chemical, and biological collections within the same calendar year and/or season. This definition is scientifically indefensible and makes no sense. The nutrient and/or DO, diel DO flux, DO saturation, and pH data can be taken *on the same date* or *after* the biological data are taken, which fails to account for known lag effects of nutrient pollution (Burkholder and Glibert 2013, and references therein). Far from "pairing" data, ADEQ's protocol allows the "cart to proceed before the horse" – water quality data can be taken *after* biological data. Alternatively, the "paired" data can be collected within *the same year*. Thus, macroinvertebrates could be collected in January. Nutrients could be collected in August. There is no science-based rationale in support of the premise that nutrient concentrations influenced the macroinvertebrates (or vice versa). Rather than enabling ADEQ to determine whether biological effects are linked to nutrients, such an approach would easily, completely miss impairment from nutrient pollution.

c) *The ADEQ protocol includes arbitrary stipulations that do not appear to have basis in science.*

Not only one but, rather, both of the 3-day continuous monitoring datasets must have at least 2 of the following 4 parameters (referred to as "translators") in exceedance, defined as:

> Diel DO flux greater than 3 mg/L,
> DO percent saturation greater than 125% for 4 or more consecutive hours,
> DO below the applicable standard for 4 or more consecutive hours, and
> pH less than 6 or greater than 9.

The Report should explain the scientific basis as to why defined DO supersaturation above 125% and DO "sags" below the applicable standards must persist for "4 or more consecutive hours." The protocol also reflects no consideration by its designers of the following facts, well accepted in science:

   ** *Many surface waters that are impaired from nutrient pollution show one, but not two or more, of these "translator" violations within a given 3-day period* – Depending on many characteristics such as temperature, flow, animal abundances, the presence of actively growing versus senescent or decomposing algal biomass, and variability in organic pollution impacts, the same stream can show any combination of these characteristics, including only one of them. The pattern can quickly change within a matter of 1-2 days depending on weather conditions. The following examples of diel DO curves are from streams known to be impaired by nutrient pollution. They illustrate that it would not be scientifically sound to require wadeable streams to show two or more of these characteristics within a 3-day period in order for the stream to be evaluated as in need of protection from nutrient pollution.

First example: A stream draining agricultural lands, with diel data taken during late summer (late July to mid-September): The streams in this study had high mean nutrient concentrations (4.7 mg TN/L and 246 µg TP/L). Depending on the period selected, diel curves for this stream show only 1 characteristic (#1 = diel change greater than 3 mg DO/L), characteristics #1 and #2 (#2 = supersaturation at greater than

Figure 4. Example 1- From Huggins and Anderson (2005).

125%), characteristics #1, #2, and #3 (low DO) during this late summer period. The fourth characteristic, pH, was not less than 6 or greater than 9 (range, 7.8 to 8.9).
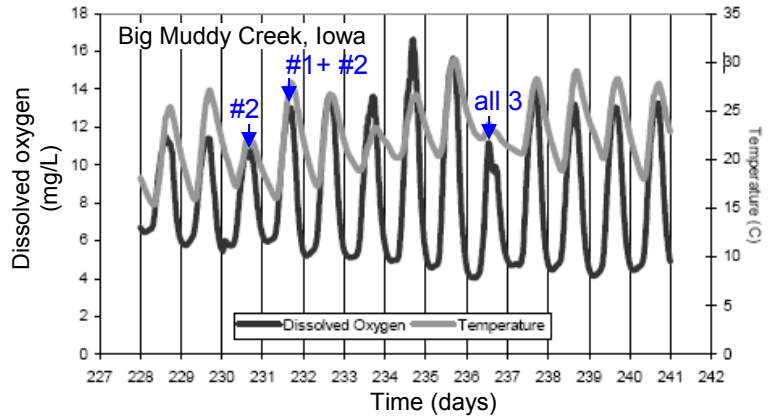
Second example: A stream draining croplands, with diel data taken throughout the growing season. This stream is highly nutrient-enriched from agricultural sources. Yet, depending upon the time of year, and even within the same season (June through late August), diel DO curves varied greatly. I have indicated dates/periods when two of the four "translators" would have been exceeded. However, there clearly are various three-day periods shown wherein none of the "translators" were exceeded. The stream was hypoxic for much of August-September, conditions that would be expected to stress or kill beneficial aquatic life. The authors of this

