UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 6
1445 ROSS AVENUE, SUITE 1200
DALLAS, TEXAS 75202 – 2733

October 31, 2016

Caleb Osborne
Associate Director, Water Division
Arkansas Department of Environmental Quality
5301 Northshore Drive
North Little Rock, AR 72118-5317

RE: Arkansas 2013 Triennial Revisions to Regulation No. 2

Dear Mr. Osborne:

I am writing in response to Ellen Carpenter's letter requesting review and approval of revisions to Arkansas' Regulation No. 2, *Regulation Establishing Water Quality Standards for Surface Waters of the State of Arkansas*. These revisions were submitted by the Arkansas Department of Environmental Quality (Department) for U.S. Environmental Protection Agency's (EPA) review via letter dated March 14, 2014, as required under federal regulations at 40 CFR §131.5. The revised water quality standards (WQS) were adopted by the Arkansas Pollution Control and Ecology Commission (Commission) via Minute Order No. 14-10 on February 28, 2014, and submitted to EPA along with an attorney's statement certifying that the revised WQS were adopted pursuant to the laws of the State of Arkansas. EPA received the WQS submission on March 18, 2014.

I am pleased to inform you that in today's action, EPA is approving the new and/or revised provisions detailed in **Section II** of the enclosed Technical Support Document (TSD) pursuant to CWA §303(c) and its implementing regulations at 40 CFR Part 131. The approved revisions include: Reg. 2.106 - Definitions; Reg. 2.304 - Physical Alteration of Habitat; Reg. 2.405 - Biological Integrity; Reg. 2.502 – Temperature; Reg. 2.504 - pH; Reg. 2.505 - Dissolved Oxygen; Reg. 2.507 – Bacteria; Reg. 2.508 – Toxic Substances; Reg. 2.509 - Nutrients; Reg. 2.510 – Oil and Grease; Reg. 2.511(A) - Site Specific Mineral Quality Criteria and Mineral Quality – Specific Standards: Delta Ecoregion; Reg. 2.511(B) - Ecoregion Reference Stream Minerals Values; Reg. 2.512 - Ammonia; *Appendix A*, including Reg. 2.511(A) - Footnote Applicable to Site-specific Mineral Quality Criteria; and, *Appendix D*. The applicability of the new and revised language associated with these revisions is described in **Section II** of the TSD.

EPA is approving the revised provisions identified in **Section III** and outlined in **Attachment 1** of the TSD. EPA has determined that these are non-substantive revisions to the state's WQS and are approved pursuant to CWA §303(c) and its implementing regulations at 40 CFR Part 131. Although these amendments are described as non-substantive, they are important because they provide clarity, correct minor errors and provide consistency within the document. Regulations 2.511(B) and *Appendix A* are also specifically discussed in this section to add clarity.

EPA is approving specific amendments to some revised provisions and has determined that it does not have enough information to act on others as described in **Section IV** of the TSD. Those approvals are made pursuant to CWA § 303(c) and its implementing regulations at 40 CFR Part 131. These provisions include portions of Reg. 2.104 - Policy for Compliance; Reg.(s) 2.502 - Temperature, 2.503 - Turbidity, 2.504 - pH, 2.505 - Dissolved Oxygen (Lakes and Reservoirs); Reg. 2.507 – Bacteria, footnote 2 (see discussion in **Section II**); Reg. 2.511(B) - Ecoregion Reference Stream Minerals Values; and Reg. 2.511(C) - Domestic Water Supply Criteria. As described in the TSD, only the approved portions of new and revised water quality standards are in effect for CWA purposes. The remaining portions do not go into effect unless and until approved by EPA as specified at 40 CFR §131.21(c). The previously approved language that has not been revised remains in effect for CWA purposes. For Ecoregion Reference Stream Minerals Values, if the state wishes to adopt alternative minerals criteria then EPA requests that ADEQ describe its proposed approach within 12 months and that the approach include a schedule outlining interim milestones leading to criteria adoption.

EPA has identified two provisions that remain disapproved as the result of EPA's 2008 and 2011 actions which are described in **Section V** of the TSD. These provisions include Reg. 2.503 - Turbidity and Reg. 2.511(A) - Site-specific Mineral Quality Criteria. Please note that the portions of these provisions that are or were previously disapproved are not effective for CWA purposes unless and until approved by EPA as specified at 40 CFR §131.21(c). The previously approved language associated with these revisions remains in effect for CWA purposes.

The approval of portions of the new and revised WQS identified in the enclosed TSD are subject to the results of consultation under section 7(a)(2) of the Endangered Species Act (ESA). Section 7(a)(2) requires that federal agencies consult with the U.S. Fish & Wildlife Service and/or National Marine Fisheries Service, as appropriate. As of today, this consultation has not been completed. By approving portions of the WQS revisions, subject to the results of consultation under section 7(a)(2) of the Endangered Species Act, EPA retains the full range of options available under CWA § 303(c) for ensuring that WQS are environmentally protective and consistent with applicable law. EPA retains the discretion to revise its approval decision of these new and revised WQS if the consultation identifies deficiencies in the WQS that require remedial action.

I would like to commend the Commission and the Department for their commitment and hard work in reviewing and revising the State's WQS. We look forward to working with you to resolve the outstanding issues related to this triennial review. If you have any questions or concerns, please contact me at (214) 665-7101, or have your staff contact Russell Nelson at (214) 665-6646 or at nelson.russell@epa.gov or Karen Kesler at (214) 665-3185 or at Kesler.Karen@epa.gov.

Sincerely,

William K. Honker, P.E.
Director
Water Division

Enclosure

TECHNICAL SUPPORT DOCUMENT
FOR EPA REGION 6 REVIEW OF:

REGULATION NO. 2: *REGULATION ESTABLISHING WATER QUALITY STANDARDS FOR SURFACE WATERS OF THE STATE OF ARKANSAS*

Revisions Adopted by the Arkansas Pollution Control and Ecology
Commission via Minute Order No. 14-10

U.S. EPA REGION 6
WATER QUALITY PROTECTION DIVISION
2016

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I. Introduction

Background

As described in §303(c) of the Clean Water Act (CWA) and in the water quality standards (WQS) regulation at 40 CFR §131.20, states and authorized tribes have primary responsibility to develop and adopt WQS to protect their waters. State and tribal WQS consist of three primary components: designated uses, criteria to support those uses, and antidegradation requirements. In addition, CWA §303(c)(1) and 40 CFR §131.20 require states to hold public hearings at least once every three years to review and, as appropriate, modify and adopt standards. As specified in 40 CFR §131.21, the Environmental Protection Agency (EPA) reviews new and revised surface WQS that have been adopted by states and authorized tribes. Authority to approve or disapprove new and/or revised water quality standards submitted to EPA for review has been delegated to the Water Quality Protection Division Director in Region 6. State or tribal WQS are not considered effective under the CWA unless and until approved by EPA.

The purpose of this Technical Support Document (TSD) is to document the review and provide the basis for EPA's actions concerning revisions to Regulation No. 2: *Regulation Establishing Water Quality Standards for Surface Waters of the State of Arkansas* adopted by the Arkansas Pollution Control and Ecology Commission (APC&EC or Commission) via Minute Order No. 14-10 on February 28, 2014.

Chronology of Events

Arkansas Department of Environmental Quality's (ADEQ's) previous triennial review occurred in 2007. Since that time, ADEQ has attempted (in 2010) to revise Regulation No. 2 (Reg. 2). However, following an extended public comment period in 2010 and 2011 and after receiving extensive comments, ADEQ did not to proceed with rulemaking. Instead, ADEQ convened three stakeholder workgroups and two sub-workgroup meetings in the summer of 2012. The workgroups consisted of local, state, and federal regulatory entities, environmental groups, and representatives of the regulated community. The workgroups were open to the public, and covered the entirety of ADEQ's proposed revisions to Reg. No. 2. Workgroup participants were allowed to comment and openly discuss the proposed revisions. Provided below is a detailed chronology of events associated with this triennial review.

January 30, 2013	ADEQ filed a Petition to Initiate Rulemaking to Promulgate Regulation No. 2
February 22, 2013	The Arkansas Pollution Control and Ecology Commission granted the petition under Minute Order 13-12
February 27, 2013	Legal notice of proposed revisions to Regulation No. 2 and public hearings published in the Arkansas Democrat-Gazette. Public comment period opened
February 28, 2013	Legal notice of proposed revisions to Regulation No. 2 and public hearings published in the Arkansas Democrat-Gazette
April 15, 2013	ADEQ held a public meeting on the triennial review of Regulation No. 2 at Allen Park Community Center in Jonesboro, AR
April 18, 2013	ADEQ held a public meeting on the triennial review of Regulation No. 2 at the Fayetteville City Administration Building in Fayetteville, AR
April 22, 2013	ADEQ held a public meeting on the triennial review of Regulation No. 2 at South Arkansas Community College in El Dorado, AR
May 8, 2013	The public comment period ended on the proposed rulemaking to amend Regulation No. 2
September 23, 2013	ADEQ held a final public meeting on the triennial review of Regulation No. 2 at ADEQ Headquarters in North Little Rock, AR
January 2014	ADEQ formally presented the final proposed amendments to Regulation No. 2 to the Public Health and Welfare Committee of the Legislative Council
February 2014	ADEQ formally presented the final proposed amendments to Regulation No. 2 to the Administrative Rules & Regulations Subcommittee of the Legislative Council

February 28, 2014	ADEQ formally presented the final proposed amendments to Regulation No. 2 to the Regulations Committee of the APC&EC
February 28, 2014	ADEQ formally presented the final proposed amendments to Regulation No. 2 to the APC&EC for adoption
February 28, 2014	The APC&EC adopted the final proposed amendments to Regulation No. 2 via Minute Order No. 14-10
March 18, 2014	Bill Honker, Director, Water Quality Protection Division, EPA Region 6, received a letter dated March 14, from Ellen Carpenter, Chief, Water Division, ADEQ, submitting the final amendments to Regulation No. 2 for EPA's review and approval
March 24, 2014	The final amendments to Regulation No. 2 adopted via Minute Order No. 14-10 became effective under State law
February 6, 2015	Bill Honker, Director, Water Division, EPA Region 6, received a letter dated February 6, 2015 from Ryan Benefield, Interim Director, ADEQ, providing clarifications on APC&EC amendments to Reg. 2

Summary of Revisions to Regulation No. 2

The 2014 triennial review resulted in over 200 revisions spanning the entirety of Reg. 2. These revisions include substantive modifications as well as a significant number of non-substantive revisions. Non-substantive revisions to Reg. 2 include typographical and grammatical error corrections, text or wording reformatting, and citation clarifications. While these may be considered minor changes, they are important to the clarity and readability of Reg. 2.

Although this is not a complete list, Reg. 2 also includes revisions to Reg. 2.104, expanding the compliance period for new permittees completing site specific criteria development. The document also includes a revision to the critical flow definition in Reg. 2.106 specifying harmonic mean flow but provides an exception for continued use of 4 cfs as the critical flow in Reg. 2.511 (A). The revisions provide for nutrient criteria in Reg. 2509, and clarify the use of ecoregional minerals criteria in Reg. 2.511 (B). The document also includes a number of corrective revisions based on previous EPA actions. More detailed descriptions of these and additional revisions to Reg. 2 and EPA's action are provided in the sections that follow.

II. New or Revised Provisions EPA is Approving

EPA has the CWA §303(c)(3) authority and duty to approve or disapprove new or revised WQS submitted by a state or authorized tribe after determining if the provisions adopted constitute a new or revised WQS. EPA has determined that the following revisions to Reg. 2 constitute new or revised water quality standards and are approved by EPA consistent with §303(c) of the CWA and its implementing regulations at 40 CFR §131.5 and 40 CFR §131.6.

Chapter 1: Authority, General Principles and Coverage

Reg. 2.106 Definitions – "Critical flows"

The modifications to this provision are intended to allow the use of more accurate stream flow or harmonic mean flows in calculating permit limitations to ensure that pollutant concentrations in permits will protect designated uses. In waters with an actual critical flow below 4 cfs, approaching no flow, the use of the 4 cfs value or other flows could result in inadequately protective effluent limits that would not reflect actual conditions, potentially leading to listings under §303(d) of the CWA. The revised provision strikes the 4 cubic foot per second (cfs) flow value which had previously been applied to unclassified waters for minerals criteria permitting implementation. The revised provision retains the previously approved harmonic mean for human health criteria and minerals criteria with the exception of site-specific minerals criteria identified in Reg. 2.511(A), where the 4 cfs flow value is retained, and Reg. 2.511(C) where a value of Q7-10 applies. Retaining the previously approved harmonic mean flow for future calculations allows the use of new data sources such as USGS Stream Stats and is approved.

Chapter 3: Waterbody Uses

Reg. 2.304 Physical Alteration of Habitat

In its 2007 triennial revision, APC&EC amended this provision in a way that altered the application of its previously approved antidegradation policy by expanding its views on allowable "not significant" degradation in Outstanding National Resource Waters (i.e., ERW, ESW, or NSW). In its January 24, 2008 action, EPA determined that allowing such degradation is not consistent with 40 CFR §131.12(a)(3) and subsequently disapproved the amendments. APC&EC is amending this provision, reverting to language previously approved by EPA in 2004.

Chapter 4: General Standards

Reg. 2.405 Biological Integrity

The revisions to Arkansas' statement on biological integrity clarify the circumstances for aquatic biota assessments, which will allow assessments to be used as a basis for the development of permit effluent limitations or conditions that are protective of aquatic life uses and are approved. EPA recommends that ADEQ develop procedures to describe how the biotic integrity narrative will be applied. For example, an index of biological integrity (IBI) would provide a quantitative approach that can be used to gauge the ecological condition of a water body.

Chapter 5: Specific Standards

Reg.(s) 2.502 - Temperature, 2.504 – pH, 2.505 - Dissolved Oxygen, 2.508 – Toxic Substances, 2.510 – Oil and Grease, and 2.511(A) – Site-specific Minerals Criteria

These provisions previously identified applicable numeric criteria as absolute maxima or minima using "shall not exceed," "shall not be below" or similar statements of frequency. With its revision, APC&EC removed the "shall not" frequency statements specific to applicable numeric criteria. Although criteria expressed as absolute maximum or minima may generally not be appropriate because they do not allow for natural variation within a water body and acceptable monitoring and/or analysis error, the state did not adopt replacement duration and frequency components for these criteria which complicate implementation and assessment. The frequency entails a certain percentage of exceedances that must occur to list waters as impaired. The duration component entails the period of record for which data is to be assessed. EPA is committed to working with ADEQ to identify appropriate scientifically defensible frequency and duration components that can be adopted as part of the WQS or by binding reference to as soon as possible.

EPA is approving those instances where the state has struck absolute maxima or minima language in the provision identified above pursuant to CWA §303(c) and its implementing regulations at 40 CFR § 131. EPA recommends that the state develop scientifically supportable frequency and duration components for applicable criteria and include those components in its WQS or reference the state's Assessment Methodology or CPP in the WQS.

Reg. 2.504 pH

The revised provision reads as follows:

"pH between 6.0 and 9.0 standard units are the applicable standards for streams. For lakes, the standards are applicable at 1.0 meter depth. As a result of waste discharges, the pH of water in streams or lakes must not fluctuate in excess of 1.0 standard unit over a period of 24 hours ~~and pH values shall not be below 6.0 or above 9.0~~.

This provision previously implied that the applicable criteria, expressed as a 6.0 to 9.0 standard unit range, represented not to be exceeded maximum values. However, ADEQ's assessment methodology allows for potential exceedances of criteria before impairment is identified. The previous range of 6.0 to 9.0 standard units has been maintained as the magnitude of the applicable criteria, but striking the phrase “shall not be below 6.0 or above 9.0” removes the absolute values and allows for the frequency and duration components of the pH criteria to be applied as intended. The inclusion of the word “standard” in the second sentence in reference to pH measurement is addressed in **Section III** and detailed in ***Attachment 1***. These modifications are approved as consistent with CWA § 303(c) and its implementing regulations at 40 CFR § 131.

In the second sentence, EPA is taking no action on the phrase “applicable at 1.0 meter depth” referring to applicable depth to determine compliance in lakes and reservoirs. This phrase does not go into effect for CWA purposes as described in 40 CFR §131.21(c) and is discussed in **Section IV**.

Reg. 2.507 Bacteria

This provision has been restructured, reorganizing and reformatting the narrative use descriptions and associated criteria into tables specific to designation, and adding footnotes. Reorganizing and restructuring the existing provision does not represent any new narrative or criteria and are considered to be non-substantive changes. The reorganized provision did not include any modifications to the state’s current numeric criteria based on EPA’s latest recreational water quality criteria (RWQC) document that was released in late November 2012. EPA recognizes that the release of its RWQC document was late in Arkansas’ public process and although the Arkansas Department of Health raised the issue during this process, there was not adequate time for ADEQ to fully consider EPA’s latest criteria recommendations.

Although the amendments to Reg. 2.507 did not result in the adoption of EPA’s recommended RWQC, the restructuring and reorganization provided clarity and makes the provision easier to interpret. These non-substantive changes have been determined to be WQS and are approved as consistent with CWA Sec. 303(c) and its implementing regulations at 40 CFR § 131.

Although these changes are non-substantive, they are not included in ***Attachment 1*** because in addition to restructuring, five new footnotes specific to this provision have been added and are detailed below. See discussion on non-substantive provisions in **Section III**. Footnote 3 and a portion of footnote 4 have been determined not to be WQS and do not require EPA action. Footnotes 1, 2, portions of footnote 4, and footnote 5 have been determined to be WQS. EPA takes no action on footnote 2 as detailed in the discussion in **Section IV** related to the 1.0 meter depth exclusion. With the exception of footnote 2, 3 and a portion of footnote 4, the remainder of these footnotes are considered non-substantive WQS that capture existing information from the current bacteria provisions and are approved as consistent with CWA Sec. 303(c) and its implementing regulations at 40 CFR § 131:

[1] May 1 to September 30:

Footnote 1 is a WQS and is approved.

[2] Applicable at 1.0 meter depth in Reservoirs and Lakes:

EPA is taking no action on Footnote 2. Consistent with the discussion in **Section IV**, this footnote does not go into effect for CWA purposes as described in 40 CFR § 131.21(c).

[3] For assessment of Individual Sample Criteria– at least eight (8) data points:

Footnote 3 is not a WQS and does not require EPA action.

[4] For calculation and assessment of Geometric Mean – calculated on a minimum of (5) five samples spaced evenly and within a thirty (30)-day period:

The portion of the footnote 4 referring to sample size is not a WQS and requires no action. The reference to the 30-day duration is a WQS and is approved.

[5] October 1 to April 30:

Footnote 5 is a WQS and is approved.

EPA is committed to working with ADEQ in the adoption of revised RWQC that reflects the latest science and is consistent with the CWA, and in the development of assessment language that will meet our shared needs.

Reg. 2.509 Nutrients

This provision has been amended, providing the following site-specific criteria for Beaver Lake:

(B) Site Specific Nutrient Standards

Lake	Chlorophyll a (µg/L)**	Secchi Transparency (m)***
Beaver Lake*	8	1.1

*These standards are for measurement at the Hickory Creek site over the old thalweg, below the confluence of War
Eagle Creek and the White River in Beaver Lake.
**Growing season geometric mean (May - October)
***Annual Average

The Beaver Lake project began with workgroups established in 2004 and culminated with a final report entitled Beaver Lake Site-Specific Water Quality Criteria Development: Recommended Criteria (FTN 2008). The project was a collaborative effort involving EPA, ADEQ, United States Geological Survey (USGS), Beaver Water District, FTN Associates, University of Arkansas, Fayetteville, and the Arkansas Water Research Center, in addition to others. The project established a weight of evidence approach which included literature and historical reviews, hydrologic analyses, statistical analyses of Beaver Lake water quality data, reference lake analyses and nutrient loading models and simulations to derive the criteria presented in this triennial revision.

Based on a review of the Beaver Lake report (FTN 2008), EPA determined that the site-specific criteria are scientifically defensible and protective of the applicable designated use. The inclusion of criteria specific to Beaver Lake is the first step in Arkansas' development of numeric nutrient criteria for lakes and reservoirs.

Reg. 2.511(A) Mineral Quality - Specific Standards: Delta Ecoregion

In its 2007 triennial revision, APC&EC made several revisions to Reg. 2.511(A). In its May 23, 2008 action, EPA approved site-specific chloride and sulfate criteria modifications for the portion of Bayou Two Prairie and its tributaries that do not have the Extraordinary Resource Water (ERW) designated use. However, in that same action EPA disapproved the revised site-specific chloride and sulfate criteria for the portion of Bayou Two Prairie adjacent to Smoke Hole Natural Area designated with the ERW use. EPA specified that water transferred from the Arkansas River to these five tributaries or the mainstem of Bayou Two Prairie upstream of the ERW portion of Bayou Two Prairie within the Smoke Hole Natural Area, could not exceed the ecoregion-based criteria of 48 mg/L and 37.3 mg/L for chloride and sulfate, respectively, that apply to the portion of Bayou Two Prairie adjacent to Smoke Hole Natural Area.

To address this disapproval, APC&EC has revised Reg. 2.511(A) to exclude that portion of Bayou Two Prairie and revised the applicable criteria for those waters outside of this segment as follows:

Stream	**Concentration – mg/L**		
	Chlorides (Cl^-)	Sulfates ($SO_4^{=}$)	TDS
Bayou Meto (mouth to ~~Bayou Two Prairie~~ Pulaski/Lonoke county line)	95**	45**	ER
~~Bayou Two Prairie (mouth to Rickey Branch)~~	~~95**~~	~~45**~~	~~ER~~
Bayou Two Prairie (Pulaski/Lonoke county line to Northern boundary of Smoke Hole Natural Area	95**	45**	ER
Bayou Two Prairie (Southern boundary of Smoke Hole Natural Area to Mouth)	95**	45**	ER

The exclusion of this portion of Bayou Two Prairie and the retention of the minerals criteria specific to the ERW segment resolves EPA's prior disapproval and is approved consistent with CWA Section 303(c) and its implementing regulations at 40 CFR § 131.

In addition, APC&EC inadvertently changed the minerals criteria applicable to Bayou Bartholomew in the 2007 triennial revision. EPA also disapproved this amendment in its 2008 action, noting that previously approved criteria from the state's 2004 amendments continued to apply. To address this disapproval, APC&EC has revised Reg. 2.511(A) revising the criteria for Bayou Bartholomew to reflect the criteria originally held in 2004 as follows:

Stream	**Concentration – mg/L**		
	Chlorides (Cl^-)	Sulfates ($SO_4^{=}$)	TDS
Bayou Bartholomew	~~50~~ 30	~~20~~ 30	~~500~~ 220

This resolves EPA's prior disapproval and is approved consistent with CWA Section 303(c) and its implementing regulations at 40 CFR § 131.

In its April 14, 2009 action EPA disapproved all proposed site-specific criteria revisions for chloride, sulfate, and Total Dissolved Solids (TDS) for the Great Lakes Chemical Corp., El Dorado Chemical Corp., and Lion Oil Company (GLCC, EDCC and Lion Oil). EPA took this action because the supporting documentation did not clearly demonstrate adequate protection of aquatic life uses for the receiving and associated waterbodies. To address this disapproval, APC&EC has revised Reg. 2.511(A) to exclude the unnamed and named tributaries of Little Cornie Bayou as follows:

Stream	**Concentration – mg/L**		
	Chlorides (Cl^-)	Sulfates ($SO_4^=$)	TDS
Little Cornie Bayou			
~~Unnamed trib from GLCC 003~~	~~538*~~	~~35*~~	~~519*~~
~~Unnamed trib to Little Cornie Bayou~~	~~305*~~	~~ER~~	~~325*~~
~~Little Cornie Bayou from unnamed trib to Louisiana State Line~~	~~215*~~	~~25*~~	~~500*~~
~~Bayou de L'Outre Creek above Loutre Creek~~	~~180~~	~~ER~~	~~970~~
~~Unnamed trib UT004 from GLCC~~	~~014*~~	~~ER~~	~~311*~~
~~Unnamed trib UT002 from GLCC~~	~~278*~~	~~90*~~	~~500*~~
~~Loutre Creek from AR Hwy 15 South to the confluence of Bayou de Loutre~~	~~256*~~	~~997*~~	~~1756*~~
~~Bayou de Loutre – from Loutre Creek to the discharge for the City of El Dorado South facility~~	~~264*~~	~~635*~~	~~1236*~~
~~Bayou de Loutre from the discharge for the City of El Dorado-South downstream to the mouth of Gum Creek~~	~~250*~~	~~431*~~	~~966*~~
~~Bayou de Loutre from the mouth of Gum Creek downstream to the mouth of Boggy Creek~~	~~250*~~	~~345*~~	~~780*~~
~~Boggy Creek - from the discharge for Clean Harbors El Dorado LLC to the confluence of Bayou de Loutre~~	~~631*~~	~~63*~~	~~1360*~~
~~Bayou de Loutre- from the mouth of Boggy Creek downstream to the mouth of Hibank Creek~~	~~250*~~	~~296*~~	~~750*~~
~~Bayou de Loutre from the mouth of Hibank Creek downstream to the mouth of Mill Creek~~	~~250*~~	~~263*~~	~~750*~~
~~Bayou de Loutre from the mouth of Mill Creek downstream to the mouth of Buckaloo Branch~~	~~250*~~	~~216*~~	~~750*~~
~~Bayou de Loutre from the mouth of Bear Creek downstream to the final segment of Bayou de loutre~~	~~250*~~	~~198*~~	~~750*~~
~~Bayou de Loutre (Final segment) – from the mouth of Bear Creek to the Arkansas/Louisiana State Line~~	~~250*~~	~~171*~~	~~750*~~

Striking these segments and the associated criteria resolves EPA's prior disapproval and is approved consistent with CWA Section 303(c) and its implementing regulations at 40 CFR § 131.

In its 2014 revisions, APC&EC adopted the following footnote applicable to the criteria for the unnamed tributaries to Flat Creek in the site specific mineral quality criteria table:

Stream	**Concentration – mg/L**		
	Chlorides (Cl^-)	Sulfates ($SO_4^=$)	TDS
Unnamed trib A to Flat Creek from mouth of EDCC 001 ditch to confluence with Flat Creek	16*†	80*†	315*†
Confluence with unnamed trib A to Flat Creek	23*†	125*†	475*†

† Not applicable for Clean Water Act purposes until approved by EPA.

This footnote was likely adopted because EPA's August 2011 disapproval of these criteria was under appeal in federal court at the time APC&EC finalized its 2014 triennial revision. In its decision, El Dorado Chemical Company v. U.S. Environmental Protection Agency, No. 13-1936, the 8th Circuit affirmed the judgment of a district court in Arkansas upholding EPA Region 6's disapproval of revised minerals criteria applicable to these two stream segments.

EPA also considers the footnote to be appropriate since it acknowledges that the stream segment descriptions and associated criteria identified above are not effective for CWA purposes consistent with 40 CFR § 131.21(c)(2). EPA has determined that this new footnote is a water quality standard since it relates directly to the applicability of criteria and is approved consistent with CWA §303(c) and its implementing regulations at 40 CFR §131. The approval of this new footnote has no effect on EPA's August 31, 2011 disapproval of these criteria as discussed in **Appendix A** and **Section V**. EPA's approval is limited to the footnote.

Reg. 2.511(B) Ecoregion Reference Stream Minerals Values

As part of ADEQ's triennial "Phase II" revision in 2007, ADEQ revised the following table with the intention of making it more user-friendly by reflecting the final calculations for chloride, sulfate, and TDS described within the text of Regulation 2. Because Regulation 2.511(B) retained the previous text describing the method for calculation and because that text referenced the revised table, the ecoregion chloride, sulfate, and TDS criteria associated with Reg. 2.511 were effectively revised to less stringent concentrations. As a result, EPA disapproved the revisions to the table in its January 24, 2008 action.

The current revisions described in the following table resolves EPA's 2008 disapproval action on Arkansas Triennial (“Phase II”) Revisions to Regulation No. 2.511(B) and are approved consistent with CWA Section 303(c) and its implementing regulations at 40 CFR § 131.

~~CALCULATED~~ ECOREGION REFERENCE STREAM VALUES (mg/~~l~~L)

Ecoregion	Chlorides (CL	Sulfates (SO_4^{2})	TDS
Ozark Highlands	~~17.3~~ 13	~~22.7~~ 17	~~250~~ 240
Boston Mountains	~~17.3~~ 13	~~15~~ 9	~~95.3~~ 85
Arkansas River Valley	~~15~~ 10	~~17.3~~ 13	~~112.3~~ 103
Ouachita Mountains	~~15~~ 6	~~20~~ 15	~~142~~ 128
Gulf Coastal Plains	~~18.7~~ 14	~~41.3~~ 31	~~138~~ 123
Delta	~~48~~ 36	~~37.3~~ 28	~~411.3~~ 390

Reg. 2.512 Ammonia

The introduction to this provision was revised as follows:

“The ~~T~~total ammonia nitrogen (N) criteria ~~shall not exceed those values~~ and the frequency of occurrence ~~established in the following tables~~ are as follows:”

In addition, the narrative for both the acute and chronic criteria tables retain a “shall not exceed” statement. The narratives read as follows:

(A) The one-hour average concentration of total ammonia nitrogen shall not exceed, more than once every three years on the average, the acute criterion as shown in the following table:

(B) The ~~thirty-day~~ monthly average concentration of total ammonia nitrogen shall not exceed those values shown as the chronic criterion in the following tables:

Although the language specifying the applicable absolute maxima was struck from the introductory sentence, the acute and chronic criteria narratives retain absolute maxima for pH dependent ammonia and also establish duration and frequency specific to these criteria. Although such “shall not exceed” language is generally not considered appropriate because it does not allow for natural variation within a waterbody and acceptable sampling and analysis error, states have the flexibility to adopt this type of limitation. But because the acute and chronic narratives establish magnitude, duration and frequency, EPA is approving the modifications to the introductory sentence and final sentence as consistent with CWA §303(c) and its implementing regulations at 40 CFR §131.

The remaining non-substantive language and symbol revisions are approved as discussed in **Section III** and detailed in ***Attachment 1***.