Figure 5. Example 2 - Continuous DO concentrations in an open-canopy agricultural stream from late April through early December (horizontal line indicates the 5 mg/L Illinois standard at the time of the study). From Morgan et al. (2006).

study described this stream as clearly impacted by nutrient pollution. Analysis of macro-invertebrate communities in a companion study (Heatherly et al. 2007) indicated that the biota of this stream were being adversely affected by nutrient pollution. Yet, this stream would not be evaluated as requiring protection from nutrient pollution if a requirement was imposed that at least two "translators" had to be exceeded within two 3-day periods, depending on the periods selected. Note that pH data were not given in Moore et al. (2006), but Heatherly et al. (2007) did not report pH below 6 or above 9.
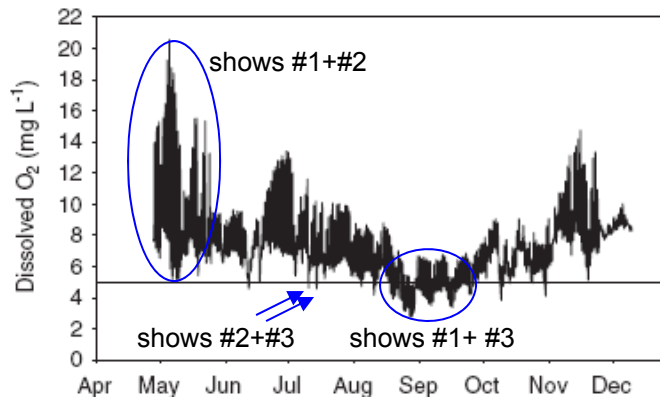
   ** *Impairment from nutrient pollution can occur without manifestation of these "translator" exceedances – Examples include nitrate and ammonia toxicity to aquatic life*, which can occur in

response to nutrient pollution when surface waters are oxygen-replete. Toxic levels of these forms of inorganic nitrogen (N_i) cause physiological stress, impaired reproduction, and death of sensitive aquatic species and life history stages. Ammonia and nitrate are considered separately below, but it should be noted that these forms of N_i have been shown to act synergistically to adversely affect aquatic life (e.g. Berenzen et al. 2001, Beketov 2004).

As reviewed in Camargo and Alonso (2006), unionized *ammonia* is highly toxic especially to fish, and is thought to act through one or more of the following mechanisms: Damage to gill epithelium, causing asphyxiation; stimulation of glycolysis and suppression of the Krebs cycle, resulting in acidosis and reduced capability of the blood to carry oxygen; uncoupling of oxidative phosphorylation, inhibiting ATP production and depleting ATP in the basilar region of the brain; disrupting blood vessels and osmoregulation, impairing liver and kidney functions; and suppressing the immune system, increasing susceptibility to disease. Ionized ammonia (*ammonium*, NH_4^+ ions) can exacerbate NH_3 toxicity by reducing internal sodium ion concentrations. Environmental conditions such as low DO can *increase* fish susceptibility to ammonia toxicity, but ammonia toxicity can also occur when oxygen supplies for fish are plentiful (Camargo and Alonso 2006). Freshwater invertebrates such as molluscs and planarians appear to be highly sensitive to NH_3 toxicity as well, and have sustained adverse impacts from chronic exposures to as little as 50 µg NH_3/L.

ADEQ includes tests for ammonia toxicity (Report, Section 6.12), but the concentrations indicated as "acceptable" are much higher than those given in the *Aquatic Life Ambient Water Quality Criteria for Ammonia in Freshwater* (U.S. EPA 2013). The U.S. EPA (2013) recommended criteria are based on sensitive freshwater bivalve mollusc species. According to the U.S. Fish and Wildlife Service (see http://www.fws.gov/arkansas-es/docs/ESDay/Photographs%20of%20Endangered%20Species%20in%20Arkansas.pdf),

> Freshwater mussels are the second most endangered group of animals in North America, second only to freshwater snails. They are indicator species of the health of our streams and rivers. Arkansas has the most species of native freshwater mussels of any state west of the Mississippi River (83 species). They also are the most endangered group of animals in Arkansas....The greatest threats facing Arkansas' mussels include...chemical pollution....

Thus, it would seem that ADEQ should have adopted the U.S. EPA (2013) criteria to protect these endangered fauna of Arkansas' wadeable streams. Yet, the Report does not mention the U.S. EPA criteria.