Appendix A

Site-Specific Designated Use Variations Supported by Use Attainability Analyses

Under the revised heading:

Site Specific Designated Use Variations Supported by ~~UAA~~Use Attainability Analyses

In its 2014 revisions, APC&EC adopted the following footnote and "†" symbol applicable for the Unnamed Tributaries to Flat Creek in the Site Specific Standards Variations Supported by Use Attainability Analysis found in Appendix A:

> "Unnamed tributary to Flat Creek from EDCC Outfall 001 d/s to confluence with unnamed tributary A to Flat Creek, Chloride 23 mg/L, Sulfate 125 mg/L, TDS 475 mg/L, (GC-2, #37) †
>
> Unnamed tributary A to Flat Creek from mouth of EDCC 001 ditch to confluence with Flat Creek, Chloride 16 mg/L, Sulfate 80 mg/L, TDS 315 mg/L, (GC-2, #38) †"

† Not applicable for Clean Water Act purposes until approved by EPA.

As noted in the discussion of **Reg. 2.511(A) – Site Specific Mineral Quality**, EPA's August 2011 disapproval of the site-specific criteria identified above was affirmed by the 8th Circuit in its decision, El Dorado Chemical Company v. U.S. Environmental Protection Agency, No. 13-1936. Although EPA has determined that this new footnote is approved, that action has no effect on EPA's August 31, 2011 disapproval of these criteria as discussed in **Section V**. As noted above, this footnote is approved consistent with CWA §303(c) and its implementing regulations at 40 CFR §131.

Appendix D

Procedures for Obtaining Director's Determination

In its 2007 triennial revision, APC&EC amended Reg. 2.304 in a way that altered the application of its previously approved antidegradation policy by expanding or clarifying its views on allowable "not significant" degradation in an Outstanding National Resource Waters (i.e., ERW, ESW, or NSW). The revisions at issue in Appendix D allowed physical alterations to ONRWs unless they "impair water quality." EPA's concern was that physical alterations in an ONRW could presumably be authorized unless they caused exceedances of applicable criteria possibly resulting in impairment of designated uses.

EPA found that the 2007 revisions to Reg. 2.304 and the referenced Appendix D were not consistent with 40 CFR §131.12(a)(3) and disapproved the amendments in January 2008 and specified that language previously approved by EPA in 2004 would continue to apply. See the previous discussion of Reg. 2.304 above and EPA's January 24, 2008 action for a more detailed discussion of both provisions. APC&EC's deletion of

Appendix D resolves EPA’s 2008 disapproval and is approved consistent with CWA §303(c) and its implementing regulations at 40 CFR §131.

III. Non-Substantive Edits that Constitute New or Revised Water Quality Standards EPA is Approving and Provisions EPA Has Previously Approved

Discussion

The CWA requires EPA to approve or disapprove new or revised WQS and specifies that state WQS must consist of designated uses and criteria to protect such uses. There are two decisions EPA must make before approving or disapproving a state or tribe’s new or revised WQS. First, EPA must determine whether the provision constitutes a new or revised WQS that EPA has CWA section 303(c)(3) authority and duty to approve or disapprove. If it does, the second decision EPA must make is whether the provision is approvable.

EPA’s understanding of what constitutes a new or revised WQS under CWA section 303(c)(3) is derived from the CWA itself, EPA’s implementing regulations, and case law. EPA’s authority and duty to evaluate whether a provision is a new or revised WQS is not dependent upon whether the provision was officially submitted to EPA for review as a new/revised WQS by the state or authorized tribe. EPA’s decision is based on four questions when evaluating whether a provision constitutes a new or revised WQS. A discussion of this process and the four questions EPA developed can be found on this EPA website: http://water.epa.gov/scitech/swguidance/standards/cwa303faq.cfm#fn2

As discussed in the **Introduction**, a significant number of non-substantive revisions throughout Reg. 2 are intended to provide clarity, correct minor errors and provide consistency within the document. As articulated in EPA’s October 2012 “What is a New or Revised WQS under CWA 303(c)?” Frequently Asked Questions document, EPA considers non-substantive edits to existing WQS to constitute new or revised WQS that EPA has the authority and duty to approve or disapprove under CWA section 303(c)(3). While such revisions do not substantively change the meaning or intent of the existing WQS, EPA believes that it is reasonable to treat such non-substantive changes in this manner to ensure public transparency as to which provisions are effective for purposes of the CWA. EPA notes that the scope of its action in reviewing and approving or disapproving such non-substantive changes would extend only as far as the actual non-substantive changes themselves. In other words, EPA’s action on non-substantive changes to previously approved WQS would not constitute an action on the underlying previously approved WQS. As a result, EPA approves the following provisions and those described in **Attachment 1** under section 303(c) of the CWA and its implementing regulations at 40 CFR § 131.

There are two provisions that have been described here for clarity. These include a discussion of **Reg. 2.511(B)** and ***Appendix A*** which are described as follows:

Chapter 5: Specific Standards

Reg. 2.511(B) Ecoregion Reference Stream Minerals Values

APC&EC has made multiple changes to Reg. 2.511(B) specific to the applicability of its Ecoregion Stream Values (ER). The revisions to this provision are as follows:

> "The following values were determined from Arkansas' least-disturbed ecoregion reference streams are considered to be the maximum naturally occurring levels. For waterbodies not listed above, any discharge which results in instream concentrations more than 1/3 higher than these values for chlorides (Cl^{-}) and sulfates ($SO4^{=2}$) or more than 15 mg/lL, whichever is greater, is considered to be a significant modification of the ~~water quality~~ maximum naturally occurring values. These waterbodies should be considered as candidates for site specific criteria development in accordance with Regs. 2.306 and 2.308. Similarly, such ~~modification~~ site specific criteria development ~~exists~~ should be considered if the following TDS values are exceeded after being increased by the sum of the increases to Cl and SO4. Such ~~modifications~~ criteria may be ~~made~~ developed only in accordance with Regs. 2.306 and 2.308. The values listed in the table below are not intended nor will these values be used by the Department to evaluate attainment of the water quality standards."

The word "were" and the terms "chlorides," "sulfates," and the related chemical formula changes, parentheses and liter "L" volume symbol are non-substantive changes and are approved.

EPA's action on other amendments to **Reg. 2.511(B), including those** provisions that are non-substantive as well as those that are substantive and have been determined to be WQS, are discussed in **Sections II and IV**.

Appendix A

Site-Specific Designated Use Variations Supported by Use Attainability Analyses

Under the heading:
Designated Uses: Gulf Coastal Ecoregion

APC&EC amended the entry for Loutre Creek from Highway 15 south to the confluence of Bayou de Loutre, deleting the domestic water supply designated use for this creek:

Loutre Creek from Highway 15 S. to the confluence of Bayou de Loutre – no domestic water supply use (GC-2, #41)

This amendment was previously approved by EPA in its April 14, 2009 action.

In addition, EPA previously approved the removal of the DWS designated use for waters associated with GLCC on November 11, 2007. In that action, EPA specifically identified the unnamed tributaries into which GLCC outfall 002 (UT002) and 004 (UT004) discharge, to the confluence with Bayou de Loutre. This approval also included the unnamed tributary to an unnamed tributary of Little Cornie Bayou (UT003), and the unnamed tributary of Little Cornie Bayou (UTLCB-2) to Little Cornie Bayou.

APC&EC has added the following entries, removing the Domestic Water Supply (DWS) use for the following waters consistent with EPA's November 2007 approval:

Unnamed trib 002 (UT002) – no domestic water supply use (GC-2, #31)
Unnamed trib 003 (UT003) – no domestic water supply use (GC-2, #34)
Unnamed trib 004 (UT004) – no domestic water supply use (GC-2, #32)
Unnamed trib to Little Cornie Bayou (UTLCB-2) - no domestic water supply use (GC-2, #18)

APC&EC also amended the entry for Bayou de Loutre, specifying where the removal of the drinking water supply uses (DWS) applies for this segment:

Bayou de Loutre from ~~Gum Creek~~ mouth of UT004 to Louisiana ~~S~~state line - no domestic water supply use (GC-2,#16).

EPA previously approved the removal of the DWS designated use for Bayou de Loutre from the mouth of UT004 to Gum Creek in its April 14, 2009 action. That action, combined with the previous DWS designated use removal for Bayou de Loutre from Gum Creek to State line means that the entire reach from Bayou de Loutre from mouth of UT004 to State line has no domestic water supply use as reflected in the revised entry.

The revisions to ***Appendix A*** described above have been previously approved by EPA under CWA Sec. 303(c), but have not been incorporated into Reg. 2 until now. They are being included in this TSD for clarity.

IV. Provisions Where EPA is Taking Partial or No Action

Chapter 1: Authority, General Principles and Coverage

Reg. 2.104 Policy for Compliance

Under a 1990 decision, the EPA Administrator determined that in order for a permitting authority to authorize a schedule of compliance, the state must have an authorizing provision for such a schedule in its WQS or implementing regulations. *In the Matter of Star-Kist Caribe, Inc.* 3 E.A.D. 172, 182-183, n.16 (1990). The National pollutant Discharge Elimination System (NPDES) regulations at 40 CFR §122.47 require that a compliance schedule only be included in an NPDES permit where "appropriate" and require compliance with the final effluent limitation "as soon as possible." Any NPDES permit establishing a compliance date more than one year from permit issuance must set interim requirements and dates for their attainment and/or progress reports.

Though discretionary on the part of the state, the Administrator has stated that authorizing provisions for compliance schedules fall within the category of implementing policies and procedures subject to EPA review under 40 CFR §131.13. *In the Matter of Star-Kist Caribe, Inc.*, 3 E.A.D. 172, 182-183, n. 16 (Adm'r 1990), *modification denied*, 4 E.A.D. 33 (EAB 1992); *In re City of Ames*, 6 E.A.D. 374 (EAB 1996). As such, authorizing provisions for compliance schedules are subject to EPA review and approval under CWA §303(c). APC&EC previously adopted and EPA approved Reg. 2.104 consistent with CWA requirements described above. In its 2014 revisions, APC&EC adopted the following amendments to Reg. 2.104:

> It shall be the policy of the Arkansas Department of Environmental Quality (hereinafter "Department") to provide, on a case-by-case basis, a reasonable time for an existing ~~facility~~ permittee to comply with new or revised water quality based effluent limits. Consequently, compliance schedules may be included in National Pollutant Discharge Elimination System (NPDES) permits at the time of renewal or permit modification initiated by the Department to require compliance with new water quality standards. Compliance must occur at the earliest practicable time,~~;~~ but not to exceed three years from effective date of permit,~~:~~ unless the permittee is completing site specific criteria development or is under a plan approved by the Department, in accordance with Reg. 2.306, 2.308, and the State of Arkansas Continuing Planning Process.

The majority of the new and revised language provides clarity as to when compliance schedules apply. However, the addition of the final sentence effectively exempts permittees from the "compliance must occur at the earliest practicable time, but not to exceed three years from the effective date of the permit" limitation specified in the provision. This language could be interpreted to allow dischargers an unspecified amount of time to develop site-specific criteria that would delay the effectiveness of the water quality-based effluent limit (WQBEL) that would otherwise apply under the currently applicable WQS. This approach appears to be inconsistent with EPA's policy as articulated in James Hanlon's May 10, 2007 memo (EPA 2007).

The Hanlon memo explains that a compliance schedule based on time needed to develop a site-specific criterion is inconsistent with CWA at section 502(17) and EPA's implementing regulations at 40 CFR §§ 122.47, 123.25(a)(18), and 122.44(d)(1)(vii)(A). Under the CWA definition, a compliance schedule is an enforceable sequence of actions or operations leading to compliance with an effluent limitation in a NPDES permit based on the currently applicable WQS. The CWA definition does not contemplate that a compliance schedule may be used to justify excluding a WQBEL based on the currently applicable standards from a permit solely to provide time to conduct an evaluation or use attainability analysis (UAA) that may result in changing the standards.

EPA Region 6 recognizes that the development and implementation of controls to meet water quality-based effluent limitations may require extended compliance schedules for certain pollutants. Although Arkansas' intent may be to move towards including extended compliance schedules in its NPDES permits in certain situations, the revised provision states that "compliance must occur at the earliest practicable time, but not to exceed three years from the effective date of the permit." In effect, the provision itself limits attainment of compliance to three years and does not allow for extended compliance beyond three years except in instances that are themselves inconsistent with the CWA definition for compliance schedules.

Based on the preceding discussion, EPA approves the majority of the revised portions of the provision as consistent with the CWA §303(c) and its implementing regulations with the exception of the final sentence identified below:

> "…unless the permittee is completing site specific criteria development or is under a plan approved by the Department, in accordance with Regs. 2.306, 2.308, and the State of Arkansas Continuing Planning Process."

Based on the state's supporting information, EPA could not determine how this exception would be implemented consistent with CWA §§303 and 502 and their implementing regulations. As a result, EPA takes no action on this sentence. This portion of the revised provision does not go into effect for CWA purposes as described in 40 CFR § 131.21(c). EPA remains committed to working with ADEQ to develop language that will meet the state's needs while being consistent with established law and EPA policy.

Chapter 5: Specific Standards

Reg.(s) 2.502 - Temperature, 2.503 - Turbidity, 2.504 - pH, 2.505 - Dissolved Oxygen (Lakes and Reservoirs), and 2.511(C) - Mineral Quality (Lakes and Reservoirs)

The following provisions have been revised, adding the phrase "applicable at 1.0 meter depth" to describe the application of specific criteria. These parameters include:

- Maximum allowable temperatures from man-induced causes
- Turbidity (measured in NTUs)
- pH
- Allowable dissolved oxygen
- Mineral quality (chlorides, sulfates and total dissolved solids)

The phrase "applicable at 1.0 meter depth" reads that the criteria for the specific parameters identified above *only* apply at 1.0 meter depth, and that there are no criteria applicable at other depths of the water bodies.

ADEQ's February 6, 2014 letter providing clarification on a number of revised provisions indicates that these changes were an attempt to standardize sampling depth to assess attainment of (numeric) water quality criteria. However, by specifying that the criteria are *applicable* rather than that they are to be *assessed* at 1.0 meter depth, the meaning of the provision was altered from what may have been intended as assessment language to a revised water quality standard.

While EPA recognizes that the epilimnion is where most aquatic life and recreational contact occurs, criteria that apply at a single depth are not protective of aquatic life in the water column as a whole. Pollutants and their effects may be found at any depth throughout the water column in lotic waters. Supporting documentation that the 1.0 meter depth is representative of the epilimnion in all lakes and reservoirs was not provided. For example, adequate DO may be limited to the epilimnion during periods of thermal stratification in lakes and reservoirs, but other conditions or contaminants may be found at different depths or concentrations that may have an effect on aquatic life when no stratification is present.

Based on the state's supporting information, EPA could not determine how the 1.0 meter depth limitation would be implemented ensuring protection of the designated use and/or aquatic life throughout the water column for the parameters described in Reg.(s) 2.502, 2.503, 2.504, 2.505 and 2.511(C). As a result, EPA takes no action on the phrase:

"Applicable at 1.0 meter depth"

As a result, this phrase does not go into effect for CWA purposes as described in 40 CFR § 131.21(c). EPA is committed to working with ADEQ to develop implementation language that will meet the state's assessment needs while being consistent with established law and EPA policy.

Reg. 2.511(B) Mineral Quality – Ecoregion Reference Stream Values

APC&EC has made multiple changes to Reg. 2.511(B) specific to the applicability of its Ecoregion Stream Values (ER). The revisions to this provision are as follows:

> "The following values were determined from Arkansas' least-disturbed ecoregion reference streams are considered to be the maximum naturally occurring levels. For waterbodies not listed above, any discharge which results in instream concentrations more than 1/3 higher than these va~~l~~ues for chlorides (Cl^{-}) and sulfates (SO4$^{=2}$) or more than 15 mg/~~l~~L, whichever is greater, is considered to be a significant modification of the ~~water quality~~ maximum naturally occurring values. These waterbodies should be considered as candidates for site specific criteria development in accordance with Regs. 2.306 and 2.308. Similarly, such ~~modification~~ site specific criteria development ~~exists~~ should be considered if the following TDS values are exceeded after being increased by the sum of the increases to Cl and SO4. Such ~~modifications~~ criteria may be ~~made~~ developed only in accordance with Regs. 2.306 and 2.308. The values listed in the table below are not intended nor will these values be used by the Department to evaluate attainment of the water quality standards."

The new phrase "These waterbodies should be considered as candidates for site specific criteria development in accordance with Regs. 2.306 and 2.308”, revisions to the phrase “~~modification~~ site specific criteria development ~~exists~~ should be considered” and the phrase “water quality” and its replacement with “maximum naturally occurring values” are approved consistent with CWA Section 303(c) and its implementing regulations at 40 CFR § 131.

EPA has determined that the new sentence at the end of the revised provision is a significant change. The sentence reads as follows:

“The values listed in the table below are not intended nor will these values be used by the Department to evaluate attainment of the water quality standards.”

A significant percentage of Arkansas’ waters have naturally low mineral concentrations. ADEQ developed the state’s Ecoregion Reference Stream Values (ER values) based on observation of least disturbed streams to ensure protection of designated uses in waters with no applicable site-specific criteria. The effect of the new sentence is that the ER values would not be used for CWA purposes, thus removing important protection for designated uses, particularly in waters with naturally low mineral levels. Federal regulations at 40 CFR § 131.11(a)(1) require states to adopt water quality criteria based on sound scientific rationale that support the most sensitive designated use. If ADEQ does not consider its ER values to be appropriate, it has flexibility in developing alternative criteria as outlined in 40 CFR § 131.11(2)(b).

To a significant extent, minerals criteria development efforts are affected by the state of the science and development of guidance by EPA. Currently, EPA is involved in multiple ongoing activities related to ionic stress on aquatic life. These efforts are all at various stages. For example, EPA is: 1) developing a field-based methodology for states to develop aquatic life criteria for conductivity (a measure of mineral concentrations), 2) conducting and collaborating with other scientists on toxicity testing to explore the effects of multiple ions on both traditional and more sensitive lab organisms, which may result in modifications to the general model, 3) developing additional lab test methods for sensitive macroinvertebrates, and 4) researching ways to harmonize field and lab approaches.

In addition, EPA’s Office of Science and Technology, in coordination with EPA Region 6 and the state of Arkansas, has developed a technical report of exploratory analyses specific to Arkansas to evaluate different approaches for deriving mineral-related criteria for sulfate, chloride, and TDS to protect aquatic life uses. This report analyzed three approaches for criteria development, an ecoregional reference approach, a laboratory toxicity based approach, and a field-based species sensitivity distribution approach. These approaches can be utilized as potential starting points for Arkansas’s minerals criteria development.

As described in 40 CFR § 131.11(b)(2), in establishing criteria, states should establish values based on: §304(a) guidance, §304(a) guidance modified to reflect site-specific conditions, or other scientifically defensible methods. These options provide states significant flexibility in their approach to criteria development. It is important to note that

EPA's §304(a) recommended criteria are not definitive values, but national guidelines that may be over-protective or under-protective at a given site.

EPA's current national policy also allows states, territories and authorized tribes to establish site-specific aquatic life criteria by setting the criteria value equal to natural background. (See *Establishing Site Specific Aquatic Life Criteria Equal to Natural Background* (1997)). Regardless of the approach taken, if existing ER values are replaced, it is important that EPA clearly understands how the criteria and supporting implementation and assessment methodology work together to protect designated uses.

The sentence related to the intent and use of ER values effectively leaves waters that do not have site-specific minerals criteria without minerals criteria that are protective of the designated uses. 40 CFR § 131.11(a)(1) outlines a clear requirement for states to adopt water quality criteria based on sound scientific rationale that support the most sensitive designated use. However, EPA also recognizes the current state of the science and that the Agency's own efforts related to the development of recommended minerals criteria are ongoing and affect ADEQ's ability to revise its minerals criteria pursuant to federal regulation. Should the state choose to develop and adopt alternative scientifically defensible minerals criteria that would protect the most sensitive designated use, EPA requests that ADEQ describe its proposed approach within 12 months and that the approach include a schedule outlining interim milestones leading to criteria adoption. EPA will provide an outline that the state can consider if it chooses to develop a plan.

EPA is taking no action on the revised sentence "The values listed in the table below are not intended nor will these values be used by the Department to evaluate attainment of the water quality standards." This sentence is not effective for CWA purposes as described in 40 CFR § 131.21(c). EPA will continue to coordinate with ADEQ as needed on the development of revised minerals criteria protective of aquatic life.

Reg. 2.511(C) Domestic Water Supply Criteria

This provision was revised as follows:

> (C) Domestic Water Supply Criteria
> In no case shall discharges cause concentrations in any waterbody to exceed 250, 250 and 500 mg/L of chlorides, sulfates and total dissolved solids, respectively, or cause concentrations to exceed the applicable ~~limits~~ criteria ~~in the streams to which they are a tributary~~, except in accordance with Regs. 2.306 and 2.308. For lakes and reservoirs applicable at 1.0 meter depth.

By striking the word "limits" and "in the streams to which they are a tributary" the provision now appropriately refers to "criteria" rather than "limits" which would be derived from the applicable criteria. These amendments and the addition of phrase "and 2.308" are considered non-substantive revisions which are discussed in **Section III** and described in ***Attachment 1***.

Consistent with actions described for provisions with similar language described above, EPA takes no action on the final sentence specifying that Domestic Water Supply criteria are applicable: "For lakes and reservoirs applicable at 1.0 meter depth." This phrase does not go into effect for CWA purpose as described in 40 CFR § 131.21(c) as discussed above.

V. Provisions Previously Disapproved by EPA

Chapter 5: Specific Standards

Reg. 2.503 Turbidity

As part of its 2014 revisions, APC&EC revised the narrative portion of this provision, which describes ecoregion-specific turbidity criteria for streams, rivers, and lakes applicable in two different flow scenarios. The more stringent criteria apply during "base flow" conditions and the less stringent criteria applying during "all flow" conditions when storm water runoff may be present. The revised narrative portion is as follows:

> **Reg. 2.503 Turbidity**
> There shall be no distinctly visible increase in turbidity of receiving waters attributable to ~~municipal, industrial, agricultural, other waste~~ discharges or instream activities. ~~Specifically, in no case shall any such waste discharge or instream activity causeturbidity values to exceed the base flows values listed below. Additionally, the non-point source runoff shall not result in the exceedance of the in stream all flows values in more than 20% of the ADEQ ambient monitoring network samples taken in not less than 24 monthly samples.~~ The values below should not be exceeded during base flow (June to October) in more than 20% of samples. The values below should not be exceeded during all flows in more than 25% of samples taken in not less than 24 monthly samples.

In its 2007 triennial revision ADEQ revised Reg. 2.106 and Reg. 2.503 with the intent of clarifying the flow conditions under which less stringent turbidity criteria specific to storm flow would be applicable. EPA disapproved revisions to Reg. 2.503 based on the position that applying criteria reflective of elevated flow scenarios to all flow conditions, including base flow, is not appropriate. EPA noted that this approach would not ensure protection of designated uses and the potential misidentification of a waterbody in the state's CWA § 305(b)/303(d) assessment as supporting its applicable fisheries designated use when it may actually be impaired due to turbidity. A more detailed discussion of this action can be found in EPA's January 24, 2008 (Phase II) disapproval and supporting TSD.

The recent amendments to Reg. 2.503 outlined above do not address the concerns outlined in EPA's 2008 disapproval. EPA sought additional information from ADEQ to explain how this provision was developed and to clarify how it ensures protection of aquatic life. The information provided in ADEQ's February 6, 2014 letter did not clarify how the application of the turbidity criteria would be protective of aquatic life given the percentage of exceedances allowed under the two flow scenarios or how the datasets are applied. Continued discussions between ADEQ and EPA staff concerning this provision has led to a better understanding of the state's approach and the Region's concerns with this provision. ADEQ and EPA staff are continuing to work to develop revised language for Reg. 2.503 and related assessment methodology prior to ADEQ's next triennial revision. The goal of this effort would be to resolve the 2008 disapproval of turbidity language and develop scientifically sound criteria that can be assessed and implemented. To facilitate a clearer understanding and possible approval, EPA recommends that ADEQ provide supporting documentation describing how turbidity criteria were originally derived to protect aquatic life and how flow relates to the terminology changes (i.e., storm flow to all flows) and exceedance rate change (20% to 25%). Changes in terminology could clarify how the turbidity criteria are applied (e.g., "seasonal standard" rather than "base flow" and "annual standard" rather than "all flows". EPA is committed to meeting with the state to further discuss the turbidity standards to resolve the outstanding disapproval.

As a result, no new action is being taken by EPA at this time with regard to Reg. 2.503. EPA's 2008 disapproval of the heading "All Flow Values" and associated text revision from "storm-flow" to "all flows" in Reg. 2.503 remains in place. As noted in EPA's 2008 action, as specified in 40 CFR § 131.21(c), these revised standards do not go into effect for CWA purposes until approved by EPA. Therefore, the previously approved heading title of "Storm-Flow" in Regulation 2.503 and the term "storm-flow" within the text of Regulation 2.503 remain in effect for CWA purposes.

Reg. 2.511(A) Site-specific Mineral Quality Criteria

In its 2014 revisions, APC&EC adopted the following footnote applicable to the criteria for the unnamed tributaries to Flat Creek in the site specific mineral quality criteria table:

Stream	**Concentration – mg/L**		
	Chlorides (Cl^-)	Sulfates $(SO_4^=)$	TDS
Unnamed trib A to Flat Creek from mouth of EDCC 001 ditch to confluence with Flat Creek	16*†	80*†	315*†
Confluence with unnamed trib A to Flat Creek	23*†	125*†	475*†

† Not applicable for Clean Water Act purposes until approved by EPA.

As discussed in **Section II** above, EPA believes that this footnote was adopted because EPA's August 2011 disapproval of these criteria was under appeal in federal court at the time APC&EC finalized its 2014 triennial revision. As noted previously, in its decision, El Dorado Chemical Company v. U.S. Environmental Protection Agency, No. 13-1936, the 8th Circuit affirmed the judgment of a district court in Arkansas upholding EPA Region 6's disapproval of revised minerals criteria applicable to these two stream segments.

EPA's approval of this footnote has no effect on EPA's prior disapproval. The criteria for the specific streams identified above remain disapproved and are not in effect for CWA purposes as described in 40 CFR § 131.21(c). EPA recommends that the state revise **Reg. 2.511(A)** and ***Appendix A*** to be consistent with EPA's prior disapproval. This action would also negate the need for the footnote.

VI. Literature Cited

FTN Associates, Ltd. (2008). *BEAVER LAKE SITE-SPECIFIC WATER QUALITY CRITERIA DEVELOPMENT RECOMMENDED CRITERIA*. Little Rock, AR.

FTN Associates, Ltd. (2013). *ALCOA INC. – BAUXITE ENVIRONMENTAL IMPROVEMENT PROJECT NOTICE OF INTENT*. Little Rock, AR.

FTN Associates, Ltd. (2013). *APPENDICES: ALCOA INC. – BAUXITE ENVIRONMENTAL IMPROVEMENT PROJECT NOTICE OF INTENT*. Little Rock, AR.

ATTACHMENT 1

NON-SUBSTANTIVE EDITS THAT CONSTITUTE NEW OR REVISED WATER QUALITY STANDARDS EPA IS APPROVING

Section	Revision	ADEQ Revision Justification
Cover	Removed the #7 that is prior to “Arkansas” at the top of the cover page.	Corrects typographical error.
Throughout	Throughout regulation, any place other than the front title page, removed the existing adoption date.	Correct date for updated document.
Throughout	Scanned appendix A and all tables within document for “tributary” and change to “trib.”	Standardization of text.
Throughout	Scanned document and change incorrect concentration units from “mg/l,” “µg/l” and “ng/l,” to “mg/L,” “µg/L” and “ng/L.”	The standard abbreviation for milligrams per liter is mg/L; µg/L is the standard abbreviation for micrograms per liter; and ng/L is the standard abbreviation for nanograms per liter.
Throughout	Scanned the entire document for the term “aquatic life” and changed to “aquatic biota,” where not referring to “aquatic life” as a designated use.	Use of the term “aquatic biota” will help differentiate between the aquatic life designated use and plant and animal life found in aquatic systems.
Throughout	Scanned the entire document for “ADEQ” and replaced with “Department.”	Reg. 2.104 states that the Arkansas Department of Environmental Quality will thereafter be referred to as the “Department” in the document.
Throughout	Throughout regulation capitalized “Extraordinary Resource Waters, Ecologically Sensitive Waterbodies, and Natural and Scenic Waterways”.	Standardization of text.
Throughout	Throughout regulation replaced “CFS” with “cfs”.	Standardization of text.
Throughout	Throughout the regulation replaced “Cr.” with “creek”.	Standardization of text.
Throughout	Throughout Appendix A replaced “TDS” with “total dissolved solids”	Standardization of text.
Throughout	Throughout the entire regulation replaced “D.O.” with “dissolved oxygen”.	Standardization of text.
Throughout	Throughout the entire regulation replaced abbreviation “Brdg” with “Bridge.”	Standardization of text.
Throughout	Throughout the entire regulation, added the appropriate state name before “state line” or the appropriate county name before “county line.” **Example:** “from mouth to Louisiana state line.”	Clarification

Throughout	Throughout entire regulation added the word "state" or "county" in front of "line" in reference to a state or county boundary. **Example:** Missouri state line.	Clarification
Throughout	Throughout entire regulation, replaced the acronym "UAA" with "Use Attainability Analysis," except for the plate legends in Appendix A (based on available space).	Required by "REGULATION FORMATTING AND DRAFTING GUIDELINES."
Table of Contents & Appendix D	Removed title "~~PROCEDURES FOR OBTAINING DIRECTOR'S DETERMINATION ON THE PROPOSED PHYSICAL ALTERATION OF AN EXTRAORDINARY RESOURCE WATERS, ECOLOGICALLY SENSITIVE WATERBODY, OR NATURAL AND SCENIC WATERWAY~~" and changed to "List of current extraordinary resource waters, ecologically sensitive waterbodies, and natural and scenic waterways."	EPA disapproved the current appendix D. Having a list of all the ERWs, ESWs, and NSWs in one location will be useful for both the Arkansas Department of Environmental Quality and other agencies and persons.
Page 1-1	Added an "s" at the end of "standard."	Corrects typographical error.
Reg 2.101	Revise this sections as follows: "Pursuant to ~~the provisions of SubChapter 2 of~~ the Arkansas Water and Air Pollution Control Act, ~~(Act 472 of the Acts of Arkansas for 1949, as amended;~~ (Ark. Code Ann. § 8-4-101 ~~et seq~~ *et seq.*), and in compliance with the requirements of the Federal Water Pollution Control Act, 33 U.S.C. § 1251 *et seq.*,~~as amended~~ (hereinafter "Clean Water Act"), the Arkansas Pollution Control and Ecology Commission, (hereinafter ~~referred to as~~ "Commission") hereby promulgates this ~~R~~regulation ~~No. 2, as amended,~~ establishing water quality standards for all surface waters, interstate and intrastate, of the State of Arkansas."	These revisions provide more accurate reference to the legal codes and acts.
Reg 2.101	Added closing parenthesis to follow "…Ark. Code Ann. 8-4-101 et seq."	Corrects typographical error.
Reg 2.101	Removed comma between "…Commission~~,~~ (hereinafter…"	Grammatical error.
Reg 2.102	Second sentence, added a comma after "value,"	Corrects typographical error.
Reg 2.104	Added text: "Arkansas" Department "of Environmental Quality (hereinafter referred to as "Department")."	Proper reference to the Arkansas Department of Environmental Quality.
Reg 2.104	Added text "National Pollutant Discharge Elimination System" and placed NPDES in parenthesis.	Defining NPDES acronym for clarification.
Reg 2.104	Revised first sentence to read "…time for an existing permitee to comply…"	Clarification of the intent of the section.