The Report also does not mention *nitrate toxicity to aquatic life* in the state's wadeable streams, as related to nutrient impairment. The main mode of action of *nitrate*, especially in fish and crayfish, is conversion of oxygen-carrying hemoglobin or hemocyanin pigments into methemoglobin or methemocyanin forms that can no longer carry oxygen, leading to hypoxia and death (Camargo and Alonso 2006, and references therein). Nitrate can interfere with steroid hormone synthesis, affect sperm motility and viability, affect fecundity, and can be toxic to embryos (Edwards et al. 2004). It can also decrease immune response, act as an endocrine disruptor, and induce hematological and biochemical changes in aquatic life (Guillette and Edwards 2005, Edwards 2005). Nitrate may also

adversely affect many metabolic processes by acting as an endocrine disruptor in fishes and reptiles (Hrubec et al. 2002, Guillette and Edwards 2005, Edwards 2005). Within body fluids, nitrate can be converted to nitrite, or can accumulate via hepatic detoxification of nitrite (Edwards et al. 2004).

Experiments have shown that nitrate concentrations well below 10 mg/L, the National Primary Drinking Water Regulation, or primary standard for nitrate in drinking water (see https://www.epa.gov/your-drinking-water/table-regulated-drinking-water-contaminants#Inorganic), can adversely affect freshwater invertebrates, fish, and amphibians (Camargo et al. 2005). Certain aquatic invertebrate and fish species have been found to be especially sensitive to nitrate toxicity. As examples, chronic nitrate toxicity for freshwater invertebrates can occur at values as low as 0.23 mg NO_3^--N/L; lowest chronic toxicity levels for adult freshwater invertebrates were 2.8-4.4 mg/L for two species of amphipods (Camargo et al. 2005). Early instar caddisfly larvae sustained adverse effects from chronic toxicity at 1.4-2.4 mg NO_3^--N/L (Camargo and Ward 1995).

The 303(d) list given in the Report includes several cases of stream impairment due to nitrate. Since the Report mentions nothing about criteria for nitrate aimed at protecting aquatic life, apparently these cases are in violation of the 10 mg/L standard, which is much too high to be protective of aquatic ecosystems.

  d) *The protocol for continuous monitoring data for assessing "nutrient-related impairment" of wadeable streams will easily miss or underestimate the DO "translators."*

The ADEQ protocol requires only two 3-day periods within the entire May-October growing season, at times when temperatures are at 22°C or higher. Such limited continuous monitoring data will easily miss or underestimate the "translators" DO flux, low DO concentrations, and DO supersaturation above 125%. Protection of Arkansas waters from nutrient pollution based on these DO "translators" will critically depend upon adequate monitoring in the summer season, including at least several days of data taken before and after precipitation events, as well as during droughts. As examples illustrating the importance of adequate sampling, see Figures 4 and 5, and accompanying descriptions and references in these Comments.

  e) *The numeric criteria (chlorophyll a, turbidity) set for the upper end of Beaver Lake are poorly conceived and do not protect this reservoir from impairment due to nutrient pollution.*

Thus far, ADEQ has designated site-specific chlorophyll *a* concentration and turbidity numeric criteria for the *upper portion only,* of *only one reservoir*, Beaver Lake. The chlorophyll *a* concentration is used as an indicator of algal biomass (Wetzel 2001). While chlorophyll *a* is considered a "response variable" to nutrient pollution, turbidity, or water-column transparency, is only considered to be related to nutrient pollution if the materials causing increased "cloudiness" are algae. Secchi depth transparency and other measures of turbidity are **not** strongly related to nutrient concentrations if the main source of the turbidity is abiotic, such as suspended sediment particles (Wetzel 2001). Thus, the chlorophyll *a* concentration can be related, at least, to nutrient

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concentrations, but turbidity is often not well related to nutrient concentrations, especially in river and reservoir systems which have appreciable abiotic (non-algal) turbidity and where much of the TN occurs as highly soluble nitrate.