Reg 2.104	Revised the second sentence as follows: "Consequently, compliance schedules may be included in National Pollutant Discharge Elimination System (NPDES) permits at the time of renewal or permit modification initiated by the Department to require compliance with new water quality standards."	Clarification of the intent of the section.
Reg 2.106	Bolded defined words.	Required by Arkansas's REGULATION FORMATTING AND DRAFTING GUIDELINES.
Reg 2.106	**Revision: Reg. 2.106:** Reformated definitions to bolded font for defined words. **Example: Abatement**: The reduction in degree or intensity of pollution.	Standardization of text.
Reg 2.106	Added U.S. in front of "Environmental Protection Agency."	Standardization of text.
Reg 2.106	Revised the 304(a) Guidance definition as: **304(a) Guidance**: Refers to Section 304(a) of the Clean Water Act, 33 U.S.C. § 1314(a), which requires the United States Environmental Protection Agency to publish and periodically update ambient water quality criteria which will be protective of human health and the environment.	To provide a more accurate reference to the legal codes and acts.
Reg 2.106	Added a period to the end of definition for "Design flow."	EPA suggestion, Corrects typographical errors.
Reg 2.106	Revised "Algae" definition as: "**Algae**: Simple plants without roots, stems, or leaves ~~which~~ that contain chlorophyll and are capable of photosynthesis."	Both changes are to correct grammatical errors.
Reg 2.106	Added "aquatic life" definition.	The term "aquatic life" is replacing the term "fishery" as a designated use in the document. "Aquatic life" more adequately describes the intent of the designated use and better fits the definition given in Reg. 2.302.
Reg 2.106	Added the definition: "**Bioaccumulation:** The process by which a compound is taken up by an aquatic organism, both from water and through food."	Bioaccumulation is referenced in the regulation, but has not been included in the definitions section.
Reg 2.106	Removed the definition: **Act**: Clean Water Act, as amended (33 U.S.C. 1251, et. seq.)	Full citations to the Clean Water Act are now included throughout the regulation so the definition is not necessary.
Reg 2.106	Revised "Continuing Planning Process" definition to "State of Arkansas Continuing Planning Process". Moved definition to proper	Proper reference of the document is the "State of Arkansas Continuing Planning Process" and it will be defined under that title.

	alphabetical order within section. The wording of the definition was not revised.	
Reg 2.106	Added the definition: "**Conventional pollutants:** Pursuant to section 304(a)(4) of the Clean Water Act, 33 U.S.C. §1314(a)(4), includes biochemical oxygen demand (BOD), total suspended solids (nonfilterable) (TSS), pH, fecal coliform, and oil and grease."	Conventional pollutant is referenced in the regulation, but has not been included in the definitions section.
Reg 2.106	Added "Criterion Continuous Concentration (CCC)" and "Criterion Maximum Concentration (CMC)" definitions.	Criterion Continuous Concentration and Criterion Maximum Concentration are referenced in the document, but have not been included in the definitions section.
Reg 2.106	Deleted the definition for Primary Season Critical Flow.	The Department is satisfied that the definitions for "Primary Season" and "Critical Flow" sufficiently define "Primary Season Critical Flow."
Reg 2.106	Revised part of "Critical flows" as: "For a seasonal ~~fishery~~ aquatic life - 1 cubic foot per second (cfs) minus the design flow of any point source discharge (may not be less than zero).;"	This is the first place in the document where "cubic foot per second" is used; therefore, the "cfs" acronym must be defined for clarification.
Reg 2.106	Revised "Department" definition to read "**Department:** The Arkansas Department of Environmental Quality, or its successor."	Required by REGULATION FORMATTING AND DRAFTING GUIDELINES.
Reg 2.106	In the "Existing uses" definition, added "Clean Water" in front of "Act" and throughout the rest of the document.	Clarification of the reference and standardization of text.
Reg 2.106	Revised *Escherichia coli* definition as: "***Escherichia coli*:** A~~a~~ rod shaped gram negative bacillus (0.5 – 3-5 microns) abundant in the large intestines of mammals."	Standardization of definition formatting.
Reg 2.106	Removed "fishery" from definition.	The term "aquatic life" is replacing the term "fishery" as a designated use in the document. "Aquatic life" more adequately describes the intent of the designated use and better fits the definition given in Reg. 2.302.

Reg 2.106	Added "ground water" definition. Defined ground water as: water below the land surface in a zone of saturation.	This is the definition of ground water provided in Regs 17, 22, and 23; the Code of Federal Regulation 40 CFR § 146.3, 40 CFR § 270.2, Safe Drinking Water Act, and Resource Conservation and Recovery Act also use this definition.
Reg 2.106	Revised the definition: "**Headwater**: ~~The source of a stream~~The upper watershed area where streams generally begin; typically consists of 1st- and 2nd-order streams."	This definition is consistent with the EPA definition.
Reg 2.106	In the "Mixing zone" definition, removed the comma and "(ZID)" acronym.	The comma is a grammatical error and the ZID acronym is removed based upon the "REGULATION FORMATTING AND DRAFTING GUIDELINES."
Reg 2.106	In the "NTU" definition, removed parenthesis from "Nephelometric Turbidity Unit" and follow with NTU in parenthesis. Formatted "Jackson Turbidity Units" and Formazin Turbidity Units in the same manner.	Proper formatting.
Reg 2.106	To clarify, this definition was revised as follows: "**Nonpoint source:** A contributing factor to water pollution that is not confined to an end-of-the-pipe discharge, i.e., stormwater runoff not regulated under Clean Water Act § 402(p)(1), 33 U.S.C. § 1342(p)(1), agricultural or silvicultural runoff, irrigation return flows, etc."	Responses to EPA suggestion to clarify definition to include a reference to the Clean Water Act.
Reg 2.106	Revised "Seasonal fishery" to "Seasonal Aquatic Life." Also replaced "fishery" with "aquatic life" within the text of the definition.	It is proposed to replace the designated use "fishery" with "aquatic life."
Reg 2.106	Added "State of Arkansas Continuing Planning Process" definition.	Formerly defined as "Continuing Planning Process." The new definition provides proper reference of the document.
Reg 2.106	Capitalized "state" in waterbodies, waterways, and waters definition.	Corrects typographical error.
Reg 2.202	Removed "…State's continuing planning process..." wording and replace with "State of Arkansas' Continuing Planning Process." Scanned document and changed all references to "State of Arkansas' Continuing Planning Process."	Proper reference of the document.

Reg 2.203	Scanned document and capitalized "Extraordinary Resource Waters, Ecologically Sensitive Waterbodies, and Natural and Scenic Waterways."	Standardization of text.
Reg 2.203	Added text "Extraordinary Resource Waters" and placed "ERW" in parenthesis.	Defining ERW acronym for clarification.
Reg 2.204	Revised the provision to read as follows: "In those cases where potential water quality impairment associated with a thermal discharge is involved, the antidegradation policy and implementing method shall be consistent with Section 316 of the Clean Water Act, 33 U.S.C. § 1326."	Clarification of the reference.
Reg 2.302	Revised "Fisheries" heading of part (F) to read "Aquatic Life." Further, revised the entire document and replaced "fisheries" with "aquatic life" where referencing the Fisheries designated use.	The term "aquatic life" more adequately describes the intent of the designated use and better fits the definition given in Reg. 2.302.
Reg 2.302	Added text "(For specific listings please refer to Appendices A and D)" to sections (A), (B), and (C).	This provides a reference to the instances where a waterbody has had a variation in use and/or standard(s) resulting from use attainability analysis.
Reg 2.302	Under revised "Fisheries" heading, capitalized sections (1), (2), and (3).	Standardization of text.
Reg 2.303	Spelled out U.S. Environmental Protection Agency and placed "EPA" acronym in parenthesis.	Defining EPA acronym for clarification.
Reg 2.303	Removed "CPP" acronym.	The acronym is not used elsewhere in the document and is therefore unnecessary.
Reg 2.308	Spelled out the acronym for WER	Defining WER acronym for clarification.
Reg 2.310	In the title, removed the capitalized "A" and replaced with a small "a."	Corrects typographical error.
Reg 2.311, No. 8 of section (A):	Revised No. 8 to read "Supporting documentation for the designation, including information which addresses the factors listed in Appendix F~~, I(A) through (P);~~"	All articles in Appendix F must be met; there is no need to list them.
Reg 2.401	Added "Unless otherwise indicated in this Chapter or in Appendix A" to the beginning of the first sentence.	To clarify that some general standards may not apply to every waterbody due to water quality standards variations supported by a use attainability analysis.
Reg 2.404	The first sentence was revised as: "Where ~~M~~mixing zones are allowed, ~~for all parameters not specifically excluded in Reg. 2.404 and~~ the	The issue of a mixing zone must be determined on a case-by-case basis. The first sentence is being revised

	effects of wastes on the receiving stream shall be determined after the wastes have been thoroughly mixed with the mixing zone volume.”	to recognize that a mixing zone can apply to a variety of parameters and circumstances.
Reg 2.404	In second paragraph, removed the commas that came before and after the information in parenthesis (this occurs twice in the paragraph).	Grammatical errors.
Reg 2.501	Added “Unless otherwise indicated in this Chapter or in Appendix A” to end of first sentence.	To clarify that some specific standards may not apply to every waterbody due to water quality standards variations supported by a use attainability analysis.
Reg 2.501	Inserted a coma after “…on occasion.”	Corrects typographical error.
Reg 2.502	Added a space between St. and Francis in table.	Corrects typographical error.
Reg 2.502	Inclusion of “Louisiana.”	Clarifies the applicable stream segment.
Reg 2.504	Inserted the word “standard” following the 1.0 in the second sentence	The inclusion of the word “standard” following the 1.0 refers to pH measurement units.
Reg 2.505	Placed the table before the text.	Easier flow of information.
Reg 2.505	Revised second paragraph: “All streams with watersheds of less than 10 mi^2 are expected to support ~~a~~ ~~fishery~~ aquatic life during the primary season when stream flows, including discharges, equal or exceed 1 cubic foot per second ~~(CFS)~~(cfs). ~~h~~However, when site verification indicates that ~~a~~ ~~fishery~~ aquatic life exists at flows below 1 ~~CFS~~cfs, such ~~fishery~~ aquatic biota will be protected by the primary standard (refer to the State of Arkansas Continuing Planning Process for field verification requirements).”	To clarify when small watersheds are expected to support aquatic life. Also, the “CFS” acronym is revised to “cfs” for standardization of text.
Reg 2.505	Replaced “state's continuing planning process” with “State of Arkansas Continuing Planning Process.”	Standardization of document.
Reg 2.505	Replaced the sentence: ~~Regulation #6 of the Arkansas Pollution Control and Ecology Commission~~ with Arkansas Pollution Control and Ecology Commission Regulation No. 6, Regulations for State Administration of the National Pollutant Discharge Elimination System (NPDES) and the striking and replacement of ~~state's~~ State of Arkansas and the capitalization of ~~c~~Continuing ~~p~~Planning ~~p~~Process.	Appropriate references to the APCEC and its implementing regulations and EPA programs and standardization of text.
Reg 2.508	Added the phrase “zone of initial dilution” and its corresponding acronym “(ZID)” as well as the	Standardization of text for the use of terms and acronyms.

	reference to the “State of Arkansas” and striking the acronym “(NOECs)”	
Reg 2.508	Removed the space between “non” and “permit.”	Corrects typographical error.
Reg 2.508	Revised the first footnote to read “These values may be adjusted by a site specific Water-Effects Ratio (WER) as defined in 40 CFR Part 131.36 (c).”	Space between Ratio and parentheses corrects typographical error. The first #1 was inadvertently let off of “Part 131.36 (c).”
Reg 2.508	Removed the “**” footnote marker from the first column for Mercury in the Dissolved Metals table.	Clarify that acute criteria are not expressed as total recoverable.
Reg 2.508	Added the footnote marker “‡” to Mercury in the Dissolved Metals table. Added the foot note,“‡ Mercury based on bioaccumulation of residues in aquatic organisms.” Removed“~~Mercury based on bioaccumulation of residues in aquatic organisms, rather than toxicity~~” from the existing “**” footnote.	Clarification.
Reg 2.508	Under “Human Health Criteria” revised second footnote as: “** 4000 ng/~~l~~L is also represented as 4.0 ug/~~l~~L, which is the ~~M~~maximum contaminant level ~~(MCL)~~ under the ~~EPA~~ Safe Drinking Water Act, ~~[~~42 U.S.C. ~~s/s~~§ 300f ~~et seq~~ *et seq*. ~~(1974)]~~”	The “M” in “maximum” does not need to be capitalized, it corrects a typographical error. Also, the acronym “MCL” does not need to be included, it is not used anywhere else in the document.
Reg 2.509	Added section heading “(A)” to the first paragraph and “(B)” to Site Specific Nutrient Criteria.	Separating narrative general standards from site specific nutrient standards
Reg 2.509	In the second sentence replaced “~~are~~” with “is.”	Grammatical error.
Reg 2.509	In last sentence of first paragraph, removed the comma between “established, numeric.”	Grammatical error.
Reg 2.509	Revised last sentence of section (A) as: “However, when excess nutrients 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.”	Clarification of which water quality standards are used to determine nutrient impairment.
Reg 2.511 (A)	Revised second sentence in first paragraph to read, “The following ~~limits~~ criteria apply to the streams indicated.”	Clarification of the intent of the section; the numbers represent criteria, not limitations used in the permitting process.
Reg 2.511 (A)	Added element names to the minerals table.	The atomic symbols for chloride and sulfate has not been defined, nor has the acronym TDS, at this point in the document.

Reg 2.511 (A)	For the Arkansas River, revised (Mouth to L&D #7) to (Mouth to Murray Lock and Dam [L&D #7]).	Adding the dam’s common name will make the stream reach description easier to interpret.
Reg 2.511 (A)	Removed the asterisks from the site specific criteria for Boggy Creek.	This revision correctly reflects the flow used during development of these site specific criteria.
Reg 2.511 (A)	Regarding the Arkansas River, revised (L&D #7 to L&D #10) to (Murray Lock and Dam [L&D #7] to Dardanelle Lock and Dam [L&D #10]).	Adding the dam’s common name will make the stream reach description easier to interpret.
Reg 2.511 (A)	Regarding the Arkansas River, revised (L&D #10 to Oklahoma line, including Dardanelle Reservoir) to (Dardanelle Lock and Dam [L&D #10] to Oklahoma line, including Dardanelle Reservoir).	Adding the dam’s common name will make the stream reach description easier to interpret.
Reg 2.511 (A)	Added “Big Creek Ditch” to Bayou DeView (20/30/270) between Lost Creek Ditch and Bayou DeView listings.	According to the Herman 7.5 minute Quadrangle, Arkansas Atlas & Gazetteer, AGFC’s Arkansas Outdoor Atlas, and USGS NHD High Resolution Flowline, the upper reaches of Bayou DeView are named Big Creek Ditch, with the uppermost reaches (headwaters) being named Lost Creek Ditch.
Reg 2.511 (A)	Revised Stennitt Creek to say “Stennitt Creek from Brushy Creek to Spring River.”	This creek is listed as “Stennitt Creek- from Brushy Creek to Spring River, TDS=456 mg/l (OH-4, #6)’’ in the variation supported by UAA list in Appendix A.
Reg 2.511 (A)	Removed the asterisks (*) from the chloride and TDS criteria for Walker Branch.	The asterisks were inadvertently added in the 2007 version of Reg. No. 2.
Reg 2.511 (A)	Added asterisks (*) to the chloride and TDS criteria for Dismukes Creek and to Big Creek from Dismukes to Bayou Dorcheat	This revision correctly reflects the flow used during development of these site specific criteria.
Reg 2.511 (A)	Under Ouachita River (Louisiana line to Camden), replaced capital “R” with lower case “r” for Hurricane Creek from Hwy 270 to Saline River in table.	Corrects typographical error.
Reg 2.511 (B)	Placed the words “were”, “chloride” and “sulfate” and the charge on the atomic symbols for these contaminates in parenthesis, (Cl^-) and ($SO_4^{=2}$).	This revision provides clarification to this sentence and accurately reflects the charge for the atoms.
Reg 2.511 (B)	Inserted the sentence “These waterbodies should be considered as candidates for a modification in accordance with Regs. 2.306 and 2.308.” The following strikeout and insertion “~~exists~~ should be considered.” And the addition of the plural for Regs. 2.306., and 2.308.	These modifications are references to or are itself assessment language, and is not considered to be WQS.

Reg 2.511 (B)	In the table, struck the word "~~Calculated~~" from the title and modified the lower case "~~l~~" to upper case "L" in reference to volume (liters).	Non-substantive change.
Reg 2.511 (C)	Replaced "limits" with "criteria."	Reg. No. 2 is not a permitting document; it contains water quality standards and criteria. Criteria is the more appropriate term.
Reg 2.511 (C)	Added an "s" to the end of "Reg." and "and 2.308" after 2.306.	Clarification that both Reg. 2.306 and 2.308 apply when mineral concentrations exceed Domestic Water Supply designated use criteria.
Reg 2.512 (B)	The ~~thirty-day~~ monthly average concentration of total ammonia nitrogen shall not exceed those values shown as the chronic criterion in the following tables:	To maintain consistency with typical monitoring data as calendar months can have from twenty-eight to thirty-one days.
Reg 2.512 (B)	In the tables, removed the comma between "temperature" and "°C."	Corrects typographical errors.
Reg 2.512 (B)	Spelled out ELS – Early Life Stage	Defining acronym for clarification
Reg 2.512 (D)	Removed the number 7 and spelled it out in "seven-day average."	Bring consistency to "seven-day average" and "four-day average," which is used later in the sentence.
Appendix A	Added a table of contents for the ecoregions.	This will increase the user friendly nature of the appendix.
Appendix A	Restarted numbering of pages after page A-2.	Currently there are 2 pages numbered A-2.
Appendix A	Updated plates to use NHD based GIS files.	NHD GIS data is the most accurate GIS data to date.
Appendix A	Throughout Appendix A, revised the following list headings as: "Site Specific Designated Use Variations Supported by ~~UAA~~Use Attainability Analysis or Other Investigations"; and "Site Specific Standards Variations Supported by ~~UAA~~ Use Attainability Analysis".	The added language will help clarify the difference between designated use variations and specific standard variations supported by UAAs.
Appendix A	On each Designated Uses ecoregion page - Added asterisks to Primary Contact Recreation; Secondary Contact Recreation; Domestic, Industrial and Agricultural Water Supply; and Aquatic Life headings. Also added footnote "**Except for those waters with designated use variations supported by UAA or other investigations."	To clarify that all designated uses do not apply to all waters
Appendix A - OH	Added Little Strawberry River to ERW and ESW lists for Ozark Highlands Ecoregion.	This river is designated on the corresponding plate (OH-3) as an ERW and ESW and has been since the 1988 version of Reg. No. 2.;

		however, they were inadvertently omitted from the lists
Appendix A - OH, ESWs	Added "Cave Springs Cave, Logan Cave, and n…" to ESW list.	These caves are already designated on the corresponding plates, but were inadvertently omitted from the list.
Appendix A - OH, ESWs	Added Rock Creek to ESW list for Ozark Highlands Ecoregion.	This creek is designated on the corresponding plate (OH-4) as an ESW and has been since the 1988 version of Reg No. 2; however, it was inadvertently omitted from the list.
Appendix A - OH	Designated Use Variations Supported…Section, added "#6" to Stennitt Creek after OH-4.	#6 corresponds to the number representing the location on the following plate and was previously inadvertently omitted.
Appendix A - BM, ERWs	Corrected the spelling of "Racoon Creek" on the ERW list for Boston Mountains ecoregion.	This creek is spelled Raccoon Creek on the corresponding plate (BM-3) and in the NHD data
Appendix A - BM, ERWs	Added Little Raccoon Creek to ERW list for Boston Mountains ecoregion.	This creek is designated on the corresponding plate (BM-3) as an ERW and ESW and has been since the 1988 version of Reg. No. 2.
Appendix A - BM, ERWs	Struck the original text; reworded to read: "Middle and Devils Forks of the Little Red River including Beech Creek, Tomahawk Creek, Turkey Creek, Lick Creek, Raccoon Creek, and Little Raccoon Creek (BM-2, BM-3)."	This overall revision provides more clarity to this entry. Little Raccoon Creek is designated on the corresponding plate (BM-3) as an ERW and ESW and has been since the 1988 version of Reg. No. 2; but, was previously, inadvertently omitted. Raccoon Creek is the correct spelling of this creek.
Appendix A - BM, ERWs	Added "Big" to Piney Creek in ERW list for Boston Mountains ecoregion.	This creek is labeled Big Piney Creek in the NSW list and in the NHD data.
Appendix A - BM, ESWs	Added Raccoon, Little Raccoon, Beech, Tomahawk, Turkey, and Lick Creeks to ESW list for Boston Mountains ecoregion.	These creeks are designated on the corresponding plate (BM-3) as an ERW and ESW and have been since the 1988 version of Reg. No. 2.

Appendix A - BM, ESWs	Struck original text; reworded to read "Middle, South, and Devils Forks of the Little Red River including Beech Creek, Tomahawk Creek, Turkey Creek, Lick Creek, Raccoon Creek, and Little Raccoon Creek and Archey Creek…"	Overall, this revision is succinct and easier to read. Additionally, Little Raccoon, Beech, Tomahawk, Turkey, and Lick Creeks are designated on the corresponding plate (BM-3) as an ERW and ESW and has been since the 1988 version of Reg. No. 2; however, they were previously, inadvertently omitted.
Appendix A - ARV	Under the Ecologically Sensitive Waterbodies heading added the term "none."	The current version of Reg. No. 2 has nothing listed under the ESW heading. Adding the term "none" will clarify that there are no ESWs in the Arkansas River Valley Ecoregion.
Appendix A - ARV	Under Designated Use Variations Supported by UAA, added a space between the word "use" and the parentheses for both entries.	Corrects typographical errors.
Appendix A - OM	Standardized the spelling of Arkansas Fatmucket mussel in ESW list.	This species is spelled two different ways, Arkansas Fatmucket mussel is the correct spelling.
Appendix A - OM	Deleted the extra space in "paleback darter" in ESW list.	Corrects typographical error.
Appendix A - OM	"southern hickrynut" was revised to "southern hickorynut" (page A-37)	Following Public Comment
Appendix A - OM	The boxes with the numbers 6 and 7 were added to plate OM-2. (page A-43)	Following Public Comment
Appendix A - GC	Moved "Lower Little" to next line in ESW descriptions.	Current placement of the word "Lower Little" gives the impression that it goes with Grassy Lake and Yellow Creek. This is incorrect; it should be Lower Little Missouri River.
Appendix A - GC	Under Designated Use Variations Supported by UAA, added a space between the word "use" and the parentheses for both entries.	Corrects typographical errors.
Appendix A - GC	Replaced "(GC-3)" with "(GC-2)" for Moro Creek under the ERW heading.	Corrects typographical error.
Appendix A - GC	Replaced "(GC-2)" with "(GC-4)" for Ouachita River near Arkadelphia under the ESW heading.	Corrects typographical error.
Appendix A - GC	Added "(GC-2, #28)" after "Dismukes Creek and Big Creek to Bayou Dorcheat – no domestic water supply."	Inadvertently omitted from previous versions.
Appendix A - GC	Added "(GC-2, #51)" after "Boggy Creek from the discharge from Clean Harbors El Dorado LCC downstream to the confluence of Bayou de Loutre - no domestic water supply use."	Inadvertently omitted from previous versions.

Appendix A - GC	Added “Variations Supported by Environmental Improvement Project”	None provided
Appendix A - GC	Added “springwater influenced” to “All sizes” in Dissolved Oxygen Table.	Reg. 2.505 Dissolved Oxygen (page 5-4) states limits for < 10, 10 – 500, > 500, *and* springwater- influenced streams in the Gulf Coastal ecoregion. As the table on page A-30 is currently written it appears the “All sizes” limits would trump the other 3, this is incorrect.
Appendix A - GC	Moved the numbers 6 and 5 (next to “All sizes) into the column below the “Spring Water Streams” heading.	Corrects typographical error.
Appendix A - GC	Revised “winger mapleleaf” to “winged mapleleaf” (page A-46)	Correction following Public Comment
Appendix A - GC	“Loutre creek” was revised to “Loutre Creek” (page A-47)	Correction following Public Comment
Appendix A - GC	The boxes with the numbers 52, 53, and 54 were added to plate GC-4. (page A-58)	Correction following Public Comment
Appendix A - D	Revised line three under the ERW heading as: “Norrell Lock and Dam (Dam #2).”	Adding the dam’s common name will make the stream reach description easier to interpret.
Appendix A - D	Added plate numbers and corresponding UAA map numbers (#38-41) to the “Variations Supported by UAA” list. (See Bayou Meto Water District UAA) [Ex: (D-3, #29)]	These numbers are labeled on Plate D-3, but were inadvertently left off most of the listings on page A-40.
Appendix A - D	Labeled ESWs on Plate D-2 using legend symbols.	The ESW delineations appear to have been inadvertently left off when the variations by UAA were added to the plate.
Appendix A - D	Revised as: “~~Lagrue Bayou~~LaGrue Bayou.”	LaGrue Bayou is the correct spelling.
Appendix A - D	“Total dissolved oxygen” was revised to “total dissolved solids”. (page A-63)	Correction following Public Comment
Appendix A - D	The boxes with the numbers 38, 39, and 40 were added to plate D-1. (page A-67)	Correction following Public Comment
Appendix C	Replaced title “SCIENTIFIC NAMES OF FISHES” with “SCIENTIFIC NAMES OF AQUATIC BIOTA.”	Appendix C is being revised to include scientific names of all aquatic biota in the regulation, not just fishes.
Appendix C	Revised the scientific names for the blacktail shiner, bluntnose darter, gravel chub, pugnose minnow, striped shiner, and whitetail shiner	As per Nelson, J. S., Crossman, E. J., Espinosa-Pérez, H., Findley, L. T., Gilbert, C. R., Lea, R. N., Williams, J. D. 2004. Common and scientific names of fishes from the United States, Canada and Mexico. 6th

		edition. American Fisheries Society, Bethesda, Maryland. ix, 386 p.
Appendix C	Revised the scientific name for the Southern redbelly dace as: “~~*Phoxinus*~~ *Chrosomus erythrogaster*”	As per Strange, R. M., and R. L. Mayden. 2009. Phylogenetic Relationships and a Revised Taxonomy for North American Cyprinids Currently Assigned to Phoxinus (Osteichthyes: Cyprinidae). Copeia 2009 (3):494-501.
Appendix E	Revised as: “~~Section~~Reg.”	Proper reference.
Appendix E	Revised part (V) as: “~~7Q10~~Q7-10”	Proper reference.

ATTACHMENT 2

BEAVER LAKE SITE-SPECIFIC WATER QUALITY CRITERIA DEVELOPMENT: RECOMMENDED CRITERIA

BEAVER LAKE SITE-SPECIFIC WATER QUALITY CRITERIA DEVELOPMENT: RECOMMENDED CRITERIA

FEBRUARY 8, 2008

BEAVER LAKE SITE-SPECIFIC WATER QUALITY CRITERIA DEVELOPMENT: RECOMMENDED CRITERIA

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EXECUTIVE SUMMARY

Beaver Lake is not only the primary public water supply for over 250,000 Arkansans, it is also a major contributor to the quality of life in Northwest Arkansas. The Arkansas Department of Environmental Quality (ADEQ) is developing site-specific numeric water quality criteria for Arkansas lakes and reservoirs. Because of its importance to all Arkansans, ADEQ selected Beaver Lake as the prototype for developing site-specific, numeric water quality criteria to protect the designated uses of this waterbody and subsequently other lakes and reservoirs throughout Arkansas. The project was supported by funding from the Walton Family Foundation, the United States Environmental Protection Agency (USEPA), and the United States Geological Survey.

A weight of evidence approach was used to develop recommendations for site-specific, numeric water quality criteria, which included considerations of:

1. Surrounding state numeric criteria for chlorophyll, Secchi transparency, total phosphorus, and total nitrogen values;
2. Ecoregion values proposed by USEPA;
3. Percentile values based on both reference lake data and extant data for Beaver Lake;
4. Hydrologic plunge point analyses;
5. Statistical analyses of data from Beaver Lake and the reference lakes;
6. Empirical nutrient loading relationships; and
7. Dynamic modeling results.

Based on this weight of evidence approach, the following site-specific, effects-based numeric water quality criteria are recommended for measurement at the Hickory Creek site in Beaver Lake:

- Growing season geometric mean chlorophyll a concentration: 8 μg/L
- Annual average Secchi transparency: 1.1 meters

Nutrient targets, not criteria, are recommended for total phosphorus (40 μg/L) and total nitrogen (0.4 mg/L).

These recommendations are considered protective and supportive of all designated uses for Beaver Lake.

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1.0 INTRODUCTION

1.1 Purpose and Participation

The United States Environmental Protection Agency (USEPA) recently issued a policy requiring all states to develop numeric nutrient criteria to protect the designated uses of waterbodies within each state. These nutrient criteria will be developed and implemented by the state of Arkansas by 2010. As part of this process, the Arkansas Department of Environmental Quality (ADEQ) is developing site-specific numeric water quality criteria for Arkansas lakes and reservoirs. Beaver Lake is a critical water resource for the economy and quality of life of northwest Arkansas, and is the public water supply for over 250,000 people. One out of every eight Arkansans gets his/her drinking water from Beaver Lake. Because of its importance to all Arkansans, ADEQ has selected Beaver Lake as the prototype for developing site-specific, numeric water quality criteria to protect the designated uses of this waterbody and subsequently other large reservoirs.

ADEQ assembled a Scientific Work Group to assist in this effort, including representatives from the University of Arkansas, Fayetteville, and the Arkansas Water Research Center. The purpose of the Scientific Work Group was to review recommendations to ADEQ on numeric water quality criteria for Beaver Lake. It is critical that the numeric water quality criteria be scientifically defensible and protect the designated uses for Beaver Lake. This approach is necessary if Arkansas is to protect the water source for one of the fastest growing areas in the state.

A Technical Subcommittee of the Scientific Work Group developed the scientific approach that was used to recommend water quality criteria for Beaver Lake. This Technical Subcommittee included representatives from ADEQ, the United States Geological Survey (USGS), Beaver Water District, FTN Associates, Ltd. (FTN), and Dr. Joe Nix (retired from Ouachita Baptist University). USGS and Beaver Water District are monitoring Beaver Lake water quality and provided data that were used in the criteria development process. In addition, USGS calibrated a water quality model that also was used to evaluate the ecological effects from different pollutant load scenarios.

1.2 Conceptual Model

Water quality standards (WQS) consist of: 1) the designated use(s) of the waterbody to be protected; 2) numeric water quality criteria that will protect the use(s); and 3) an anti-degradation policy. This project focused on the first two parts of the WQS – designated uses and recommended numeric criteria. USEPA has recently emphasized numeric effects-based criteria instead of criteria for specific physical or chemical parameters. With over 10,000 new chemicals being developed each year, developing chemical-specific criteria for each new chemical would be exceedingly difficult. Stream and lake biological indicators integrate the myriad physical and chemical factors occurring within these waterbodies. These integrated ecological effects, therefore, can provide the basis for water quality criteria. In addition, effects-based criteria, such as changes in water clarity, biological diversity, or fish production, typically can be related more closely to specific designated uses.

By definition, water quality criteria serve to protect the designated uses for the waterbody. The conceptual process for the development of effects-based water quality criteria related to waterbody designated uses as part of this project is illustrated below.

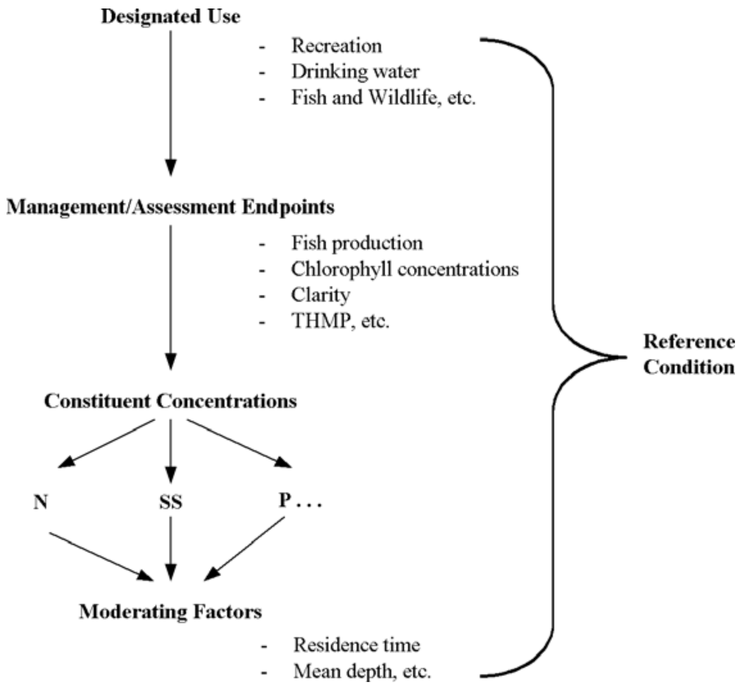


Figure 1.1. Conceptual process for the development of effects-based water quality criteria.

Trihalomethane precursors (THMP), listed in Figure 1.1, are potential carcinogenic compounds formed from chlorinating drinking water that has elevated organic compounds, while nitrogen (N) and phosphorus (P) are nutrients that stimulate nuisance algae blooms, and suspended sediments (SS) decrease water clarity and increase drinking water treatment costs.

1.3 Weight of Evidence

A weight-of-evidence approach was used to arrive at the recommended water quality criteria for Beaver Lake. A weight-of-evidence approach uses multiple lines of evidence, balancing the strengths and weaknesses of each line of evidence, to derive criteria that reflect the concurrence among these multiple lines of evidence, the association between the criterion and the stressors affecting the criterion, and potential risks to the system both from attainment and non-attainment of the criterion. The lines of evidence considered in deriving water quality criteria for Beaver Lake included:

1. Designated uses;
2. Literature review for comparable lakes;
3. Historical perspective, including:
    - Demographic watershed changes,
    - Historical water quality trends, and
    - Land use.
4. Hydrologic and plunge point analyses;
5. Statistical analyses of Beaver Lake water quality;
6. Reference lake water quality and analyses;
7. Nutrient loading model estimates for selected water quality variables; and
8. CE-QUAL-W2 simulations of Beaver Lake water quality.

These multiple lines of evidence were weighted based on their different strengths and used to derive the recommended numeric water quality criterion.

1.4 Analyses Background

1.4.1 Beaver Lake System Description

Beaver Lake is the first of four large impoundments on the White River managed by the United States Army Corps of Engineers (USACE) (Figure 1.2). The other USACE impoundments on the White River are, in downstream order, Table Rock Lake, Bull Shoals Lake, and Norfork Lake. Beaver Lake was created to provide project purposes of flood control, hydroelectric power generation, fish and wildlife propagation, and water supply for northwest Arkansas. Beaver Dam was first authorized by the United States Congress in 1954 under the Flood Control Act of 1944, which granted USACE the authority to propose such projects, and resulted in the construction of many dams and reservoirs throughout the United States.

Beaver Lake covers 11,421 hectares in Washington, Benton, and Carroll counties at its conservation/water supply pool level (341 meters National Geodetic Vertical Datum (NGVD)). Beaver Lake receives drainage from approximately 307,174 hectares in Washington, Benton, Carroll, and Madison counties. The three primary tributaries to Beaver Lake (listed in size order) are the White River, War Eagle Creek, and Richland Creek (Figure 1.3). On average, the White River contributes approximately 30% of the inflow to Beaver Lake.

1.4.2 Reference Lake Systems

Lake Greeson, DeGray Lake, and Lake Ouachita were selected as reference reservoirs (Figure 1.4), because there has been limited development in their watersheds. As such, they were considered to be examples of the best possible water quality for reservoirs in Arkansas. These reservoirs are located in a different, but similar, ecoregion of Arkansas than Beaver Lake.

1.4.3 Historical Studies of Beaver Lake

Beaver Lake has been the subject of numerous water quality studies over the years. Differences in sampling, methodologies, analytical parameters and methodologies, and levels of quality assurance and control associated with all of these studies led us to use primarily long-term routine monitoring data collected by ADEQ and USGS in our analyses. However, data from two previous water quality studies were included in our analyses, the National Eutrophication Survey (NES) and the Beaver Clean Lakes Study (CLS).

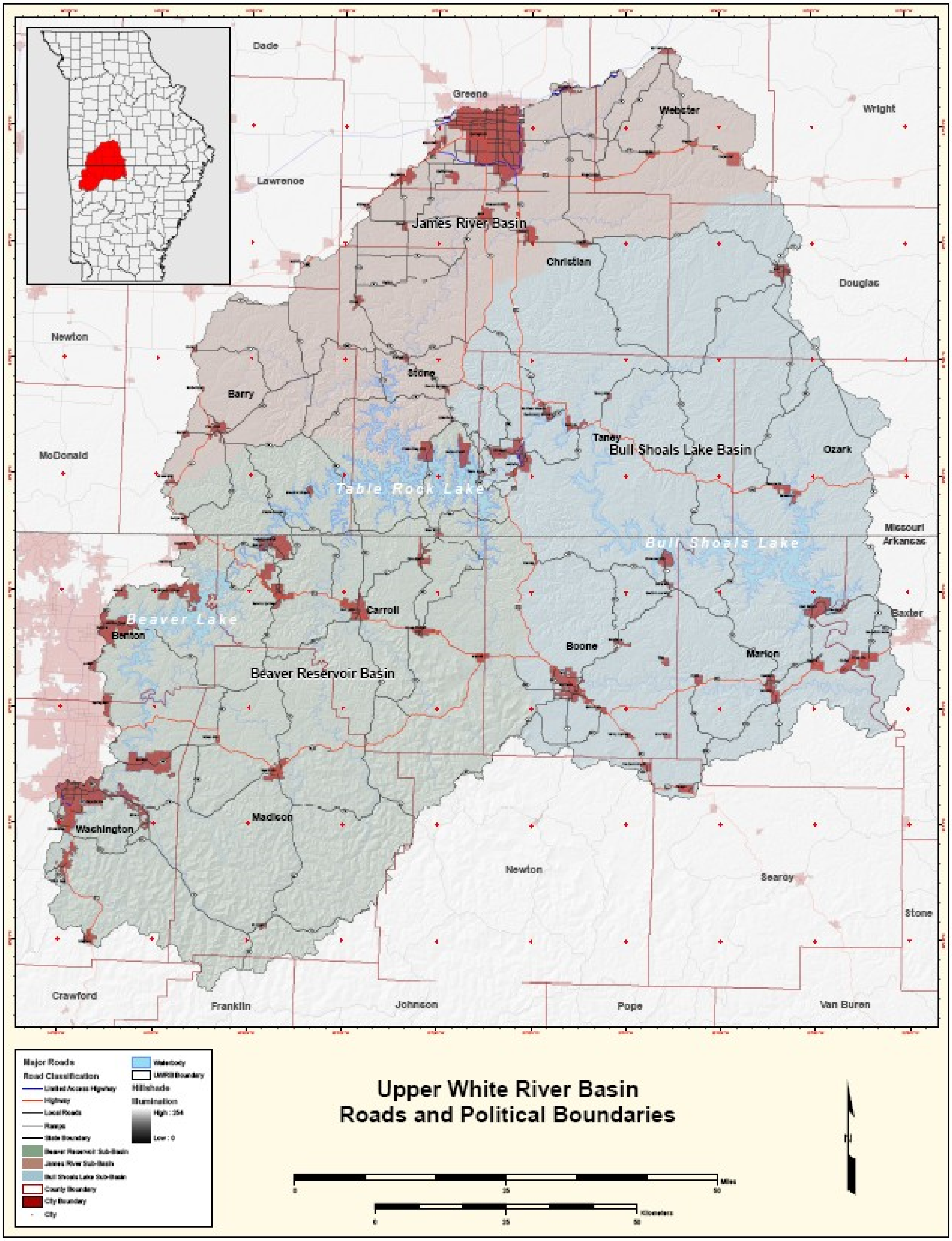


Figure 1.2. Upper White River Basin, Arkansas and Missouri.

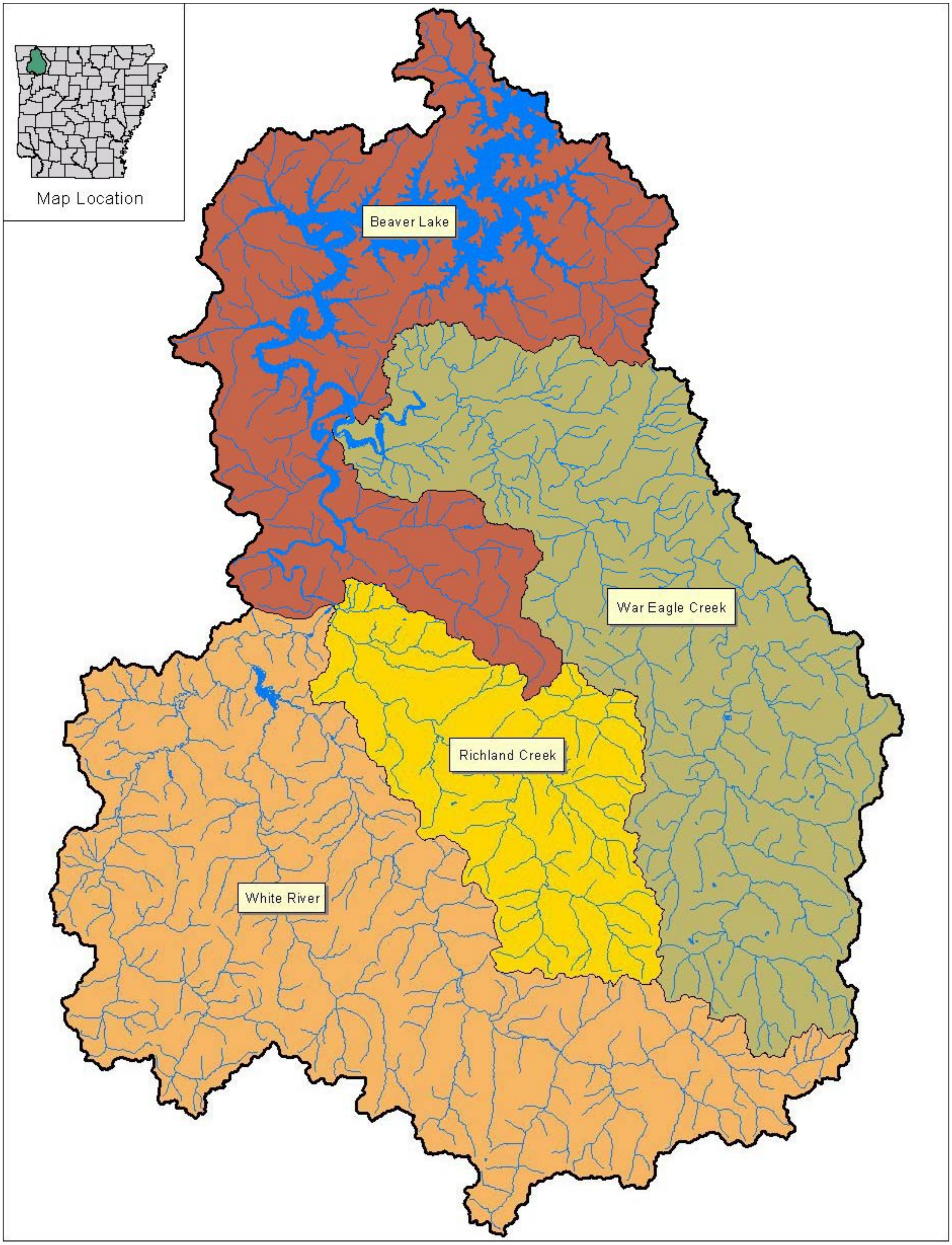


Figure 1.3. Beaver Lake watershed with sub-basins.

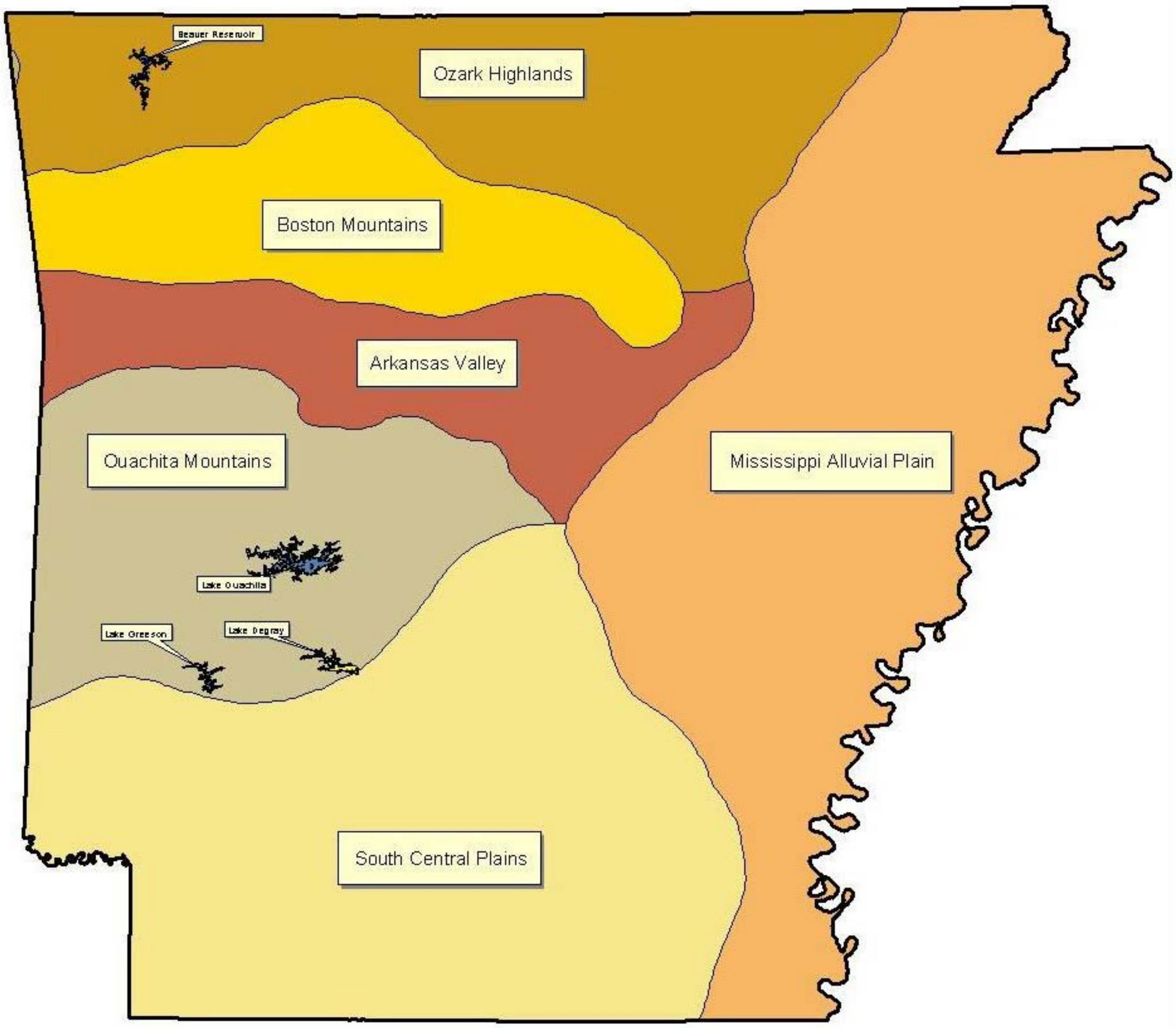


Figure 1.4. State map showing ecoregions and location of Beaver, Ouachita, Greeson, and DeGray Lakes.

1.4.3.1 National Eutrophication Survey

From 1972 until 1976, USEPA conducted the NES to determine the number of lakes in the US that were eutrophic because of nutrient loadings primarily from wastewater treatment facilities. Beaver Lake was sampled in 1974 because the City of Fayetteville wastewater treatment plant discharged into the White River. While nutrient loading from the Fayetteville wastewater treatment plant was significantly decreased in 1987, the NES provides an historical perspective on Beaver Lake water quality in 1974. While the tributaries to Beaver Lake were sampled on a monthly basis, the reservoir was only sampled on three occasions: spring, summer, and fall.

1.4.3.2 Beaver Clean Lakes Study

In 1991, FTN conducted a USEPA CLS on Beaver Lake through Section 314 funding of the USEPA Clean Lakes Program. Reservoir sampling occurred 14 times during the year at multiple locations in Beaver Lake so that seasonal dynamics in chlorophyll concentrations, nutrient concentrations, and Secchi depth could be determined.

2.0 DESIGNATED USES

Under Arkansas WQS specified by Arkansas Pollution Control and Ecology Commission (APCEC) Regulation No. 2, the designated uses for Beaver Lake are:

- Primary contact recreation,
- Propagation of fish, wildlife and aquatic life, and
- Domestic, industrial, and agricultural water supply.

Note the designated uses are not the same as the project purposes. Numeric water quality criteria for Beaver Lake are listed in Table 2.1. Beaver Lake is currently attaining WQS. In general, domestic water supply represents the highest priority use for Beaver Lake and is associated with the most stringent WQS. Therefore, water quality criteria development initially focused on protecting this designated use.

Table 2.1. Beaver Lake numeric water quality criteria.

Constituent	WQS
Turbidity (NTU) Primary/Storm	25/45
pH (standard units)	6.0 – 9.0
Dissolved Oxygen (mg/L)	5.0
Total Dissolved Solids (mg/L)	160
Numeric Nutrient Criteria	None

Some stream tributary reaches to Beaver Lake, however, are not attaining their designated uses and are listed on the 2004 ADEQ 303(d) list of impaired waterbodies as high priorities for remediation. Specific water quality problems associated with these non-attaining stream reaches are listed in Table 2.2. The Station Identification is specific to individual ADEQ monitoring sites.

Table 2.2. Stream reaches within the Beaver Lake watershed listed on ADEQ's 2004 303(d) list.

River	Reach No.	Length (miles)	Station ID	Impaired Use(s)	Source	Cause
White River near Goshen, AR	023	6.2	WHI 52	Aquatic Life, Agriculture and Industry	Road Construction, Agriculture	Total dissolved solids, sulfates, chlorides
White River near Durham, AR	027	23.8	WHI 106	Aquatic Life	Unknown	Dissolved oxygen
West Fork, east of Fayetteville	024	27.2	WHI 51	Aquatic Life, Agriculture and Industry	Unknown, Road Construction, Agriculture	Sulfates, total dissolved solids
War Eagle Creek	060	28.3	N/A	Drinking Water, Agriculture and Industry	Municipal Point Source	Total dissolved solids, sulfates, chlorides
Holman Creek	059	9.1	WHI 70	Drinking Water, Agriculture and Industry	Municipal Point Source	Total dissolved solids, sulfates, chlorides

3.0 LITERATURE AND STATE SOURCES FOR CRITERIA

3.1 Information Sources

A literature search on nutrients, phosphorus, fish, and THMPs (disinfection byproducts) was initially performed at the University of Arkansas Mullins Library using InfoLinks (University of Arkansas electronic library catalog of books) in 2003. This information search was updated in 2006. In addition, a recent review by Virginia Polytechnic Institute and State University was included in the development of nutrient criteria (Younos et al. 2007). Resources (papers, manuscripts, symposia) were reviewed if the lakes and reservoirs were in the southern tier of states (Arkansas, Alabama, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, and Texas). Over 100 reports and journal articles were reviewed, with over 50 sources containing quantitative relationships between nutrients and biological endpoints. These quantitative relationships were used to estimate chlorophyll, Secchi depth, and THMP concentrations based on different nutrient (nitrogen and phosphorus) scenarios. This is discussed further in Chapter 8.0, Modeling Analyses.

Electronic searches were also conducted to identify state nutrient criteria and aggregate ecoregional criteria developed by USEPA. Particular emphasis was again placed on southern states. A summary document prepared by USEPA (2003) incorporates information on nutrient standards for states, tribes, and territories based on a survey of these entities during 2002 (www.USEPA.gov/waterscience/standards/wqs/library). This document served as a base, which was expanded through literature searches of state, tribe, and territory websites in 2006.

3.2 Numeric Criteria

Table 3.1 lists the numeric nutrient-related WQS that have been adopted by states and numeric criteria proposed by USEPA for ecoregions covering Beaver Lake and its watershed. Some states have also developed lake or site-specific criteria so a range from the lowest criterion value to the highest criterion value for different lakes is shown. Nutrient criteria listed for Mississippi are recommended only, and have not proceeded through the rule-making process to become WQS. Mississippi is currently considering a site-specific approach for nutrient criteria in their lakes and oxbows. USEPA ecoregion criteria are based on the 25th percentile of extant data available over the last decade of lake and reservoir monitoring within the ecoregion. In most cases, the data for Ecoregion 38 (Boston Mountains) are limited. Ecoregion 39 represents the Ozark Highlands (see Figure 1.4).

Table 3.1. Numeric nutrient-related WQS adopted by southern states and USEPA guidance criteria for Beaver Lake ecoregions. For states that have site-specific lake criteria, the range of criteria are shown.

Parameter	Source	State or Ecoregion	Standard of Guidance
Chlorophyll a (µg/L)	State Criteria	Alabama	5 – 17 (site-specific)
		Georgia	5 – 27 (site-specific)
		Mississippi	20 (reservoir)
		North Carolina	10 (trout) 40 (non-trout)
		Oklahoma	10 (drinking water)
		South Carolina	10 or 40 (ecoregion-based)
	USEPA Ecoregion Guidance (XI) (1)	Ecoregion 38	6.6
		Ecoregion 39	6.1
Total phosphorous (µg/L)	State Criteria	Georgia(2)	< 0.25 – 5.5 lb/ac-ft/yr
		Mississippi	90
		Oklahoma	168 (Eucha) 141 (Spavinaw)
		South Carolina	20 – 90 (ecoregion)
	USEPA Ecoregion Guidance (XI) (1)	Ecoregion 38	5.0
		Ecoregion 39	24.4
Total nitrogen (mg/L)	State Criteria	Georgia	< 4.0
		Mississippi	1.0
		South Carolina	0.35 or 1.5 (ecoregion)
	USEPA Ecoregion Guidance (XI) (1)	Ecoregion 38	0.12
		Ecoregion 39	0.5
Secchi (m)	State Criteria	Mississippi	0.45
	USEPA Ecoregion Guidance (XI) (1)	Ecoregion 38	1.8
		Ecoregion 39	2.0

Notes:
(1) USEPA Ecoregion criteria represent the 25th percentile of extant data.
(2) Georgia total phosphorus criteria are based on loading rather than concentration.

3.3 Additional Considerations

Carcinogenic compounds, such as trihalomethanes and haloacetic acids, can be formed from organic matter during disinfection of drinking water when there are even relatively low concentrations of organic matter in the raw water supply (Chapra et al. 1997, Walker 1983). Organic carbon in raw water, including algal cells and the organic compounds released by algae, can react with chlorine during treatment to form these compounds. While there are treatment procedures that can reduce the formation of these carcinogenic compounds, the procedures increase treatment costs.

Because Beaver Lake is a drinking water source for northwest Arkansas, another water quality criteria consideration was to minimize the formation of these disinfection byproducts in the raw water. The Oklahoma Water Resources Board established a chlorophyll a criterion of 10 µg/L for drinking water reservoirs based on a study that demonstrated the risk of THMP increased significantly when chlorophyll a concentrations in the raw water exceeded this criterion (Downing et al. 2001). Other studies have found that when chlorophyll a concentrations or total organic carbon concentrations exceed 1 to 2 µg/L or 2 mg/L, respectively, there was a high likelihood that trihalomethane concentrations would exceed the USEPA drinking water criterion of 80 µg/L.

4.0 DEMOGRAPHIC CHANGES, 1990-2000

The Beaver Lake watershed includes portions of Benton, Carroll, Madison, and Washington counties in northwest Arkansas. Northwest Arkansas has experienced rapid population growth for almost two decades (Table 4.1). Between 1990 and 2006, the total population in this four-county area increased by 76% (from 241,180 to 425,266), compared to the population increase of approximately 20% for the entire state over the same period. While the majority of this growth has occurred outside of the Beaver Lake watershed, it does represent an increase in water supply demand for the area, which is supplied primarily from Beaver Lake, as well as an increase in hydropower demand and recreational users of Beaver Lake.

Table 4.1. Comparison of historical and current northwest Arkansas county populations.

County	1990	2000	2006*
Benton	97499	153406	196,045
Carroll	18654	25357	27,339
Madison	11618	14243	15,361
Washington	113409	157715	186,521
Total	241180	350721	425266
Percent Change		45%	21%

Notes: * = from Table GCT-T1 Population Estimates online at:http://factfinder.census.gov/servlet/GCTTable?_bm=y&-geo_id=04000US05&-_box_head_nbr=GCT-T1&-ds_name=PEP_2006_EST&-_lang=en&-format=ST-2&-_sse=on

Population change within the Beaver Lake watershed was estimated through area proportioning. The Beaver Lake watershed includes one-third of Benton County, one-half of Washington County, and all of Madison County. These proportions of total county population were assumed to reside in the Beaver Lake watershed. The resulting numbers are shown in Table 4.2. Between 1990 and 2006, the estimated watershed population increased approximately 72%. This population increase has the potential to affect Beaver Lake water quality through land use changes.

Table 4.2. Comparison of historical and current Beaver Lake watershed population.

County	1990	2000	2006*
Benton	29250	46022	58814
Madison	11618	14243	15,361
Washington	56704	78858	93260
Total	97572	139123	167435
Percent change		42%	20%

Notes: * = from Table GCT-T1 Population Estimates online at http://factfinder.census.gov/servlet/GCTTable?_bm=y&-geo_id=04000US05&-_box_head_nbr=GCT-T1&-ds_name=PEP_2006_EST&-_lang=en&-format=ST-2&-_sse=on

Housing units in the Beaver Lake watershed were estimated based on the proportions of the county used for estimating population. Housing unit estimates are summarized in Table 4.3. Between 1990 and 2000, the number of housing units in the watershed increased approximately 40%. In 1990, approximately 50% of housing units in Benton County used septic tanks or cesspools for sewage disposal, along with approximately 30% of housing units in Washington County, and 76% of housing units in Madison County (Bureau of the Census 1991). Malfunctioning septic systems can contribute to nutrient enrichment of reservoirs. The Census Bureau stopped collecting household information on water supply and wastewater disposal after 1990, so there are no estimates for 2000.