The upper portion of a reservoir generally is the area with the highest nutrient concentrations, contributed by the incoming river, but also the highest turbidity and the highest flow relative to the middle and lower (by the dam) reservoir waters (Wetzel 2001). The high turbidity and high flow in the upper reservoir depress algal growth, thereby minimizing algal response to nutrient supplies. The algae cannot fully respond to the high nutrient supplies because the high turbidity restricts the light they need for photosynthesis, and the high flow moves them out of the area into the middle reservoir too quickly; they can consume the nutrients, but they do not have the light they need or the time to grow, that is, to translate that uptake into more biomass. Therefore, the upper end of a reservoir usually has much lower algal biomass than the middle and lower end. As the algae are moved through the reservoir by the slowing current, they are able to use the nutrients they consumed in the upper end of the reservoir and grow, making much more biomass. The water clears during this transport, and is usually much clearer at the lower end of the reservoir; and the water movement is much slower at the lower end of the reservoir above the dam, allowing good light for growth so that noxious algal blooms commonly occur in the lower reservoir.

Thus, high incoming nutrient supplies usually coincide with high flow, high turbidity, and relatively low algal biomass (indicated by relatively low chlorophyll a concentrations) at the upper end of a reservoir. *High incoming nutrient supplies in the upper end of a reservoir also commonly lead to high algal biomass at the lower end of the reservoir.*

ADEQ developed a numeric criterion for chlorophyll *a* in the upper end of the Beaver Lake reservoir as 8 μg/L (depth, 1 meter). An average (mean) chlorophyll *a* concentration of 8 μg/L indicates conditions that are *midway between moderately nutrient-enriched* (which limnologists call mesotrophic, for example, waters that are nutrient-enriched enough to develop medium-sized algal blooms) *and highly nutrient-enriched* (referred to as eutrophic) (Wetzel 2001 – see Table 4 below). Thus, ADEQ deemed it acceptable for even the upper end of the reservoir, which should be low in algal biomass, to have moderate algal biomass concentrations.

Table 4. Average (mean, or arithmetic mean, AM) concentrations in lakes and reservoirs ranging from nutrient-poor to nutrient-rich. From Wetzel (2001).

General level of productivity	Suspended microalgal chl*a*
oligotrophic (pristine, nutrient-poor)	average 2 μg/L
mesotrophic (moderately productive)	average 5 μg/L
eutrophic (nutrient-rich, highly productive)	average 14 μg/L

Note, however, that Table 4 refers to **average (mean, or arithmetic mean, AM)** chlorophyll *a* concentrations. ADEQ imposed another stipulation to make this numeric criterion less protective

even for the upper end which should have the lowest algal biomass in the entire reservoir: Rather than setting a numeric criterion for chlorophyll a that is an average or mean for the May-October growing season, ADEQ elected to make this criterion a **geometric mean (GM)** . *GMs are always lower than AMs* unless all of the data for a given parameter are the exact same number, which is highly unlikely.

Rather than setting a numeric criterion of 8 µg chlorophyll *a*/L as an AM concentration that is acceptable over the growing season (May-October), ADEQ designed a less protective criterion by stipulating that it must be a GM. The following examples illustrate the difference between a GM and an AM. Numbers indicate the chlorophyll *a* concentration in micrograms per liter (µg/L), rounded to the nearest integer:

	Year 1	Year 4			
Samples:	3, 4, 5	14, 15, 30	GM: 8	AM: 12	median: 10
Samples:	17, 22, 14	4, 6, 2	GM: 8	AM: 11	median: 10
Samples:	4, 3, 5	28, 14, 15	GM: 8	AM: 12	median: 13

First example above: Low concentrations occurred when the sparse number of samples (n = 3) were taken in the first year; but the (again, sparse) sampling in the second (4th) year caught a developing noxious algal bloom. There is no way to know whether the chlorophyll *a* concentration continued to rise because additional samples were not taken, despite the fact that this level of chlorophyll would have caused obvious water discoloration. There is no way to assess the bloom duration or impacts.

Second example: A substantial algal bloom (perhaps subsiding) was detected by the sparse sampling during the first year. There is no way to assess the bloom duration or impacts. The sparse sampling during the second (4th) year detected had low algal biomass.

Third example: Low algal biomass was measured by the sparse sampling in the first year; but the sparse sampling in the second year detected a major bloom that may have been occurring for some time; there is no way to assess the bloom duration or impacts.