Table 4.3. Estimated increase in housing units in the Beaver Lake watershed.

County	1990	2000
Benton	12433	19284
Madison	5182	6537
Washington	23674	32165
Watershed Total	41289	57986

Northwest Arkansas is generally considered to be experiencing economic growth. However, not all residents of this area benefit from the strong economy. The number of people living below the poverty level in Beaver Lake watershed is estimated from US Census data (www.census.gov) and shown in Table 4.4. Between 1990 and 2000, the number of people in the Beaver Lake watershed estimated to be living below the poverty level increased by 40%. This was slightly less than the population increase during this period (42%); therefore, the percentage of the estimated watershed population living below poverty level actually decreased by 1%.

In 2000, approximately 18% of the people in Arkansas were living below the poverty level. The economic strength of northwest Arkansas is reflected in the fact that the percentage of people in Beaver Lake watershed living below poverty level (13%) was less than the percentage for the state.

Table 4.4. Estimated number of people living below the poverty level in Beaver Lake watershed.

County	1990	2000
Benton	3079	5067
Madison	2307	2616
Washington	7957	11052
Watershed Total	13343	18735
Percent	14%	13%

5.0 ORDER OF MAGNITUDE ESTIMATES – SETTING THE STAGE

Stream and reservoir water quality information was reviewed and order of magnitude estimates (OMEs) or “back-of-the envelope” estimates (such as relative depth, area erosion, and residence time) were calculated for Beaver Lake. These assist in initial determinations of the relative importance of various reservoir processes in controlling reservoir water quality, such as sedimentation, stratification, mixing, inflow placement, light penetration, and dissolved oxygen (DO) dynamics. These estimates provide initial insight and knowledge about certain reservoir characteristics that can be useful in water quality analyses, model calibration, and development of appropriate management strategies, including water quality criteria.

OMEs provide insight on the potentially important processes and the potential dependence among processes. The estimates are usually within factors of 3 to 5 (or better) of actual values (Fischer et al. 1979). Given the temporal and spatial variability in most environmental variables and characteristics, estimates within a factor of 3 to 5 can be useful. For example, knowing whether summer average chlorophyll a concentrations are estimated to be 3 µg/L or 30 µg/L immediately indicates whether the reservoir is likely to be oligotrophic or eutrophic, respectively. OMEs are the first step, and an integral part, of any water quality analyses and criteria recommendations. Table 5.1 provides the general morphometric characteristics of Beaver Lake and the OMEs calculated from them.

5.1 Morphometric Estimates

Drainage area/surface area (DA/SA) ratios indicate potential area water, sediment, and nutrient loads to a reservoir and the relative usefulness of various watershed best management practices (BMPs) for improvement of reservoir water quality. The DA/SA ratio of Beaver Lake, 27:1, is greater than 10:1 (Table 5.1), which indicates that watershed water, sediment, and nutrient loads could significantly impact reservoir water quality. Because the DA/SA ratio is less than 50:1, even watershed management practices implemented farther up in the watershed can contribute to improved reservoir water quality. Water quality improvements in reservoirs with a large DA/SA ratio (>50:1) typically become a function of where in the watershed the BMPs are implemented. Our observations are that improvements in stream water quality from BMPs implemented near the upstream end of large drainage basins (i.e., DA/SA >50:1) are diminished by downstream loadings to the reservoir.

Table 5.1. Beaver Lake attributes and OMEs at conservation – water supply pool level.

Reservoir Attributes (based on USACE project data)	**Value**
Volume, $\forall$ (m^3)	2.04×10^9
Surface Area, SA (km^2)	114
Watershed Area, DA (km^2)	3,072
Length (thalweg length from Highway 45 to dam), L (km)	124
Length of shoreline, L_s (km)	723
Mean width, W (km), SA/L	16
Maximum depth, Z_m (m)	62
Mean depth, Z (m), $\forall$/SA	18
OMEs	**Value**
Drainage area/surface area, DA/SA	27
Aspect ratio, L/W	7.5
Shoreline development ratio $L_S/2\sqrt{\pi SA}$	19.1
Relative depth (%) $\frac{88.6Zm}{\sqrt{SA}}$	51%
Residence time, (yr),$\forall/Q$	1.5
Single storm flushing ratio $Q_S / \forall$	0.2
Photic zone depth (m) $1nZ_{1\%} = 1.352 + 0.745\ 1nZ_s$	8

Note: Q = Average annual total outflow = 42.35 m^3/s (NES 1977)
Qs = largest daily total inflow on record (White River + War Eagle) = 4503 m^3/s
Z_s = average Secchi depth of all reservoir stations for 2000-2004 = 2.6 m

The aspect ratio (comparison of length to average width) provides an indication of how important longitudinal versus lateral gradients might be in a waterbody. The aspect ratio in Beaver Lake is 7.5. An aspect ratio (length divided by width) greater than 4.0 indicates that longitudinal gradients are more important than lateral gradients in water quality (Jirka and Harleman 1979). Plug flow models or models that account for longitudinal gradients in these reservoirs will be more appropriate than 1-D or continuously stirred tank reactor (CSTR) models. Because longitudinal gradients are more important than lateral gradients, this also indicates that a 3-D model is probably not warranted for simulating reservoir water quality, unless there are specific issues associated with local inputs and associated lateral gradients.

The shoreline development ratio indicates the degree to which a waterbody may deviate in shape from that of a circle. For example, a perfectly circular reservoir has a shoreline development ratio of 1.0. The greater the ratio is above 1.0, the more dendritic the system is with greater potential for extensive littoral development, macrophytic and benthic production, and organic loading. A highly dendritic reservoir with multiple coves and embayments may have a ratio of 15 or greater (Thornton et al. 1990). The shoreline development ratio in Beaver Lake (19:1) indicates a highly dendritic reservoir with multiple coves and embayments.

Relative depth is the ratio of maximum depth to average diameter of the reservoir surface. The smaller the relative depth (e.g., <1.0), the greater the potential for wind disruption of thermal stratification because of shallow water conditions (Wetzel 1983). The relative depth for Beaver Lake is 0.51, indicating there is the potential for wind to disrupt thermal stratification. However, Beaver Lake is deep and serpentine and has no long fetches for southerly prevailing winds during summer.

5.2 Hydrologic Estimates

Estimates can also be made using hydrologic characteristics. The theoretical hydraulic residence time is defined as reservoir volume divided by total annual inflow. Residence time is one indicator of potential water quality problems. For example, reservoirs with residence times that are less than 100 days typically have stronger longitudinal gradients and greater productivity than reservoirs with residence times that are greater than 100 days (Thornton, unpublished data). Greater productivity in reservoirs with residence times less than 100 days is typically associated with larger DA/SA ratios, greater sediment and nutrient loads in conjunction with greater areal loads, and areas of maximum primary productivity farther down the reservoir. Beaver Lake has a theoretical hydraulic residence time of 1.5 years, which would indicate it has a relatively large volume compared to annual discharge volume from the watershed.

For reservoirs with residence times greater than 100 days, the area of maximum primary productivity is generally in the upper 5 to 10% of the reservoir where inflowing water laden with nutrients plunges below the surface into the metalimnion or hypolimnion before entering the main portion of the reservoir. Primary productivity is relatively low in the lower portion of the reservoir because of low epilimnetic nutrient concentrations (Kimmel et al. 1990; Thornton et al. 1980). Beaver Lake has a theoretical residence time of 1.5 years, so maximum productivity would be expected in the upper part of the reservoir.

The single-storm flushing ratio can indicate the extent to which inflow waters can disrupt stratification, the distance to which inflow waters can move into the reservoir, and the contribution of inflow waters, through nutrient loading, to nutrient supplies in the epilimnion. If the single-storm flushing ratio exceeds 1 (i.e., the inflow in the single storm is greater than the volume in the reservoir), thermal stratification will be disrupted and the reservoir will completely mix. Minimal mixing is associated with ratios less than 0.5 (Mueller et al. 1981). Beaver Lake has a ratio of about 0.2 for a large inflow (White River + War Eagle), so it is highly unlikely that a single, large storm event would result in complete mixing.

The photic zone is defined as the zone from the reservoir surface to the depth at which light is 1% of the surface value. It is within the photic zone that light is assumed to be sufficient for algal growth. The depth of the photic zone can be estimated from Secchi disk depth measurements using an empirical equation developed by Williams et al. (1980). Nutrient-enriched water entering from the tributaries can flow into the metalimnion as an interflow during the summer stratified period and be made available for algal uptake and growth, if light is available. In Beaver Lake, the photic zone depth is estimated as 8 meters.

6.0 HYDROLOGIC ANALYSES

6.1 Hydrologic Characterization

The flow record for the White River near Fayetteville (USGS Gage 07048600) and the Fayetteville precipitation record were analyzed to characterize years as dry, average, or wet. The historical average annual White River flow for the period from 1964 through 2005 was calculated, along with the standard deviation of annual average flow for the same period. The average flow for each year of record (calendar year, not water year) was then calculated. The historical average total precipitation for the period from 1895 through 2005 was calculated, along with the "1 and "2 standard deviations from this historical average and the precipitation total for each year from 1960 through 2005. The annual flow and precipitation values were plotted along with lines showing the historical average and its 95% confidence interval, as well as the historical average plus and minus the standard deviation (Figures 6.1 and 6.2; all figures located at the end of Chapter 6).

Those years with an average flow and total precipitation within ± 1 standard deviation of the historical averages were classified as average years (1998, 1999, 2001, 2002). Those years with an average flow and precipitation total that were similar to or greater than the historical average plus one standard deviation were classified as wet years (1984, 1985, 1990, 1993). Those years with an average flow and precipitation total similar to or lower than the historical average minus one standard deviation were classified as dry years (1980, 1983, 2003, 2005). Note that classifications based on flow did not always agree with those based on precipitation (i.e., the precipitation total was not always outside the historical standard deviation when average annual flow was (see Figures 6.1 and 6.2)). Therefore, only those years where there was reasonable agreement between the flow and precipitation-based classifications were assigned a hydrologic classification. To maintain comparable amounts of data for wet, dry, and average years, only the four most recent classified years (listed in parentheses above) were used in subsequent evaluations of conditions during dry, average, and wet years.

The flow record available upstream of the reference reservoirs (DeGray, Greeson, Ouachita) was not as extensive. Long-term data (from 1942 through present) were available only for the Ouachita River (Figure 6.3). The hydrologic classifications of dry, average, and wet years for the Ouachita and White Rivers agreed the majority of the time; therefore, the White River/Beaver Lake hydrologic classification of years was also used for the reference reservoirs.

6.2 Plunge Point Analyses

The plunge point in a reservoir is the location where, during stratified conditions, the buoyant force of a cooler inflow becomes greater than the inertial force, and the inflow moves from the surface to the depth with similar buoyancy (temperature) (Figure 6.4). The greatest productivity in reservoirs typically occurs just downstream of the plunge point, where nutrients from the inflow are readily available and turbidity in the photic zone decreases dramatically as the inflow plunges beneath the surface (Figure 6.5). Knowing the location of the plunge point in a reservoir provides insight into where in the reservoir the greatest response to nutrient inputs would be expected to occur.

6.2.1 Average Condition Plunge Points

6.2.1.1 Lake Ouachita and DeGray Lake

Plunge points were calculated for monthly average conditions for Lake Ouachita and DeGray Lake during the growing season. These plunge points were calculated using monthly average inflow, inflow temperature, and lake surface water temperature for the period 1993 through 2006. The formula used to calculate the plunge points was from Savage and Brimberg (1975). The results of these calculations are shown in Table 6.1. Locations of these plunge points are shown on Figures 6.6 and 6.7. These results show the plunge points generally moving upstream through the growing season. There are two reasons for this phenomenon. First, the stratification, or thermal buoyancy, becomes stronger, and second, the likelihood of high flow events diminishes.

Table 6.1. Depths at plunge points calculated for monthly average conditions at Lake Ouachita and DeGray Lake.

Month	Lake Ouachita (m)	DeGray Lake* (m)
April	NA	
May	17.01	
June	7.63	
July	4.26	1.6
August	2.21	
September	3.85	4.9
October	12.10	0.7

Notes: NA = Does not plunge because inflow temperature is warmer than lake surface temperature.
* = Plunge points for base flows reported by Ford and Johnson (1983)

6.2.1.2 Beaver Lake (White River and War Eagle Inflows)

Plunge points were calculated for monthly average conditions for Beaver Lake (White River and War Eagle inflows) during the growing season. These plunge points were calculated using monthly average inflow, inflow temperature, and lake surface water temperature for the period 1993 through 2006. The formula used to calculate the plunge points was from Savage and Brimberg (1975). The results of these calculations are shown in Table 6.2. Locations of these plunge points are shown on Figure 6.8. These results also show the plunge points generally moving upstream through the growing season.

Table 6.2. Depths at plunge points calculated for monthly average conditions at Beaver Lake inflows.

Month	Beaver Lake - White River (m)	Beaver Lake - War Eagle (m)
April	NA	47.11
May	38.78	7.43
June	NA	7.60
July	4.96	3.71
August	1.67	1.24
September	1.81	0.90
October	NA	1.96

NA = does not plunge because inflow temperature is warmer than lake surface temperature

6.2.2 Storm Flow Plunge Points

Plunge points were also calculated for storm events at DeGray and Beaver Lakes. Inflow and temperature data were not available for storm events during the target years at Lakes Ouachita or Greeson.

6.2.2.1 DeGray Lake Storm Flow Plunge Points

High flow events were identified from USGS flow records for Station 07359610 (Caddo River at Caddo Gap). Plunge points calculated using temperature data collected close to the high flow events are shown in Table 6.3 and on Figure 6.9.

Table 6.3. Depths at plunge points calculated for selected storm events at DeGray Lake.

Storm Flow Date	Caddo River Flow (cms)	Depth at Plunge Point (m)
8/31/1976	6.9	1.8*
10/24/1976	200	6.1*
6/17/1977	370	5.6*
11/14/1978	500	7.6*
5/01/1979	190	6.2*
5/16/1980	103	3.4*
10/16/1980	168	4.7*
5/17/1989	71.4	15.75
5/27/1989	31.1	9.06
7/15/1989	13.2	4.75
7/17/1989	45.3	10.79
9/9/1989	6.7	2.93

*Values reported by Ford and Johnson (1983)

6.2.2.2 Beaver Lake Storm Flow Plunge Points

Plunge points in Beaver Lake were calculated for several storm events in years classified as wet (1990, 1995), dry (1983, 2003, 2005), and average (1999, 2001) (Table 6.4). Storm events were considered if there were increases in White River flow over a couple of days following rainfall events (http://waterdata.usgs.gov/nwis/sw). In the majority of cases, the rainfall events recorded at the White River Gage 07048600 associated with the flow increases had a recurrence interval of less than one year (National Climatic Data Center (NCDC) 1968). The exception is the 5/19/90 storm flow, which was associated with a rainfall event with a recurrence interval of greater than 100 years (NCDC 1968). Note that the data needed to calculate the plunge point were not available for the majority of the storm events identified during the target years, which limited the number of estimates. The locations of these plunge points are shown on Figure 6.10.

Table 6.4. Depths at plunge points calculated for selected storm events at Beaver Lake.

Storm Flow Date	Hydrologic Classification	White River Flow (cms)	Depth at Plunge Point (m)
05/14/1983	Dry	76.2	22.13
05/19/1990	Wet	210.0	NA
05/03/1993	Wet	139.0	NA
08/24/1993	Wet	15.7	6.42
05/04/1999	Average	274.7	59.87
09/12/1999	Average	2.3	1.58
05/30/2001	Average	49.6	16.71
09/09/2001	Average	21.9	6.02
09/17/2001	Average	36.2	13.35
09/01/2003	Dry	15.7	5.53
08/07/2005	Dry	1.2	1.06

Note: Average May White River flow is 20.81 cms, August is 1.56 cms, and September is 2.13 cms.
N/A = does not plunge because inflow temperature is warmer than lake surface temperature.

6.2.3 Beaver Lake Plunge Points, All Dates

Plunge points were calculated for all sample dates (not just storm events) between May and September with all the necessary data during 1993 (wet year), 2002 (average year), and 2003 (dry year). Plunge points were calculated using the method from Savage and Brimberg (1975). The data and calculated plunge points are listed in Table 6.5. Location of these plunge points are shown on Figure 6.11.

Table 6.5. Depths at plunge points calculated for sampling events at Beaver Lake.

Date	Hydrologic Classification	White River Flow (cms)	Depth at Plunge Point (m)
05/04/1993	Wet	32	NA
08/26/1993	Wet	1	0.637
05/14/2002	Average	10.3	6.68
06/20/2002	Average	5.5	6.44
07/10/2002	Average	1.1	0.866
07/23/2002	Average	3.3	2.49
08/22/2002	Average	2.3	1.37
09/04/2002	Average	0.4	0.476
05/07/2003	Dry	10.7	12.4
07/30/2003	Dry	3.4	1.30
09/09/2003	Dry	0.8	0.782

Notes: N/A = does not plunge because inflow temperature is warmer than lake surface temperature.

NA means a plunge point could not be calculated because the inflow temperature was warmer than the lake surface temperature. Therefore the inflow would be expected to travel along the surface as an overflow (see Figure 6.4).

6.3 Plunge Point Conclusions

During stratification, the plunge point determines the relative location of the transition zone in reservoirs. The transition zone typically is characterized by higher phytoplankton productivity and biomass and can be the most fertile area in the reservoir (Kimmel et al. 1990). Silt and clay particles settle or sediment in this zone, which increases light penetration (Figure 6.5). Nutrient concentrations, although lower than in the riverine zone, are still relatively high and sufficient to stimulate phytoplankton production and blooms because light is available as water clarity increases. During stratification, this transition zone extends down-reservoir from the plunge point until nutrient limitation occurs and phytoplankton biomass and production decrease. The area in the lower portion of the reservoir near the dam typically has the best water quality.

The transition zone is dynamic, as evidenced by the location of the plunge point. Its location is determined both by thermal stratification and inflow. During storm events, the plunge point moves further into the reservoir and then retreats back, upstream as storm flow returns to base flow. In Beaver Lake, the location of this transition zone, based on satellite images and empirical equation estimates, appears to extend from upstream of Highway 412 to the Beaver Water District intake near Lowell. If WQS are attained within the transition zone, then, in general, water quality further downstream in the reservoir should also attain WQS. The plunge point analyses provide insight into possible locations for monitoring water quality to determine if WQS are attained for Beaver Lake.

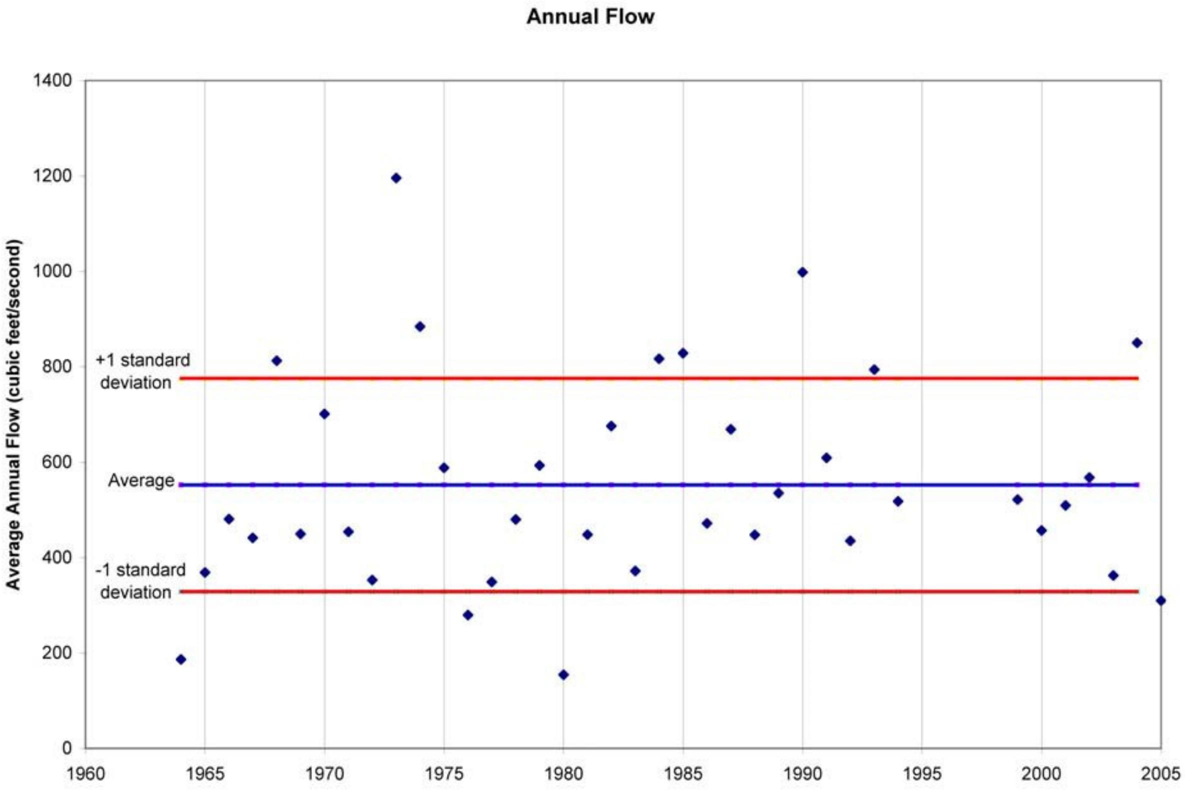


Figure 6.1. Hydrologic characterization of White River flows.

[redacted]

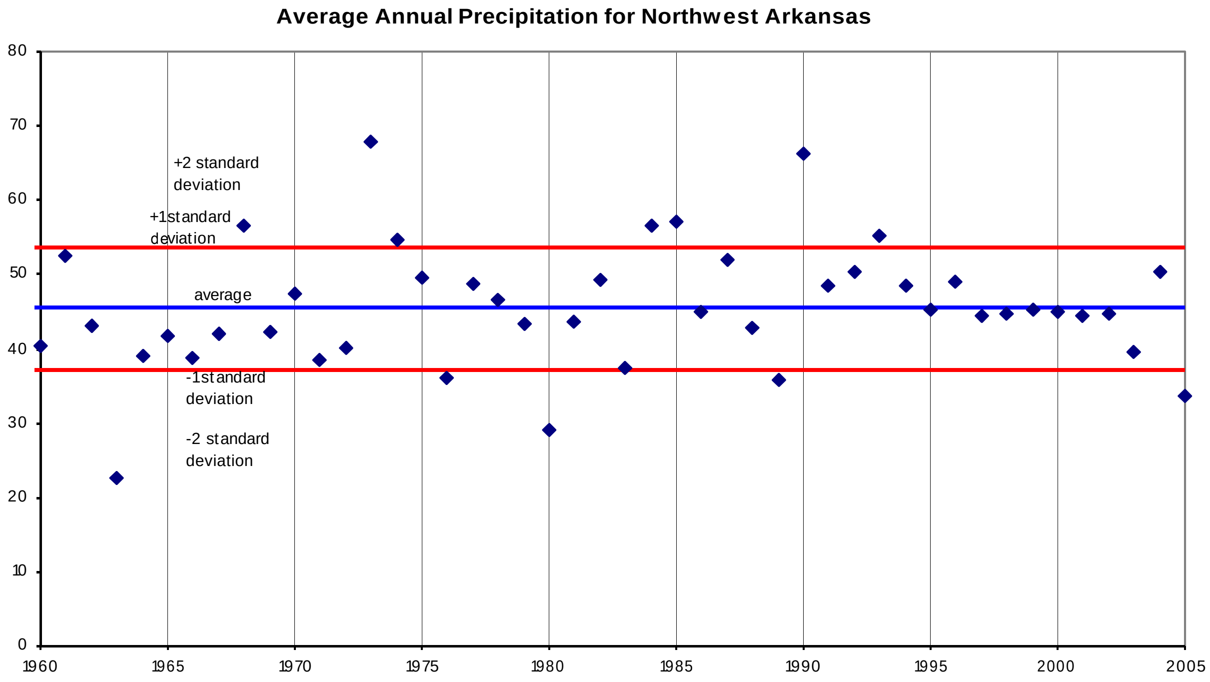


Figure 6.2. Hydrologic characterization of Fayetteville precipitation.

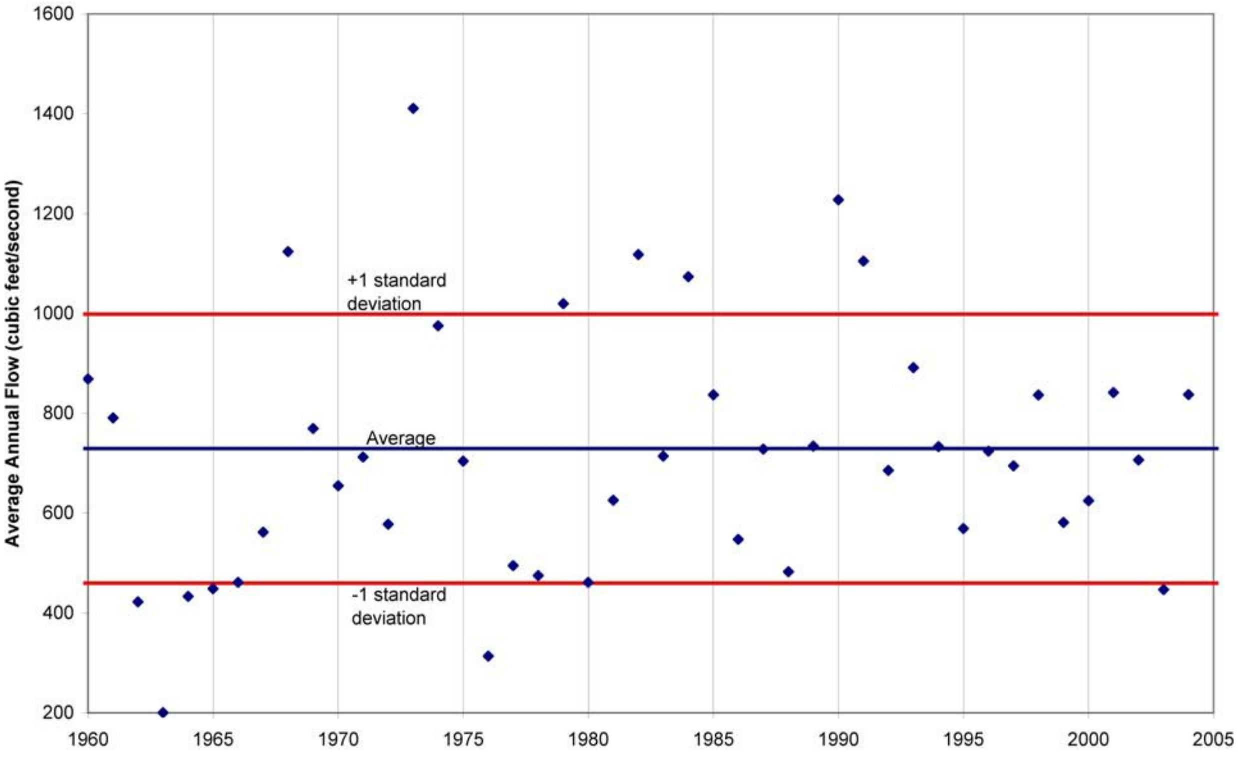
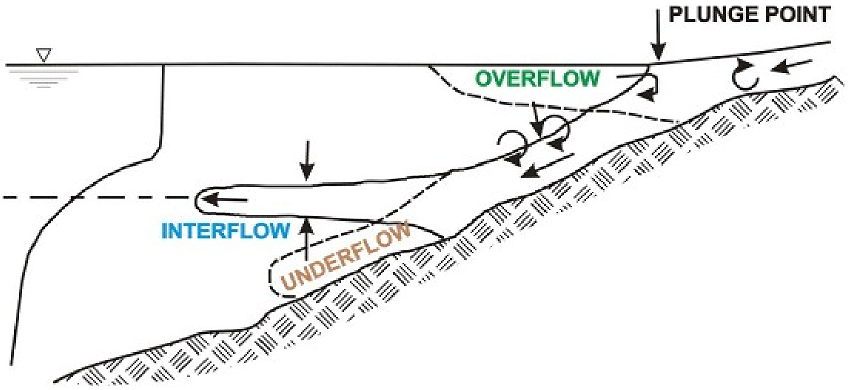


Figure 6.3. Hydrologic characterization of Ouachita River flows.



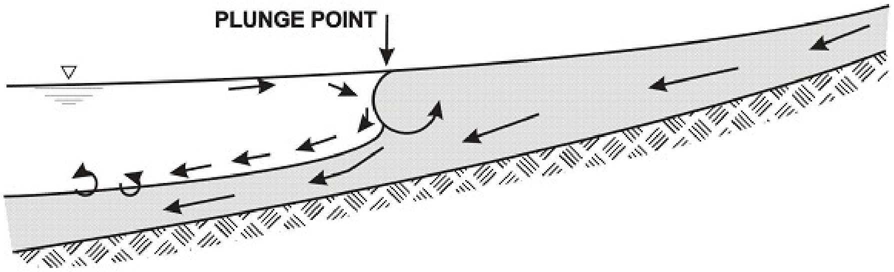


Figure 6.4. Plunge point dynamics in reservoirs.

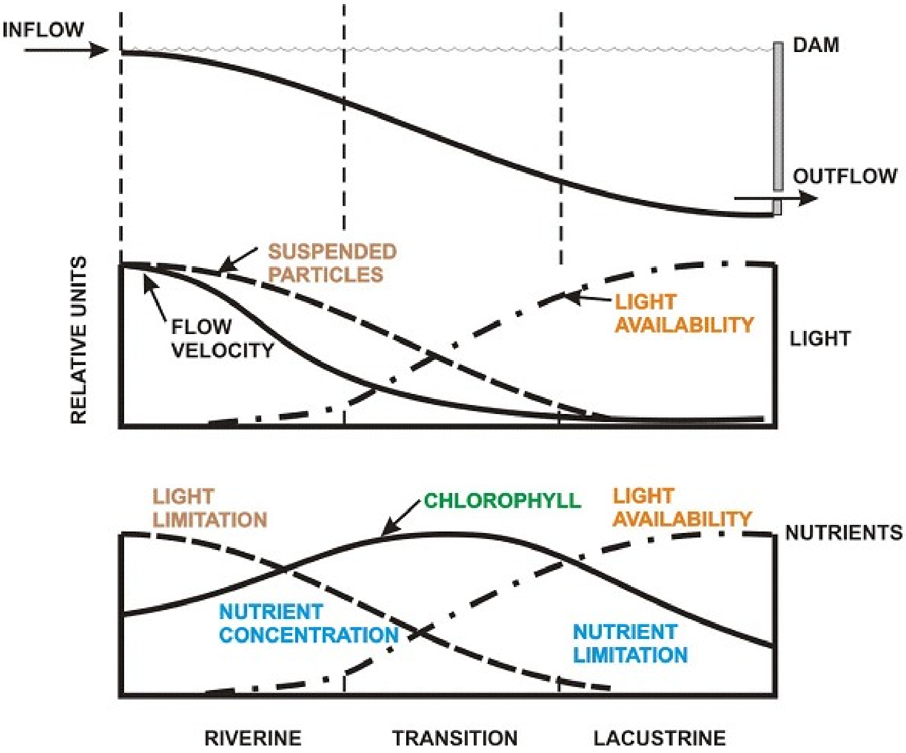


Figure 6.5. Gradients in water quality constituents associated with the plunge point, which defines the location of the transition zone.

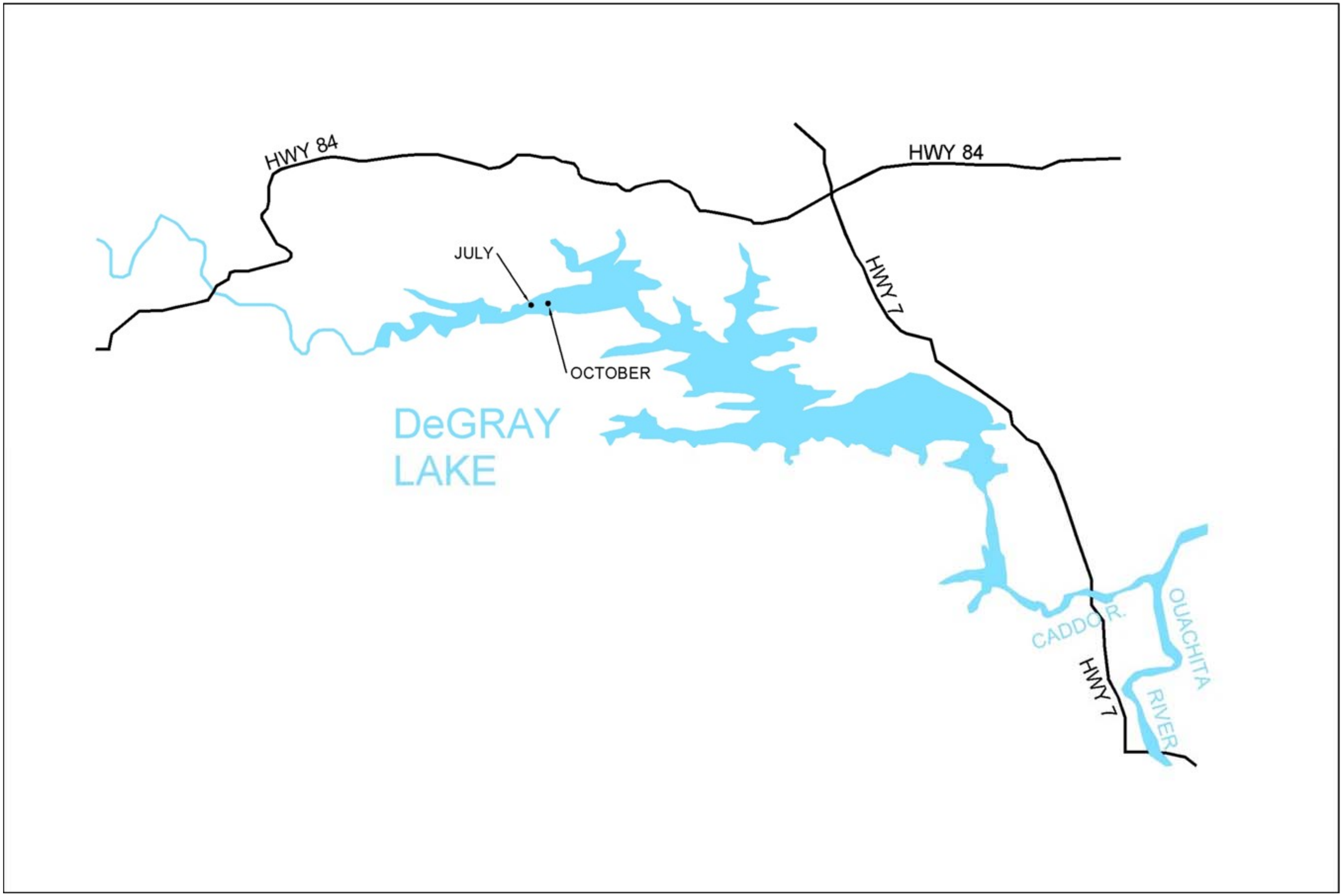


Figure 6.6. Locations of plunge points in DeGray Lake for monthly average conditions.

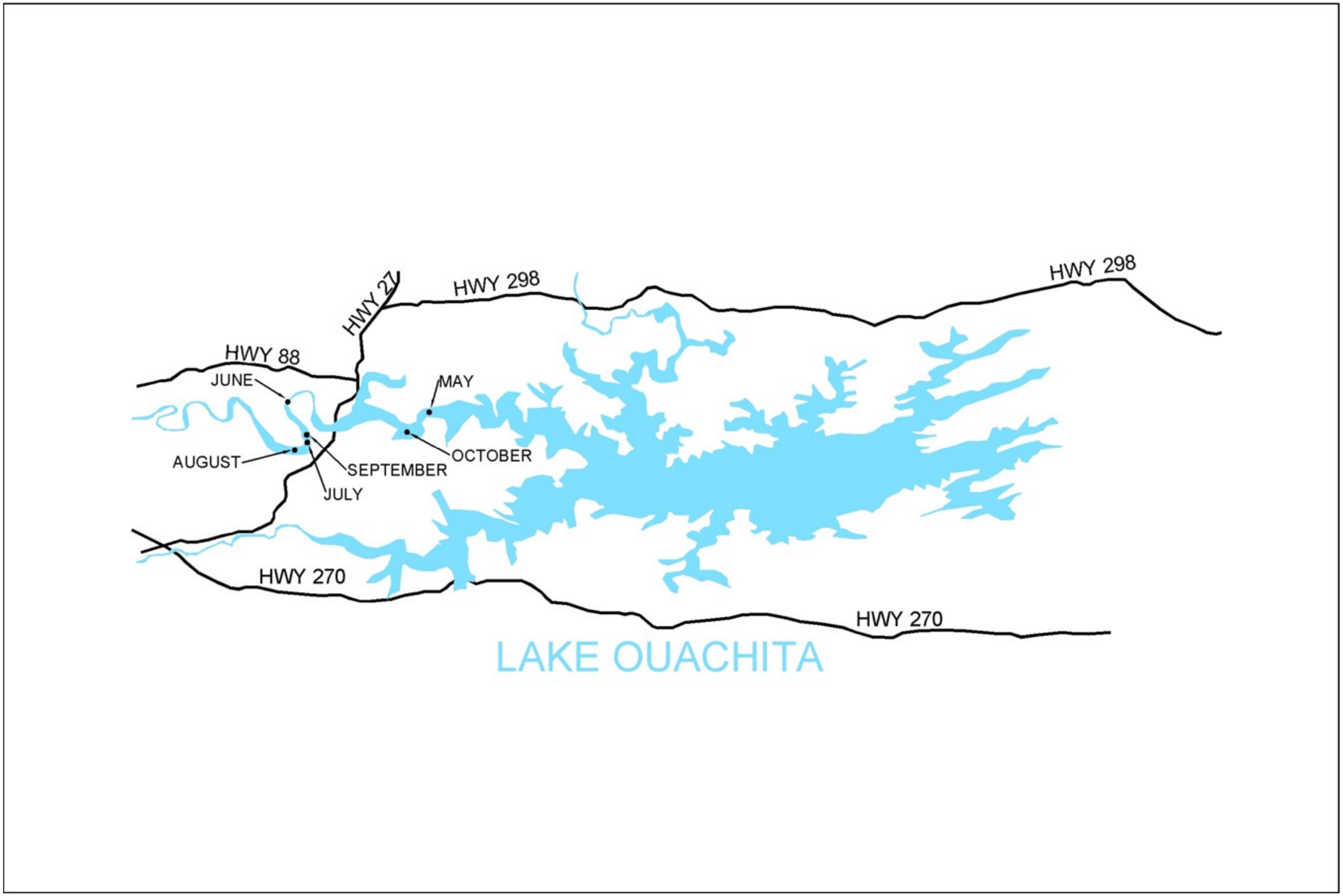


Figure 6.7. Locations of plunge points in Ouachita Lake for monthly average conditions.

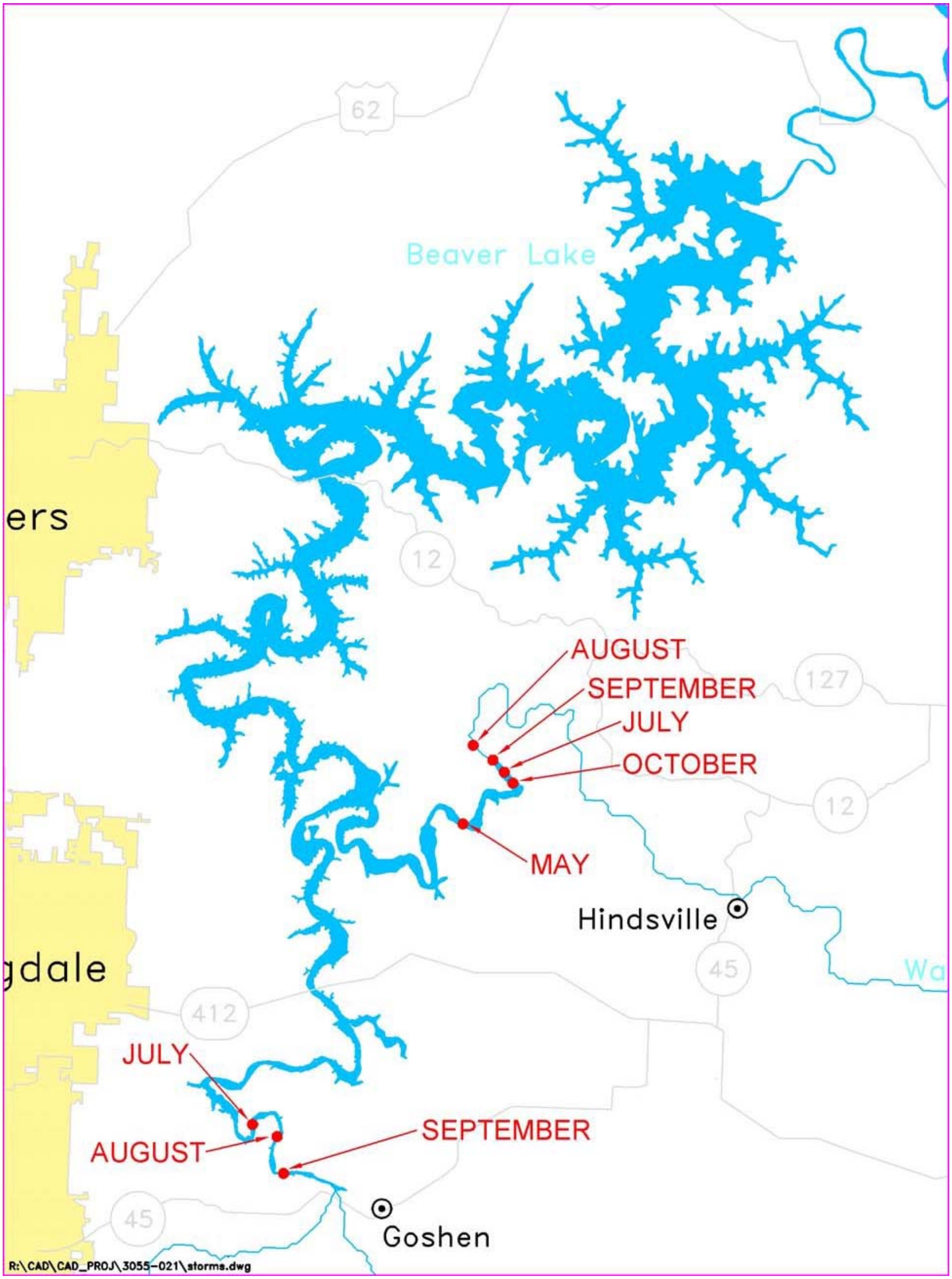


Figure 6.8. Locations of plunge points in Beaver Lake for monthly average conditions.

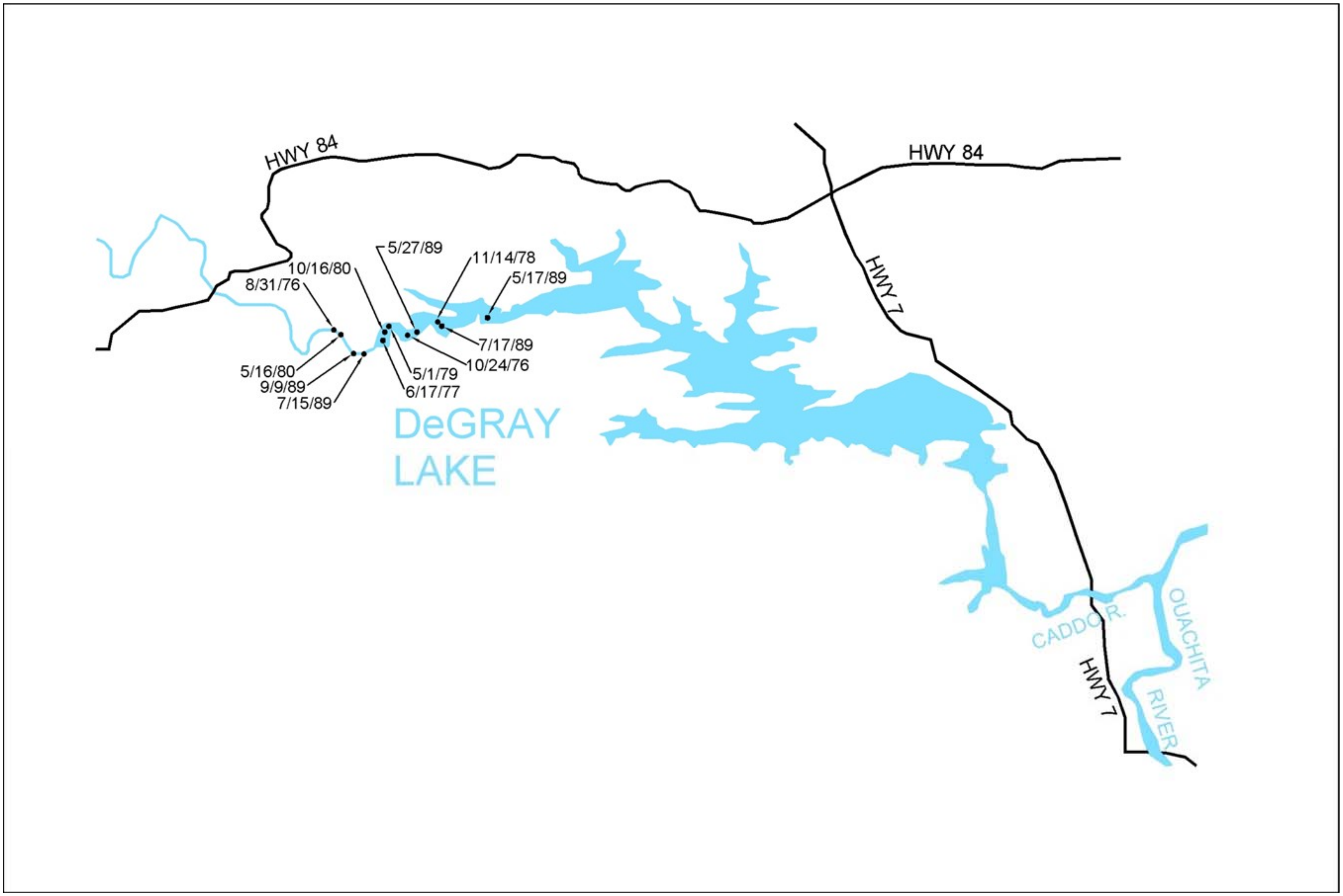


Figure 6.9. Locations of plunge points in DeGray Lake for high-flow storm events.

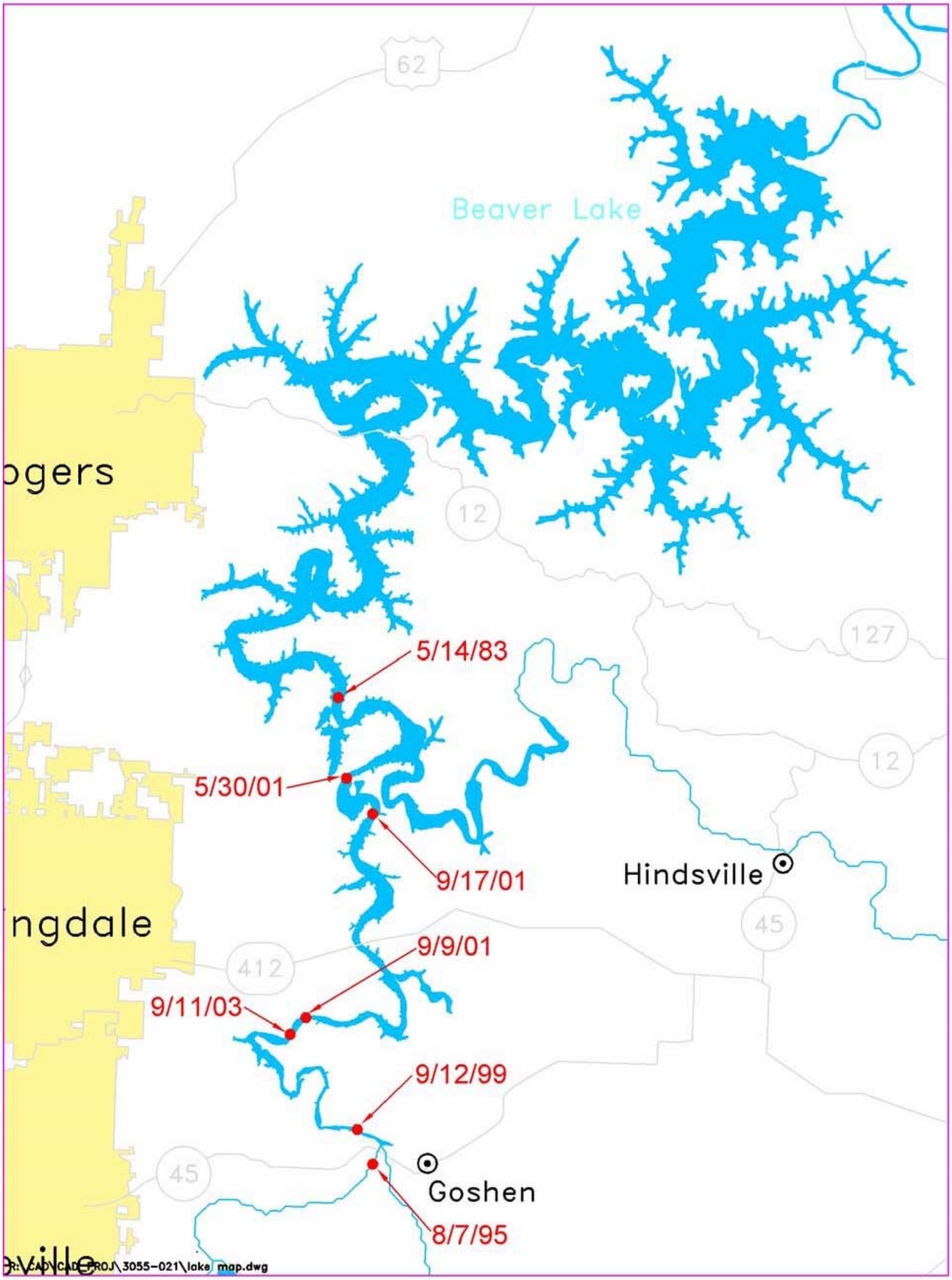


Figure 6.10. Locations of plunge points in Beaver Lake for high-flow storm events.

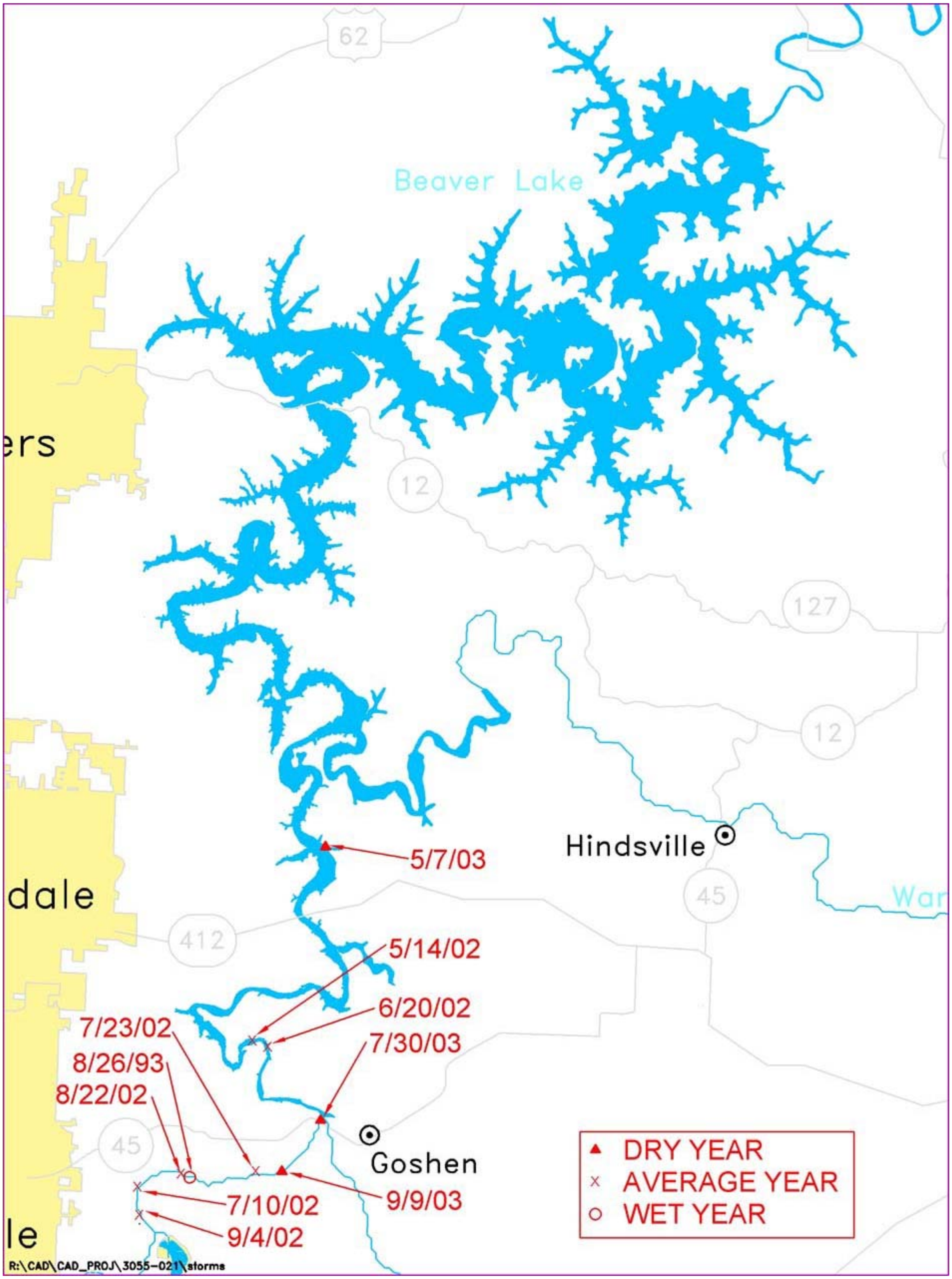


Figure 6.11. Locations of plunge points in Beaver Lake for wet, average, and dry year sampling dates.

7.0 STATISTICAL ANALYSES

7.1 Beaver Lake Analyses

Water quality data collected in Beaver Lake and its tributaries were compiled into a single database. Included in the database are water quality data from USEPA's NES, the Beaver Lake CLS, ADEQ/Arkansas Department of Pollution Control and Ecology (ADPCE) sampling programs, and USGS and USACE sampling programs. Data from the Beaver Water District sampling program for 1993 through 2006 were compiled in a separate database.

7.1.1 Summary Statistics

Summary statistics were calculated for Secchi transparency, DO, chlorophyll a, total phosphorus, and various nitrogen species, as well as ratios of nitrogen to phosphorus. These statistics were calculated for the photic zone by location (Table 7.1). These statistics indicated that there are longitudinal gradients in Beaver Lake water quality. With the exception of chlorophyll concentrations, mean and median values for other water quality constituents were similar at all stations. Mean concentrations of chlorophyll, however, were significantly different than median chlorophyll concentrations, which indicates that each station had chlorophyll blooms and greater chlorophyll concentrations than indicated only by median values

Table 7.1. Annual summary statistics, by location.

Parameter	Annual	Highway 412	Lowell	Dam
Secchi transparency (m)	mean	1.2	1.8	5.0
	median	1.1	1.7	4.9
Chlorophyll a (µg/L)	mean	32.6	12.1	11.0
	median	7.2	4.2	1.1
Total Nitrogen (mg/L)	mean	0.42	0.29	0.22
	median	0.40	0.30	0.18
Total Phosphorus (µg/L)	mean	35	21	14
	median	30	20	10

7.1.2 Longitudinal Water Quality Perspective

Water quality stations in Beaver Lake and its tributaries were ordered based on their distance from the dam (Figure 7.1; all figures are located at the end of this chapter). Box and whisker plots indicate the distribution of a data set as shown in Figure 7.2. Box and whisker plots of historical Secchi transparency, turbidity, chlorophyll a, total nitrogen, and total phosphorus measurements, as well as nitrogen to phosphorus ratios, were developed for all data (Figures 7.3 through 7.8), and for the wet, dry, and average years together (Figures 7.9 through 7.13). These plots exhibited expected longitudinal patterns of water quality.

Ratios of historical total nitrogen to total phosphorus in the photic zone of Beaver Lake (Figure 7.8) generally indicated phosphorus limitation (i.e., were greater than 10). At the upper reservoir station (Site 4), all of the ratios were greater than 10. In the downstream portions of Beaver Lake, there were some ratios that were less than 10, and at the dam there was at least one ratio that was less than 4, indicating nitrogen limitation. However, at all of the Beaver Lake stations, at least 75% of the ratios were greater than 10. At the inflow station (Site 5) over 25% of the ratios were less than 10, and a little less than 25% of the ratios were less than 4, indicating nitrogen limitation.

The box and whisker plots comparing water quality in Beaver Lake under different hydrologic conditions (dry, average, wet) indicated that in the reservoir, Secchi transparency tends to be highest during average hydrologic years and lowest during wet years (Figure 7.9). Except at the dam, Secchi transparency during dry, average, and wet hydrologic years was not statistically different. At the dam, Secchi transparency during wet years was statistically different from transparencies during dry and average years. In general, Secchi transparency was highest at the dam and decreased upstream in the reservoir, with the lowest values at the inflow station.

Beaver Lake chlorophyll a concentrations also tended to be highest during average hydrologic years and lowest during wet years (Figure 7.10). Overall, chlorophyll a concentrations were lowest at the dam and tended to be highest at the upper reservoir station. Typically, chlorophyll a concentrations are highest in the transition zone or the upper portions of the reservoir just downstream of the plunge point (Thornton et al. 1990).

Total phosphorus concentrations in Beaver Lake tended to be less than detection levels in the photic zone, so there was no indication that total phosphorus concentrations in the photic zone differed under different hydrologic conditions, except at the inflow station (Figure 7.11). At the inflow station, total phosphorus concentrations were highest during wet years and lowest during dry and average years. Total phosphorus concentrations during the dry and average years were not statistically different; however, wet year concentrations were statistically different from concentrations in average years. Overall, the highest total phosphorus concentrations occurred at the inflow station and were statistically lower at the downstream stations.

A box and whisker plot of turbidity data available for the Beaver Lake (Figure 7.14) exhibited the expected decreasing trend within Beaver Lake (Sites 1 through 4). The plot also indicated that the White River site (Site 5), and particularly the West Fork site (Site 7), accounted for the majority of the turbidity entering Beaver Lake. Turbidity levels in Richland Creek (Site 6) and War Eagle Creek (Site 10) were significantly lower than White River levels.

7.1.3 Trend Analyses

7.1.3.1 Tributary Water Quality

Long-term water quality data collected from the three major Beaver Lake tributaries (White River, Richland Creek, and War Eagle Creek) were examined for evidence of trends. Initial plots of nutrient, conductivity, turbidity, total suspended sediment, and total organic carbon data over time suggested that water quality in all three tributaries had changed (Figures 7.15 through 7.17).