The central question should be, *What is the best approach, with very small sample numbers such as are relied upon by ADEQ, to estimate the "true" average condition?* When sample sizes are small and the data are used to represent a long period (e.g., several months, such as the May-October period), statisticians recommend use of **medians** rather than geometric means or arithmetic means.   (It is worthy of mention that the best-known use of GMs, for fecal bacteria, are based on 4-5 samples *per month*, a much smaller time period.) Note that in 2 of the 3 examples above, the median is closest to the AM; in the other example, the median is eqi-distant between the GM and the AM. Overall, these examples indicate that the AM depicts a "truer" mean than the GM with small sample sizes which ostensibly are taken to represent relatively long periods (here, the small sample size of 6 supposedly representing 5 months, or the entire growing season). Also note that *even the medians are **higher** than the GMs in all three examples.*

Small sample sizes around 5-6 have been found to have much larger uncertainty in estimating a true GM than larger sample sizes (Parkhurst 1998, Sokal and Rolff 2012). Because the "n" relied upon by ADEQ for assessing nutrient-related impairment is so small, it would be better to base compliance on medians than on GMs. Both the GM and the median are less sensitive to outliers than the mean. The advantage of the median is that, for small datasets, it can be a better (= more reliable, more realistic) measure of central tendency in data that are not normally distributed (Sokel and Rolff 2012) – and water quality (nutrient, chlorophyll) data are often *not* normally distributed (Burkholder et al. 2006, Sokel and Rolff 2012).

These realistic examples illustrate that in general, GMs substantially underestimate the "true" average condition as indicated by medians. Parkhurst (1998) wrote,

> Concentrations of chemical substances and microorganisms are often averaged for scientific and regulatory purposes. Geometric means are sometimes used for these purposes, but they are biased low and do not represent components of mass balances properly. They should be abandoned in favor of arithmetic means, unless they are clearly shown to be preferable for specific applications. Arithmetic means are unbiased, easier to calculate and understand, scientifically more meaningful (at least for concentration data), and more protective of public health.

Regarding use of turbidity as a "nutrient criterion" or as an indicator of meeting a drinking water use, the Secchi depth transparency numeric criterion is an annual average (**!**). As an annual average, the data will provide no science-based way to evaluate whether the upper lake is meeting its designated use for drinking water. Regarding any utility of an "annual average Secchi depth transparency": If the turbidity in the upper lake was all related to algae, and if the measurements coincided with chlorophyll *a* measurements, and if the measurements were restricted to the growing season, then Secchi depth transparency might be useful in providing some indirect information about nutrient pollution (see Wetzel 2001). However, the turbidity in the upper lake is caused both by algae and suspended solids coming in from the river. Annual average Secchi depth transparency data provide no meaningful information about nutrient impairment to the upper lake, either.

f) *The Report provides no explanation as to why ADEQ has designed unbalanced listing versus delisting criteria for upper Beaver Lake.*

Although the upper end of Beaver Lake was described as having "numeric nutrient criteria" (chlorophyll *a*, turbidity) to protect it from nutrient-related impairment, and although the Listing and Delisting Methodologies are given under the section heading, "**6.9 Nutrients – Assessment Methodology for Nutrients**" (Report, p.46), "suddenly" readers learn on p.49 that the only issue of concern for ADEQ regarding upper Beaver Lake will be whether it supports its ***drinking water*** designated use – not whether it is impaired from algal blooms (indicated by high chlorophyll *a*) or other impacts that are at least related to nutrient pollution. Moreover, *nothing whatsoever is mentioned about nitrate, which is actually the only nutrient that **has** a drinking water standard*.

The Listing Methodology states that there must be **3 or more exceedances** of the chlorophyll *a* criteria (see comment #8d above) within the 5-year period of record; and (**?** or**?** – not clarified) there must be 3 or more exceedances of the Secchi [depth] transparency criteria within the 5 years.

versus

Delisting will occur when there are **2 or fewer exceedances** of the chlorophyll *a* criteria **and 2 or fewer exceedances of Secchi depth** transparency within a 5-year period.

Scrutiny of the Report yielded no information about the actual number of chlorophyll samples required per growing season in upper Beaver Lake.   The site-specific water quality criteria development document (FTN Associates 2008, p.9-21) recommended monthly sampling because they felt that it would be "consistent with the current ADEQ monitoring program, and it provides sufficient information for estimating growing season chlorophyll…." However, for about 20 yr ADEQ has monitored lakes only in one of every five years (Report, p.22). Regardless, a difference of as little as only ONE chlorophyll sample and ONE turbidity sample (Secchi depth transparency) between listing and delisting seems illogical and suggests that there is poor protection of upper Beaver Lake from impairment due to high chlorophyll *a* as an indicator of noxious algal blooms.