Water quality data for the White River at Highway 45 were available from 1980 to the present (Figure 7.15). The plots of total phosphorus and ammonia exhibit significant drops in concentration levels in late 1989 or early 1990. This change was due to the new Fayetteville wastewater treatment system that came online (1987). Nitrate + nitrite concentrations, however, appear to have increased since the Fayetteville wastewater treatment system came online. Conductivity also appears to exhibit and increasing trend. Increasing conductivity in streams has been correlated with increasing urbanization of the stream watershed (Paul and Meyer 2001;

Roy et al. 2003). Total organic carbon and total kjeldahl nitrogen concentrations appear to have downward trends over time.

Water quality data for some parameters measured in Richland Creek were available from 1980 to the present. Plots of total phosphorus, total kjeldahl nitrogen, total organic carbon, and turbidity appear to indicate decreasing trends in concentration levels. The plot of nitrate + nitrite appears to indicate an increasing trend over time.

Water quality data for War Eagle Creek were generally available from the early 1990s to the present. The plots of total phosphorus, turbidity, and conductivity suggest increasing trends for these parameters. The plots of total suspended sediment, ammonia, and total organic carbon indicate concentrations of these parameters have decreased over time. The plot of nitrate + nitrite appears to show concentrations increasing between about 1991 and 2000, and then decreasing since 2000 or 2001.

Water quality trends in the White River and War Eagle Creek were examined more closely using Seasonal Kendall-Tau trend analysis (see Sections 7.1.3.3 and 7.1.3.4).

7.1.3.2 Onset and Duration of Anoxia

Initially, DO data collected near Lowell in Beaver Lake by USGS, USACE, and FTN (CLS) were used to determine the earliest date (Julian day) when DO less than 2 mg/L occurred. Since there were gaps in this data during the 1990s, DO data collected by Beaver Water District at their intake were added to the analyses. Examination of the USGS and USACE data revealed that most of the DO data collected by these agencies prior to 2001 were not adequate for estimating date of onset and duration of hypoxic conditions. Most of these years USGS and USACE sampled only three to four times a year (Figures 7.18 and 7.19). A minimum sampling frequency of once per month is necessary to provide a reasonable estimate of date of onset of hypoxic conditions. Beaver Water District sampling frequency ranged from monthly to every 2 weeks.

Examination of the useable data revealed several years where data were available from more than one source. Slightly different start and end dates for hypoxic conditions (DO less than 2 mg/L) were exhibited by the data from different sources (Figure 7.20). New duration values were calculated for these years using the earliest start date and latest end date from available sources. The earliest start date from available sources was also used for these years in the analyses described below.

The earliest Julian day with measured DO less than 2 mg/L was plotted versus year with a linear regression line (Figure 7.21). This plot indicated that there could be a decreasing trend in the Julian day when hypoxic conditions occur, i.e., hypoxic conditions could be occurring earlier. Linear regression analysis of these data did not indicate a significant relationship ($R^2 = 0.08$, $P = 0.38$). Tree analysis (see Section 7.1.5) indicated that there was a statistically significant difference in the day of the year when hypoxia began before and after 1997 (Figure 7.22).

The number of days between the first and last Julian days with measured DO less than 2 mg/L was plotted versus year with a linear regression line (Figure 7.23). This plot indicated that there could be an increasing trend in the duration of hypoxic conditions near the Beaver Water District intake, i.e., hypoxic conditions could be lasting longer. Linear regression analysis of these data did not indicate a significant relationship ($R^2 = 0.13$, $P = 0.24$). Tree analysis (see Section 7.1.5) indicated that there was a statistically significant difference in the duration of hypoxic conditions before and after 1997 (Figure 7.24).

7.1.3.3 Seasonal Kendall-Tau Trend Analyses of Water Quality – Analyses

Water quality data at War Eagle Creek (USGS Gage 0749000), White River (USGS 07048700), Beaver Lake at Highway 412 (USGS Gage 07048910), and Beaver Lake near Lowell (USGS Gage 07049200) collected between 1990 and 2005 were analyzed for long-term trends using Seasonal Kendall-Tau. The parameters analyzed were nitrate + nitrite N, nitrate N, total nitrogen, total phosphorus, turbidity, conductivity, and total organic carbon. The majority of the data used for the analyses were collected by USGS, ADEQ, and USACE. Where it was available, data collected by Beaver Water District were also included in the analyses. Analyses were performed using the USGS-developed program for Kendall trend analyses (USGS 2006).

The lake stations data were adjusted for variability related to sample depth by performing the Seasonal Kendall-Tau analysis on the residuals from LOWESS smoothing of the water quality data versus sample depth. Nutrients in particular usually display characteristic gradients with depth. Total organic carbon at the Lowell station was not adjusted for depth so the Beaver Water District raw water total organic carbon data could be included to increase the size of the data set. Sample depth information was not really available for the Beaver Water District values, so it could not be adjusted. A plot of the Beaver Water District raw water data and total organic carbon data from other sources indicated that reported values were similar, and did not vary much with depth (Figure 7.25). As a result, combining the total organic carbon data and not adjusting them was deemed appropriate.

Plots of the White River data versus the natural log of White River flow at USGS Gage 07048600 indicated relationships between water quality concentrations and flow rate (Figure 7.26). Therefore, the White River data were adjusted for variability related to flow rate by performing the Seasonal Kendall-Tau analysis on residuals from LOWESS smoothing of the water quality data versus the natural log of the reported flow rate. Long-term flow data were not available for War Eagle Creek between 1990 and 1998. Gage height data were available for most of the period between 1990 and 2005, but plots of War Eagle Creek data versus gage height did not indicate relationships between them (Figure 7.27). Plots of the War Eagle Creek data versus the natural log of War Eagle Creek flow for 1998 through 2005 indicated effects of flow on total phosphorus, turbidity, and conductivity. Therefore, these parameters from War Eagle Creek were adjusted for variability related to flow rate by performing the Seasonal Kendall-Tau analysis on residuals from LOWESS smoothing of the parameters versus the natural log of the reported flow rate.

7.1.3.4 Seasonal Kendall-Tau Trend Analyses of Water Quality – Results

Seasonal Kendall-Tau analyses of War Eagle Creek data indicated the most statistically significant ($p \leq 0.05$) water quality trends. Output from the Seasonal Kendall-Tau analyses that indicated trends is summarized in Table 7.2.

Table 7.2. Seasonal Kendall-Tau output indicating trends in War Eagle Creek water quality.

Parameter	Tau Correlation Coefficient	P	Trend Direction	Kendall Line Equation
Nitrate	-0.284	0.0549	Decreasing	NO_3 = 0.92 – (0.02667 * time)
Total Organic Carbon	-0.421	0.0034	Decreasing	TOC = 2.695 – (0.1 * time)
Conductivity	0.325	0.0278	Increasing	Conductivity = 4.295 * time

Notes: Time = decimal year – 1991.75 (beginning of first water year with data)
Conductivity was adjusted for flow prior to analysis.

Seasonal Kendall-Tau analyses of White River data indicated a statistically significant trend only in total phosphorus ($p = 0.0238$). The analysis indicated a decreasing trend in total phosphorus (TP = -0.002106 * time). Seasonal Kendall-Tau analyses of the selected water quality parameters from the Beaver Lake station at Highway 412 did not indicate any statistically significant ($p < 0.05$) trends. Seasonal Kendall-Tau analyses of the selected water quality parameters from the Beaver Lake station near Lowell did not indicate any statistically significant ($p < 0.05$) trends.

7.1.3.5 NES to Present

The only common monitoring station among the 1974 NES, 1991 CLS, and 2001 through 2002 USGS study was the dam station (Table 7.3). In general, there were no significant differences in any of the water quality constituent means or medians.

The monitoring station near Lowell, Arkansas, was a common site between the 1991 CLS and the 2001 through 2002 USGS study. Although there were no significant differences among constituent mean and median values, chlorophyll and total nitrogen concentrations were higher in 2001 through 2002 compared with 1991, but water clarity was better in 2001 through 2002 compared with 1991.

Table 7.3. Comparison of historical Beaver Lake summary statistics.

Parameter		Dam			Lowell	
		NES	CLS	2001-2002	CLS	2001-2002
Chlorophyll a (µg/L)	mean	2.8 (4) (b)	1.1 (13)	2.0	2.6 (14)	5.8 (27)
	median	2.7	0.8	1.9	3.8	5.9
Secchi depth (m)	mean	4.5	4.7	5.5	1.8	2.0
	median	4.2	5.2	5.7	1.7	2.0
Total phosphorus (µg/L)	mean	10 (14) (c)	4 (78)	20 (50) (a)	13 (47)	20 (26) (a)
	median	11	5	20	17	20
Total nitrogen (mg/L)	mean	0.38	0.48	0.37	0.44	0.56
	median	0.35	0.49	0.35	0.59	0.68

Notes:
(a) TP values are affected by minimum detection level of 20 µg/L.
(b) Number in parentheses is sample number for chlorophyll and Secchi variables.
(c) Number in parentheses is sample number for total phosphorus and total nitrogen.

7.1.4 Water Quality Percentile Analyses

In its guidance document on developing nutrient criteria for lakes and reservoirs (USEPA 2000), USEPA recommends setting nutrient criteria based on the 25th percentile of existing data for a system (75th percentile for Secchi transparency). Therefore, for Beaver Lake, the 25th percentile of chlorophyll a and trophic zone total phosphorus and total nitrogen, as well as the 75th percentile Secchi transparency, were determined for the available Highway 412 data and the Lowell data. These values are summarized in Table 7.4. In addition, the 25th percentiles of annual average total phosphorus and total nitrogen, and geometric average chlorophyll a for the growing season, along with the 75th percentile of annual average Secchi transparency, were determined for Highway 412 and Lowell sites (Table 7.5). The values in Tables 7.4 and 7.5 are very similar.

Table 7.4. Potential criteria determined using USEPA method for selected Beaver Lake stations – raw data.

Site	25th Percentile Chlorophyll a (µg/L)	75th Percentile Secchi Transparency (m)	25th Percentile Total Phosphorus (mg/L)	25th Percentile Total Nitrogen (mg/L)
Highway 412	2.6	0.76	0.020	0.65
Lowell	2.35	1.1	0.013	0.39

Table 7.5. Potential criteria determined using USEPA method for selected Beaver Lake stations – annual statistics.

Site	25th Percentile Growing Season Geometric Mean Chlorophyll a (µg/L)	75th Percentile Annual Average Secchi Transparency (m)	25th Percentile Annual Average Total Phosphorus (mg/L)	25th Percentile Annual Average Total Nitrogen (mg/L)
Highway 412	2.9	0.77	0.025	0.705
Lowell	2.4	1.35	0.020	0.38

7.1.5 Change-Point Analyses

Change-point statistical analysis is a procedure for identifying natural changes in variance of a constituent. This nonparametric procedure is based on a series of rules for partitioning variance into classes or categories, each with a more homogeneous variance structure. These rules are incorporated into classification and regression tree (CART) analyses.

Qian et al. (2003) noted that the change-point nonparametric deviance reduction approach for identifying water quality change points “is consistent with the tree-based modeling (i.e., CART) approach,” and that “the change point is the first split of a tree model when *x* is used as the single predictor variable. As a result, the commonly available tree model software … can be used.” We used the tree model in the Systat version 9.0 statistical software program to identify change points in Beaver Lake data from 1979 through 2005 collected in the photic zone.

7.1.5.1 Chlorophyll a

Change-point analyses of chlorophyll a concentrations paired with total phosphorus, total nitrogen, and turbidity were conducted. The analysis did not identify a significant change in chlorophyll a concentrations associated with total phosphorus concentrations. A significant change in the chlorophyll a data was identified at 0.5 mg/L total nitrogen (Figure 7.28). There were 100 chlorophyll a measurements associated with total nitrogen concentrations less than 0.5 mg/L, with a mean value of 2.71 mg/L chlorophyll a. There were 95 chlorophyll a measurements associated with total nitrogen concentrations greater than 0.5 mg/L, with a mean value of 5.85 mg/L chlorophyll a. A significant change in the chlorophyll a data was also identified at 0.26 nephelometric turbidity units (NTU) turbidity (Figure 7.29). There were five chlorophyll a measurements associated with turbidities less than 0.26 NTU with an average value of 38 µg/L. There were 290 chlorophyll a measurements associated with turbidities greater than 0.26 NTU, with an average value of 4.8 µg/L.

Change-point analyses pairing chlorophyll a concentrations and location in the reservoir indicated a significant difference in chlorophyll a concentrations at Highway 412 and at stations downstream of Highway 412. At Highway 412 there were 92 chlorophyll a measurements with a mean value of 11.3 µg/L. Downstream of the Highway 412 station there were 305 measurements with a mean value of 3.1 µg/L. This indicates that the highest chlorophyll a concentrations occur in the upper reservoir, as would be expected.

Change-point analyses pairing total phosphorus concentrations and location in the reservoir indicated a significant difference in total phosphorus concentrations upstream and downstream of the station near Lowell. At the Lowell and Highway 412 stations there were 127 total phosphorus measurements with a mean value of 0.023 mg/L. Downstream of the Lowell station there were 373 measurements with a mean value of 0.013 mg/L. The location of the highest total phosphorus concentrations was similar to the location of the highest chlorophyll a concentrations, as would be expected.

Additional tree modeling for individual locations in the reservoir identified total phosphorus and turbidity thresholds associated with change points in chlorophyll a concentrations. Chlorophyll a change points associated with total phosphorus were identified at only two of the Beaver Lake stations. At Site 2 (see Figure 7.1), chlorophyll a was statistically different (less) when total phosphorus concentrations were less than 0.010 mg/L (Figure 7.30), and at Lowell (Site 3), chlorophyll a was statistically different (greater) when total phosphorus concentrations were less than 0.040 mg/L (Figure 7.31). Also at Lowell, chlorophyll a was statistically different (greater) when turbidity was less than 2.6 NTU (Figure 7.32). At Site 4 (Highway 412), chlorophyll a was statistically different (greater) when turbidity was less than 26 NTU (Figure 7.33).

7.1.5.2 Secchi depth

Change-point analyses of Secchi depth paired with total phosphorus, total nitrogen, and turbidity were conducted. For these analyses, all total phosphorus, total nitrogen, and turbidity values reported for the photic zone were associated with the sample day Secchi transparency. Analyses with total phosphorus were conducted both including and excluding total phosphorus reported as less than detection (less than detection values were set to the detection level in the data set). Results of these analysis are summarized as follows:

1. When cases with total phosphorus less than detection values were included, a Secchi depth change point was identified at 0.007 mg/L total phosphorus (Figure 7.34). There were 112 Secchi measurements associated with total phosphorus less than 0.007 mg/L, with a mean value of 4.9 meters. There were 541 Secchi measurements associated with total phosphorus greater than 0.007 mg/L, with a mean value of 3.0 meters;
2. When cases with total phosphorus less than detection values were excluded, the Secchi depth change point was at 0.011 mg/L total phosphorus (Figure 7.35). There were 187 Secchi measurements associated with total phosphorus less than 0.011 mg/L, with a mean value of 4.2 meters. There were 231 Secchi measurements associated with total phosphorus greater than 0.011 mg/L, with a mean value of 2.1 meters;
3. For Secchi measurements associated with total nitrogen data, a Secchi depth change-point was identified at 0.75 mg/L total nitrogen (Figure 7.36). There were 320 Secchi measurements associated with total nitrogen less than 0.75 mg/L, with a mean value of 4.1 meters. There were 109 Secchi measurements associated with total nitrogen greater than 0.75 mg/L, with a mean value of 2.4 meters; and
4. For Secchi measurements associated with turbidity data, a Secchi depth change point was identified at 1.8 NTU turbidity (Figure 7.37). There were 324 Secchi measurements associated with turbidity less than 1.8 NTU, with a mean value of 4.2 meters. There were 334 Secchi measurements associated with turbidity greater than 1.8 NTU, with a mean value of 2.0 meters.

Change-point analyses pairing Secchi transparency and location in the reservoir indicated a significant difference in Secchi transparency upstream and downstream of Highway 12. At the dam and Highway 12 stations there were 313 Secchi transparency measurements with a mean value of 5.0 meters. Upstream of Highway 12 there were 314 measurements with a mean value of 1.7 meters.

Additional tree modeling identified total phosphorus thresholds associated with change points in Secchi depth at different locations in the reservoir. These analyses showed that Secchi transparency was statistically different (greater) when total phosphorus concentrations were less than 0.011 to 0.008 mg/L at stations downstream of Lowell. At Lowell, Secchi transparency was statistically different (greater) when total phosphorus concentrations were less than 0.031 mg/L, and at the upper reservoir station, Secchi transparency was statistically different (greater) when total phosphorus concentrations were less than 0.040 mg/L.

7.2 Reference Conditions

7.2.1 Reference Streams

In the late 1980s, ADEQ identified least-disturbed streams in the Ozark Highlands and Boston Mountains Ecoregions of the state for development of ecoregion water quality standards (ADPCE 1987). These streams are listed in Table 7.6. Nutrient concentrations in these streams can also contribute to development of nutrient water quality criteria for Beaver Lake. Average nutrient concentrations from the ecoregion water quality study are included in Table 7.6. Note that these data were collected between 1984 and 1986, and consist of three samples collected on each sample date. Nutrient concentrations in the least-disturbed streams in the Ozark Highlands Ecoregion are higher than in the Boston Mountain Ecoregion. Since the majority of the Beaver Lake watershed is located in the Ozark Highlands Ecoregion, data from this ecoregion will be used for comparison to Beaver Lake tributaries.

Water quality data are currently collected from only four of the Ozark Highlands least-disturbed streams: Flint Creek, Long Creek, War Eagle Creek, and Kings River. Analysis of historical and current measurements of total phosphorus, phosphate phosphorus, and nitrate + nitrite indicate that for Flint Creek, War Eagle Creek, and Kings River (near Berryville), current levels of these nutrients are similar to the levels in the early 1990s (Figures 7.38 through 7.40). Current nutrient concentrations in Long Creek, especially phosphorus, appear significantly higher than occurred historically (Figure 7.41).

Table 7.6. Ecoregion least-disturbed streams (ADPCE 1987).

	Total Phosphorus (mg/L)		**PO_4 P (mg/L)**		**NO_2+NO_3 (mg/L)**		**NH_3-N (mg/L)**	
	Spring	**Summer**	**Spring**	**Summer**	**Spring**	**Summer**	**Spring**	**Summer**
Ozark Highlands Ecoregion								
South Fork Spavinaw Creek	0.01	0.01	0.01	0.01	1.51	0.92	0.04	0.01
Flint Creek	0.15	0.08	0.09	0.01	1.86	0.92	0.10	0.04
Yocum Creek	0.07	0.03	0.03	0.02	1.52	0.72	<0.01	<0.02
Long Creek	0.04	0.03	0.03	0.01	0.95	1.03	0.03	0.04
War Eagle Creek	0.03	0.05	0.02	0.03	0.62	1.15	0.07	<0.01
Kings River	0.02	0.09	0.02	0.07	0.19	0.38	0.08	0.01
Average	0.05	0.04	0.03	0.02	0.95	0.73	<0.05	<0.02
Boston Mountains Ecoregion								
Indian Creek	0.01	0.01	<0.01	0.01	<0.01	<0.01	0.04	0.02
Hurricane Creek	0.01	0.02	<0.01	<0.01	<0.01	<0.01	0.03	0.01
Archey Fork Creek	0.02	0.03	0.02	0.01	0.02	0.03	0.03	<0.01
Illinois Bayou	0.01	0.03	0.01	0.02	0.04	0.05	0.03	0.02
Lee Creek	0.05	0.02	0.02	<0.01	0.05	0.03	0.02	0.01
Mulberry River	0.05	0.03	0.01	<0.01	0.05	0.01	0.01	<0.01
Average	0.02	0.02	<0.01	<0.01	<0.03	<0.02	0.02	<0.01

7.2.2 Reference Reservoirs

Data were compiled for Lake Greeson, DeGray Lake, and Lake Ouachita. These data sets included data from ADEQ/ADPCE, USACE, and USGS sampling programs. Very little water quality data were available for Lake Greeson, so it was eventually dropped from the analyses. Water quality in DeGray Lake and Lake Ouachita was characterized using longitudinal plots of data, plunge point estimates, and change-point analysis.

7.2.2.1 Longitudinal Water Quality Plots

Water quality stations in DeGray Lake, Lake Ouachita, Lake Greeson and their tributaries were ordered based on their distance from the dam (Figures 7.42 through 7.44). Box and whisker plots (see Figure 7.2) of historical Secchi transparency, turbidity, chlorophyll a, total nitrogen, and total phosphorus measurements versus location in the reservoir were developed for all three reservoirs. Plots of total phosphorus, total nitrogen, and turbidity used only data from samples taken from near the surface of the reservoirs. Analyses of these parameters were restricted to the photic zone because that is the part of the water column where the response of algal productivity and Secchi transparency has been strongest in reservoirs. Most of the data available for DeGray Lake were not categorized by depth (i.e., TOP, MID, BOTTOM). For DeGray Lake, all data collected from depths less than 20 ft were categorized as TOP samples. This depth was an estimate of the depth of the photic zone (2 * Secchi transparency) for DeGray Lake. Secchi transparency data were not available for the majority of the DeGray Lake samples; therefore, it was not possible to calculate the depth of the photic zone for each sample date. The overall historical average Secchi transparency of DeGray Lake was 2.6 meters. This Secchi transparency suggests a photic zone approximately 17 ft deep, which was rounded up to 20 ft.

Water quality in reservoirs typically varies longitudinally. The box and whisker plots helped us characterize and compare the water quality variability at different locations in the reservoirs. These plots also showed us that useable amounts of data at all locations in the reservoir were available only for DeGray Lake. For the most part, water quality data for Lake Ouachita and Lake Greeson were available only near the dam and for the primary tributaries. Therefore, DeGray Lake was the only reservoir for which longitudinal variability could be characterized. The longitudinal variability of DeGray Lake is summarized below:

1. Secchi depths exhibited an increasing trend from the lake headwaters to the dam, with Secchi depths near the dam statistically different (greater) from those in the upper lake (Figure 7.45);
2. Total phosphorus concentrations exhibited a decreasing trend from the lake headwaters to the dam. Total phosphorus concentrations near the dam were statistically different (less) from those in the upper lake and tributaries. The greatest maximum total phosphorus concentration was measured in the upper lake, 19.5 miles upstream of the dam (Figure 7.46);
3. Total nitrogen concentrations exhibited a decreasing trend from the lake headwater to the dam (Figure 7.47). The median at each lake sampling site was statistically different (less) from the upstream station;
4. Turbidity measurements exhibited a decreasing trend from the lake inflows to the dam (Figure 7.48). Turbidity values near the dam were statistically different (less) from those in the upper lake and tributaries; and
5. Chlorophyll a concentrations also exhibited a decreasing trend from the upper lake to the dam (Figure 7.49). Chlorophyll a concentrations near the dam were statistically different (less) from those in the upper lake. The greatest maximum

chlorophyll a concentration was measured in the upper lake, 19.5 miles upstream of the dam (the same location as the maximum phosphorus and nitrogen concentrations).

7.2.2.2 Percentile

In its guidance document on developing nutrient criteria for lakes and reservoirs (USEPA 2000), USEPA recommends setting nutrient criteria based on the 75th percentile of existing data from a reference system. Therefore, for DeGray Lake and Lake Ouachita, the 75th percentile of chlorophyll a, trophic zone total phosphorus and total nitrogen, and the 25th percentile of Secchi transparency were determined for the data for the upper lakes. These values are summarized in Table 7.7.

Table 7.7. Potential criteria for upper lake stations in reference reservoirs using USEPA method.

Reservoir	75th Chlorophyll a (µg/L)	25th Secchi Transparency (m)	75th Total Phosphorus (mg/L)	75th Total Nitrogen (mg/L)
DeGray Lake	9.0	0.9	0.038	0.765
Ouachita Lake	--	1.4	0.016	0.33

7.2.2.3 Change-Point Analyses

Change-point analyses (see Section 7.1.5) were conducted on DeGray Lake water quality data sampled from less than 20 ft deep (except chlorophyll a, which was assumed to be collected only in the photic zone).

7.2.2.3.1 Chlorophyll a

Change-point analyses were conducted on chlorophyll a concentrations paired with total phosphorus, total nitrogen, and turbidity. The analyses did not identify a significant change in the chlorophyll a distributions when associated with total nitrogen or turbidity. A significant change in the chlorophyll a distributions was identified at 17 µg/L total phosphorus (Figure 7.50). There were 543 chlorophyll a measurements associated with total phosphorus measurements less than 17 µg/L, with a mean value of 2.83 µg/L chlorophyll a. There were 150 chlorophyll a measurements associated with total phosphorus concentrations greater than 17 µg/L, with a mean value of 4.89 µg/L chlorophyll a.

7.2.2.3.2 Secchi Depth

Change-point analyses were conducted on Secchi depth paired with total phosphorus, total nitrogen, and turbidity. Results of these analyses are summarized below.

1. In Secchi measurements associated with total phosphorus (Figure 7.51), a Secchi depth change point was identified at 14 µg/L total phosphorus. There were 1,247 Secchi measurements associated with total phosphorus concentrations less than 14 µg/L, with a mean value of 2.71 meters. There were 1,155 Secchi measurements associated with total phosphorus concentrations greater than 14 µg/L, with a mean value of 1.68 meters;
2. In Secchi measurements associated with total nitrogen, a Secchi depth change point was identified at 0.46 mg/L total nitrogen (Figure 7.52). There were 767 Secchi measurements associated with total nitrogen concentrations less than 0.46 mg/L, with a mean value of 2.43 meters. There were 695 Secchi measurements associated with total nitrogen concentrations greater than 0.46 mg/L, with a mean value of 1.68 meters; and
3. In Secchi measurements associated with turbidity, a Secchi depth change point was identified at 3.7 NTU turbidity (Figure 7.53). There were 1,568 Secchi measurements associated with turbidity measurements less than 3.7 NTU, with a mean value of 2.63 meters. There were 1,013 Secchi measurements associated with turbidity measurements greater than 3.7 NTU, with a mean value of 1.60 meters.

The mean and standard deviations of the Secchi measurements above and below the total phosphorus and turbidity change points were very similar. The means of the Secchi measurements above and below the total nitrogen change point were similar to the means above and below the total phosphorus and turbidity change points, but the standard deviations were different.

7.3 Comparison Between Beaver Lake and Reference Reservoirs

7.3.1 Inputs

The average nutrient concentrations reported for inflows to the reference reservoirs and Beaver Lake during the period from 1989 through 2006 are listed in Table 7.8. Average nutrient concentrations reported for the inflows to the reference reservoirs are all less than the Ozark Highlands Ecoregion average concentrations (these streams are not located in the Ozark Highlands Ecoregion). Average nutrient concentrations reported for the White River (at Highway 45) are greater than the averages for the ecoregion. Average nutrient concentrations reported for Richland Creek are all less than the ecoregion averages. Average recent nutrient concentrations reported for War Eagle Creek are similar to or greater than the ecoregion averages.

Table 7.8. Comparison of inflow concentrations for reference reservoirs and Beaver Lake from 1989 to 2006.

	Total P (mg/L)	**PO_4 P (mg/L)**	**NO_2+NO_3 (mg/L)**	**NH_3-N (mg/L)**
Ozark Highlands Ecoregion (1984 – 1986)				
Average	0.045	0.025	0.84	<0.035
Reservoir Inflows (1989 – 2006)				
Self Creek (Greeson)	0.019	0.009	0.251	0.013
Little Missouri River (Greeson)*	0.019	0.002	0.147	0.019
Caddo River (DeGray)*	0.045	0.013	0.170	-
Iron Fork (Ouachita)	0.019	0.002	0.039	0.015
Ouachita River (Ouachita)	0.039	0.009	0.171	0.017
South Fork River (Ouachita)*	0.021	0.011	0.122	0.018
White River (Beaver)	0.081		1.03	0.052
Richland Creek (Beaver)	0.045		0.387	0.036
War Eagle Creek (Beaver)*	0.054		1.37	0.029

* These are least-disturbed reference streams from ADEQ 1987.

Table 7.9 shows a comparison of nutrient loads to Beaver Lake and the reference reservoirs. These loads are calculated from the average flows recorded by USGS gages on tributaries and the average concentrations of nutrients measured in the tributaries. The least-disturbed Beaver Lake load is calculated using the average flows recorded by USGS gages on the tributaries, and the lower of the measured concentration or the Ozark Highlands

Ecoregion least-disturbed average concentration. Nutrient loads for the reference reservoirs are less than half the Beaver Lake existing and least-disturbed loads. In part, this is because inflows to the reference lakes are lower than for Beaver Lake. Lake Ouachita has almost as much inflow as Beaver Lake, but still has a significantly lower load because the inflow concentrations are so much lower for Lake Ouachita than for Beaver Lake.

Table 7.9. Comparison of nutrient loads to Beaver Lake and the reference systems.

Waterbody	Inflow (cfs)	Total P (kg/day)	NO_x (kg/day)	NH_3 (kg/day)
Beaver Lake (existing)	964	161	2443	102
Beaver Lake (least-disturbed)	964	106	1830	78
DeGray Lake	594	65	247	
Lake Ouachita	814	74	330	34
Lake Greeson	131	6.1	47	6.1

7.3.2 Reservoir Water Quality

Water quality in Beaver Lake was compared to water quality in DeGray Lake by comparing the longitudinal box and whisker plots for these two reservoirs (plots of Beaver Lake data are shown in Figures 7.3 through 7.8; DeGray Lake plots are shown in Figures 7.42 through 7.44). Secchi transparencies measured at the dam in Beaver Lake tended to be greater than those measured at the dam in DeGray Lake. This is likely a result of the fact that Beaver Lake is longer than DeGray Lake, so more material has settled out of the water column by the time water reaches Beaver Dam. Chlorophyll a concentrations at all Beaver Lake sites were similar to those reported for DeGray Lake. Total phosphorus concentrations at all Beaver Lake sites except the dam (Site 1) were greater than (statistically significant) total phosphorus concentrations reported in DeGray Lake. Total nitrogen concentrations at all Beaver Lake sites were greater than (statistically significant) total nitrogen concentrations reported for similar locations in DeGray Lake. Turbidity values at the mid and upper DeGray Lake stations were greater than (statistically significant) Beaver Lake turbidity values for similar locations. However, Beaver Lake inflow (White River) turbidity was greater than (statistically significant) for DeGray Lake (Caddo River). Overall, it does appear that Beaver Lake is more nutrient-rich than DeGray Lake. However, Secchi transparency and chlorophyll a concentrations in Beaver Lake do not appear to be significantly different.