Recommendations

The following recommendations are offered toward the goal of strengthening the protocols for assessing impaired surface waters in Arkansas, and strengthening protection of the surface water resources in the state:

- Clear time frames should be stipulated for Integrated Reporting Categories 4(b), Category 5-Medium, and Category 5-Low, so that cleanup of known-impaired waters within these categories is not "indefinitely postponed."

- Monthly data frequency should be required for Tiers III and IV data. Bimonthly or quarterly data are adequate for screening (Tiers I and II), but not for assessment of average conditions and attainment of designated uses.

- The "two seasons" requirement for macroinvertebrate sampling should be clarified to stipulate that the seasons should be selected to avoid temperature extremes. At least two years of sampling should be required for assessment data in order to at least partly account for inter-annual variation.

- The Aquatic Life Designated Use Listing Protocol should be altered so that it accurately evaluates Partially Supporting macroinvertebrate communities, rather than "suddenly transforming" them into Fully Supporting communities as accomplished by the present protocol.

- The Aquatic Life Designated Use Listing Protocol should be altered so that it accurately evaluates loss of fish species diversity, loss of sensitive species, and an increase in pollution-tolerant fish species as "acceptable" (supporting).

- ADEQ should assess surface waters throughout the state for historic data where available and present DO conditions *throughout* the water column. The reservoir DO criterion should be altered to include protection of benthic aquatic life from low DO stress during the critical season in waterbodies where bottom-water hypoxia/anoxia have been or are being exacerbated by human-related activities.

- Throughout the state, intermittent streams with enduring (perennial) pools and small perennial headwater streams draining watersheds less than 10 square miles in areal extent should have a critical-season DO criterion that protects them from hypoxia/anoxia.

- The Arkansas water quality criteria for *Escherichia coli* fecal bacteria should be significantly reduced in order to protect human health safety. The criteria should be altered to follow the U.S. EPA (2012) recommendation, and compliance should also follow U.S. EPA (2012).

- Arkansas should develop numeric **nutrient** criteria . At present the state has not developed any ***phosphorus and nitrogen numeric criteria***. Criteria for both nutrients are needed, rather than criteria for chlorophyll *a* and turbidity which are ***not*** nutrients. In the Report these criteria are erroneously called "numeric nutrient criteria." Adding yet more confusion, the chlorophyll a and turbidity criteria are not being used to assess nutrient conditions, related to aquatic life use; rather, they are being used to assess whether upper Beaver Lake is meeting its designated use for drinking water. Arkansas should look to states such as Minnesota and Wisconsin as examples of numeric nutrient criteria.

- The ADEQ protocol for excess TN and TP in wadeable Arkansas streams should be set at the 25th percentile of all streams data within a given ecoregion following U.S. EPA recommendations, rather than at the much-less-protective 75th percentile.

- The ADEQ protocol for evaluating whether wadeable streams have nutrient-related impairment should use data for water quality that, when paired with biological data, include a science-based lag period so that a link between poor water quality and impaired biota can actually be assessed. Apparently arbitrary stipulations should be clarified and clearly science-based. The protocol should also be substantially altered to require only one, rather than two or more, of the four translators in violation; and to include criteria to protect aquatic life from excessive nitrate and ammonia toxicity, which can cause adverse impacts without manifestation of any of the "translators." Continuous monitoring data for the DO "translators" should be increased to include several days of data taken before and after precipitation events, and data taken during droughts.

- The numeric criteria (chlorophyll *a*, turbidity) set for the upper end of Beaver Lake should be redesigned so that they are science-based and protective rather than reactive. Toward that goal, median chlorophyll *a* concentrations should be used rather than geometric means. The chlorophyll *a* criterion of 8 µg/L for the upper, most turbid end of the reservoir should be lowered so that the middle and lower reservoir are afforded more protection from excessive algal blooms. Use of annual average Secchi depth as an indicator of nutrient-related

impairment, or as an indicator of the lake meeting its designated use for drinking water, should be abandoned because it does not provide meaningful information for either.

- The number of chlorophyll *a* samples required per growing season and per five-year period to assess whether upper Beaver Lake meets its designated uses requires clarification.

- The rationale for the imbalance between Listing and Delisting Methodologies for upper Beaver Lake requires clarification so that readers can assess whether the methodologies are science-based, and whether the protocol provides meaningful protection for this surface waterbody.
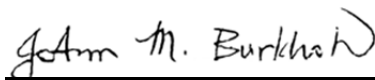
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