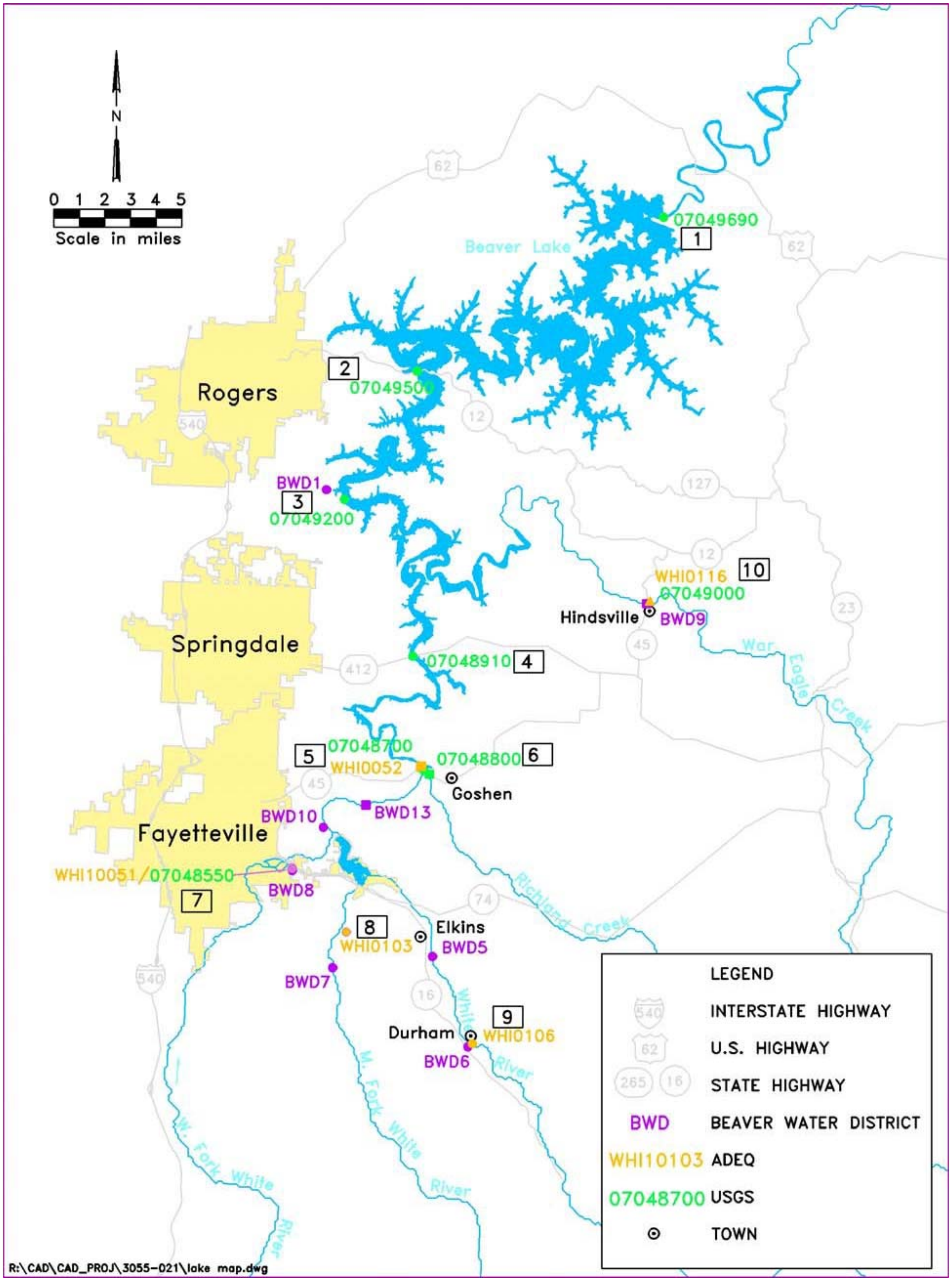


Figure 7.1. Map of Beaver Lake water quality stations for analyses.

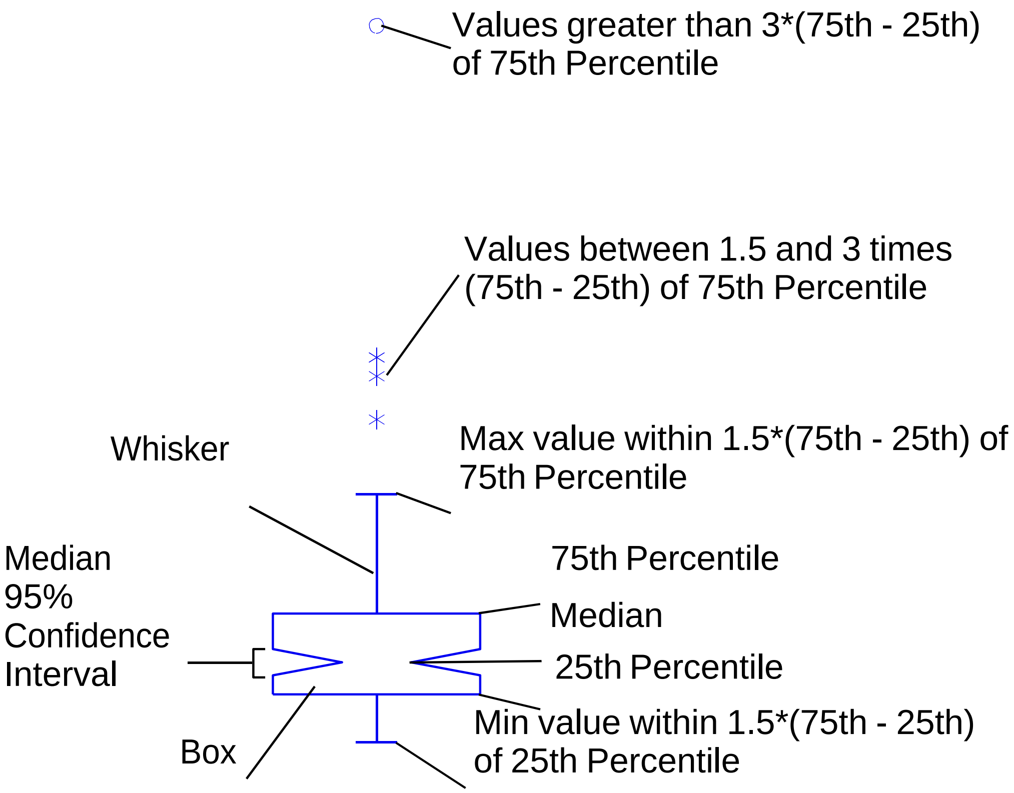


Figure 7.2. Explanation of box and whisker plot.

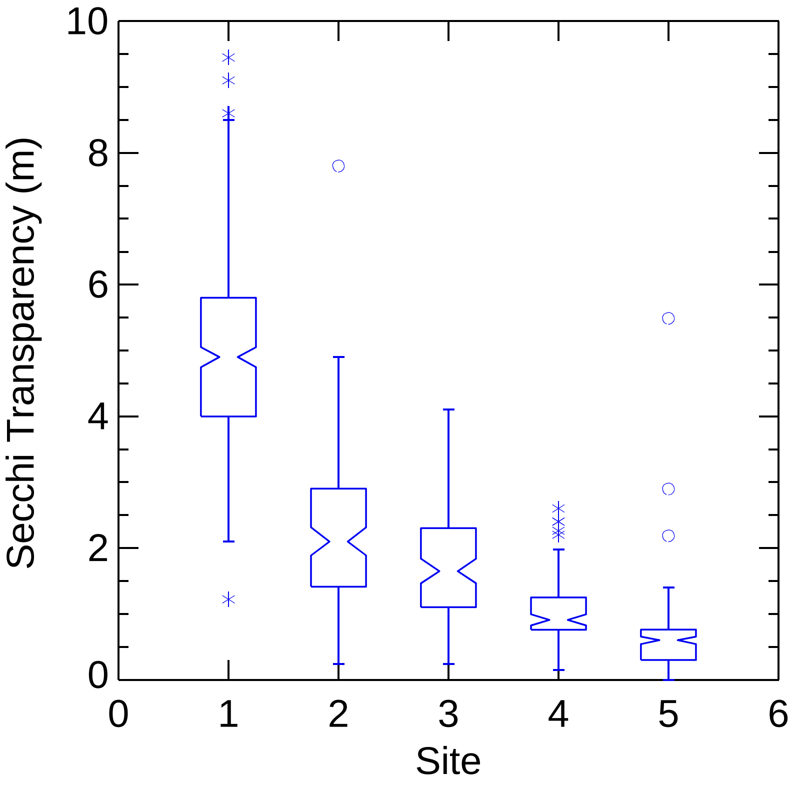


Figure 7.3. Box and whisker plot of Secchi transparency at selected Beaver Lake locations.

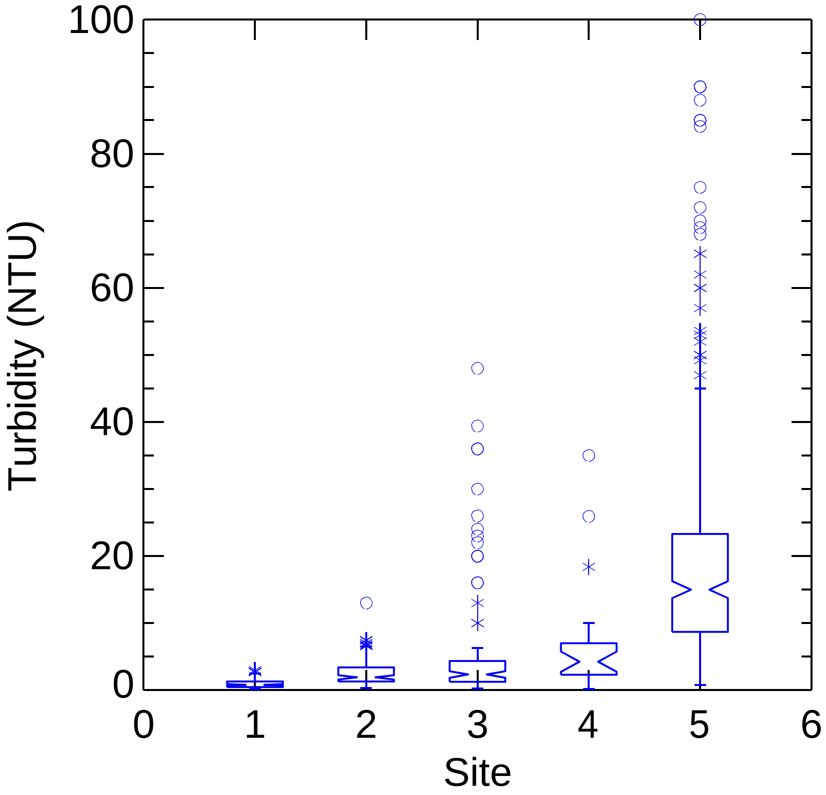


Figure 7.4. Box and whisker plot of turbidity at selected Beaver Lake locations.

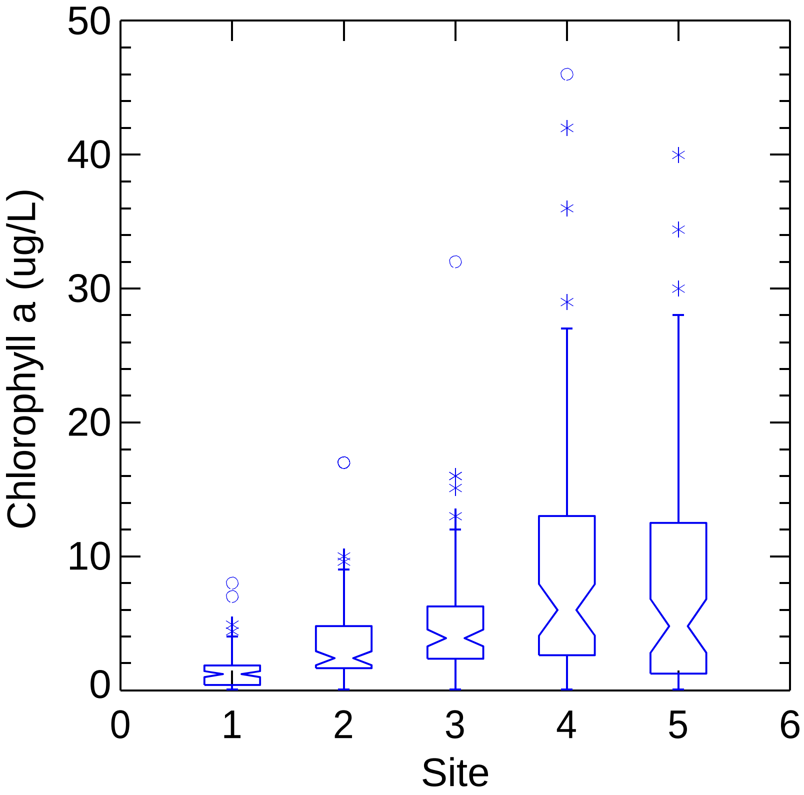


Figure 7.5. Box and whisker plot of chlorophyll a at selected Beaver Lake locations.

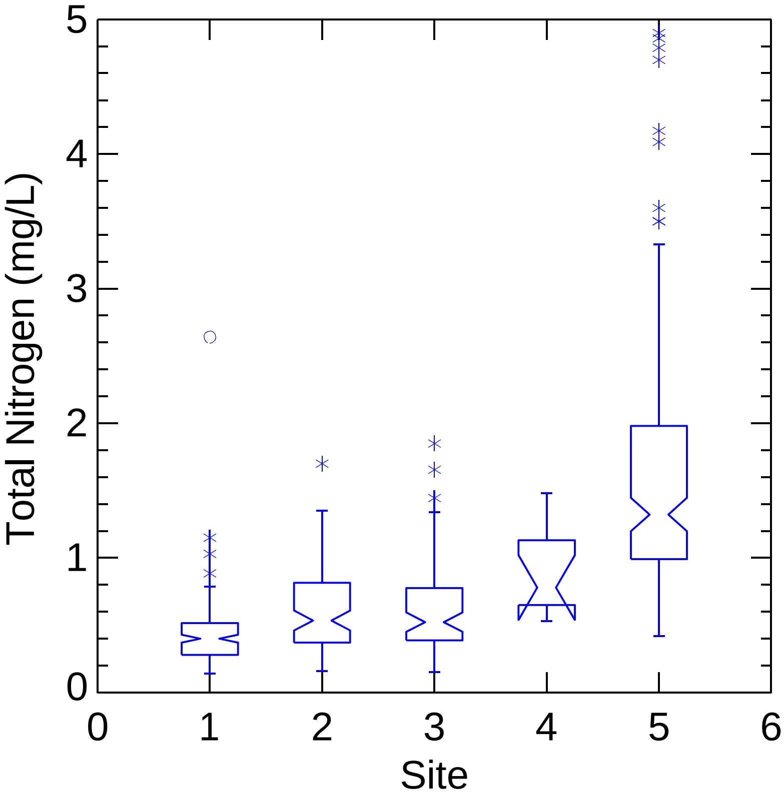


Figure 7.6. Box and whisker plot of total nitrogen at selected Beaver Lake locations.

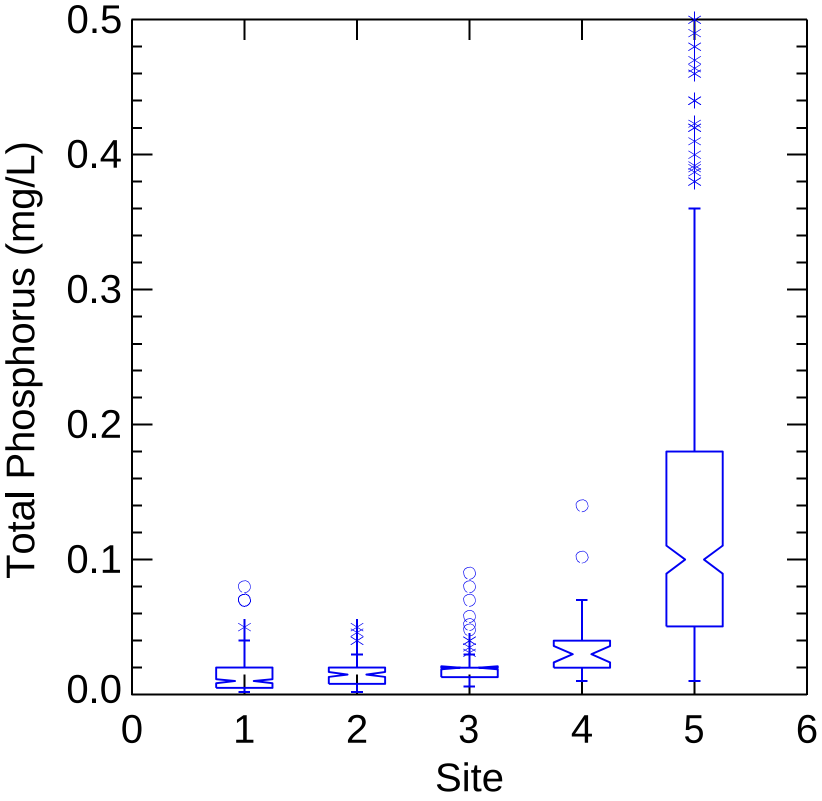


Figure 7.7. Box and whisker plot of total phosphorus at selected Beaver Lake locations.

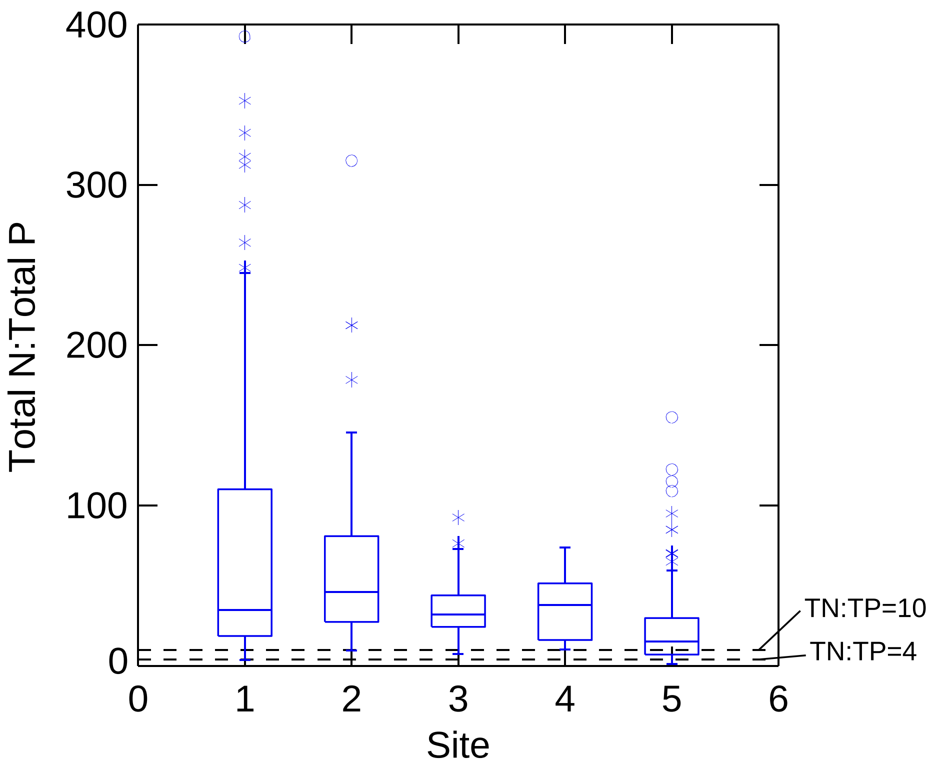


Figure 7.8. Box and whisker plot of ratios of total nitrogen to total phosphorus at selected Beaver Lake locations.

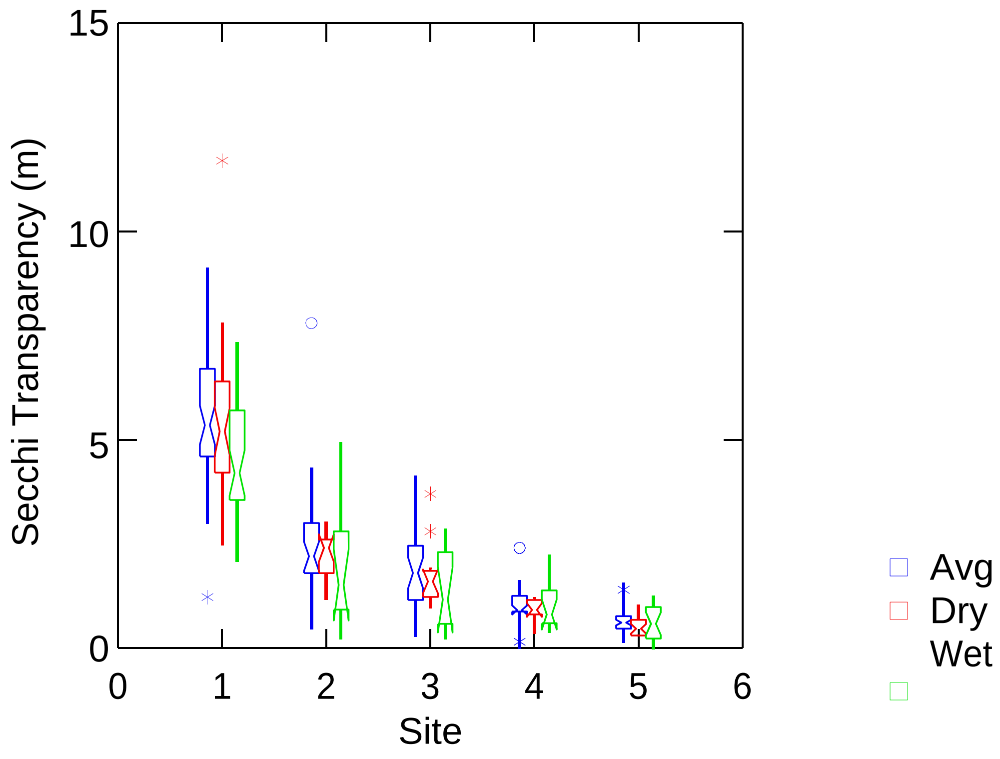


Figure 7.9. Secchi transparency during wet, average, and dry years at selected Beaver Lake

sites.

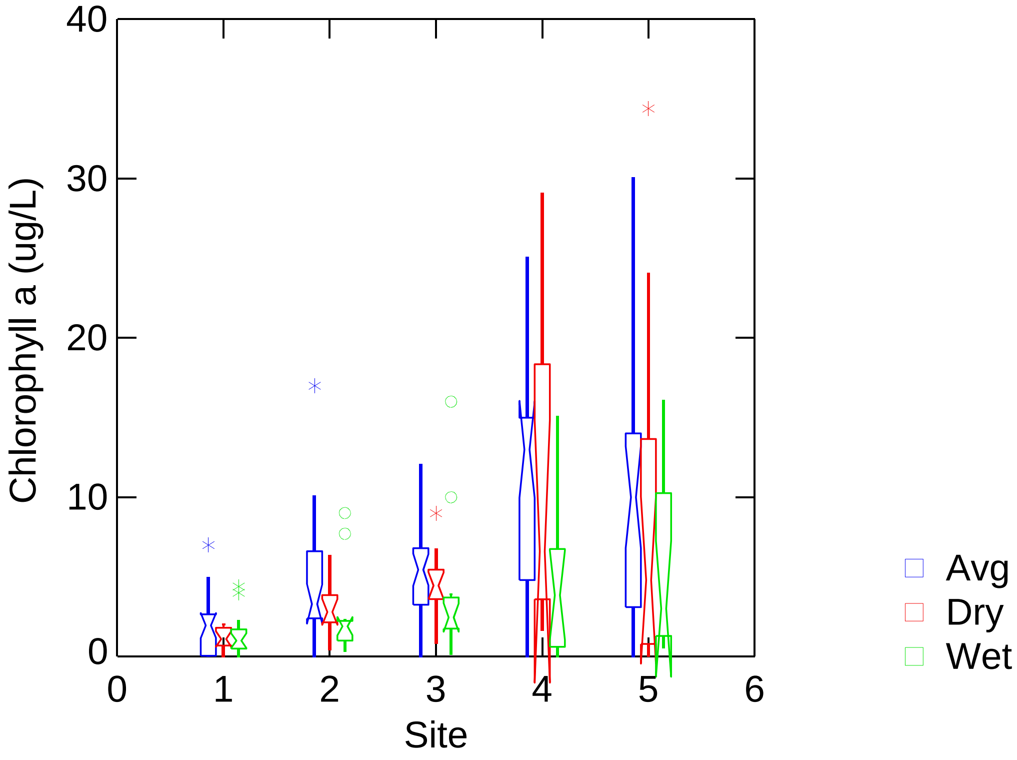


Figure 7.10. Chlorophyll a concentrations during wet, average, and dry years at selected Beaver Lake sites.

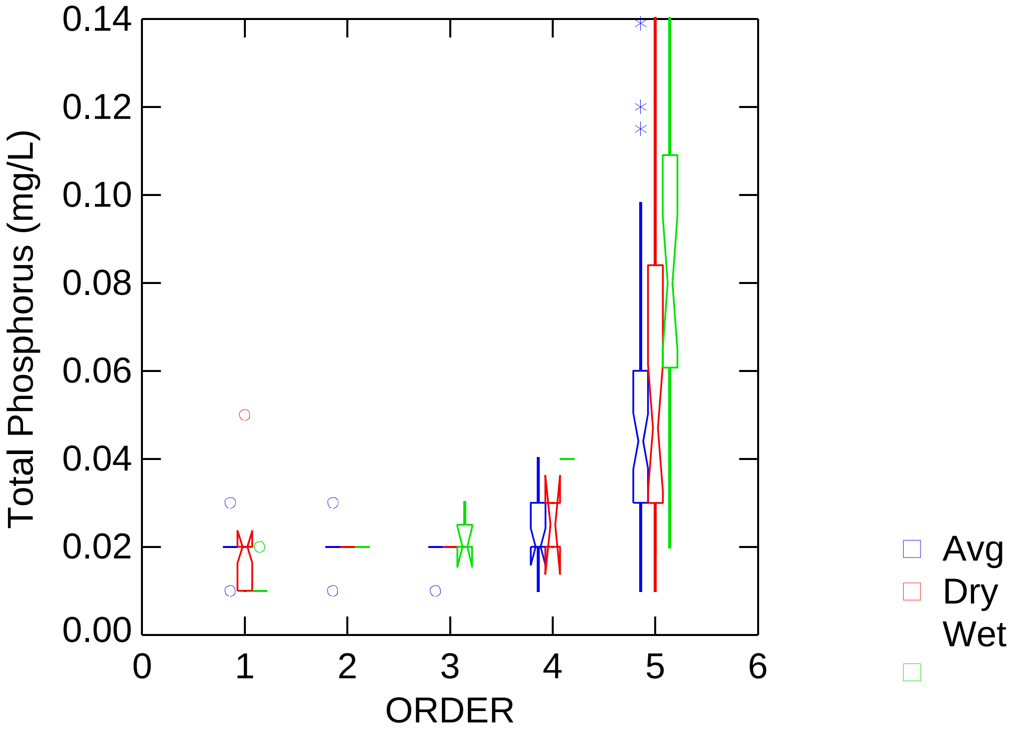


Figure 7.11. Total phosphorus concentrations during wet, average, and dry years at selected

Beaver Lake sites.

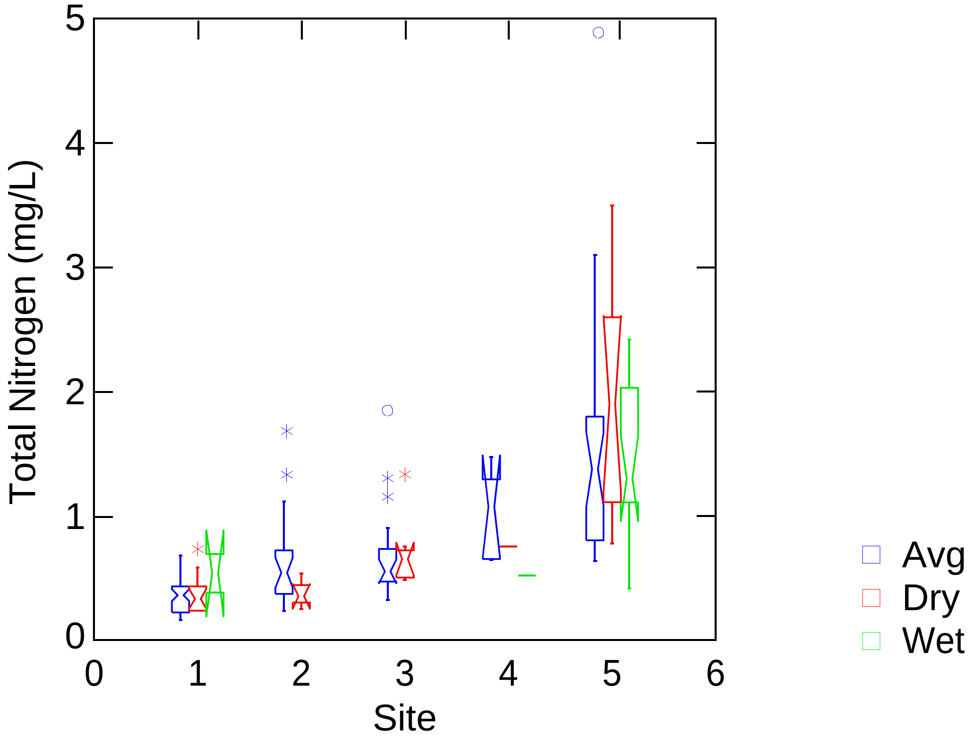


Figure 7.12. Total nitrogen concentrations during wet, average, and dry years at selected Beaver Lake sites.

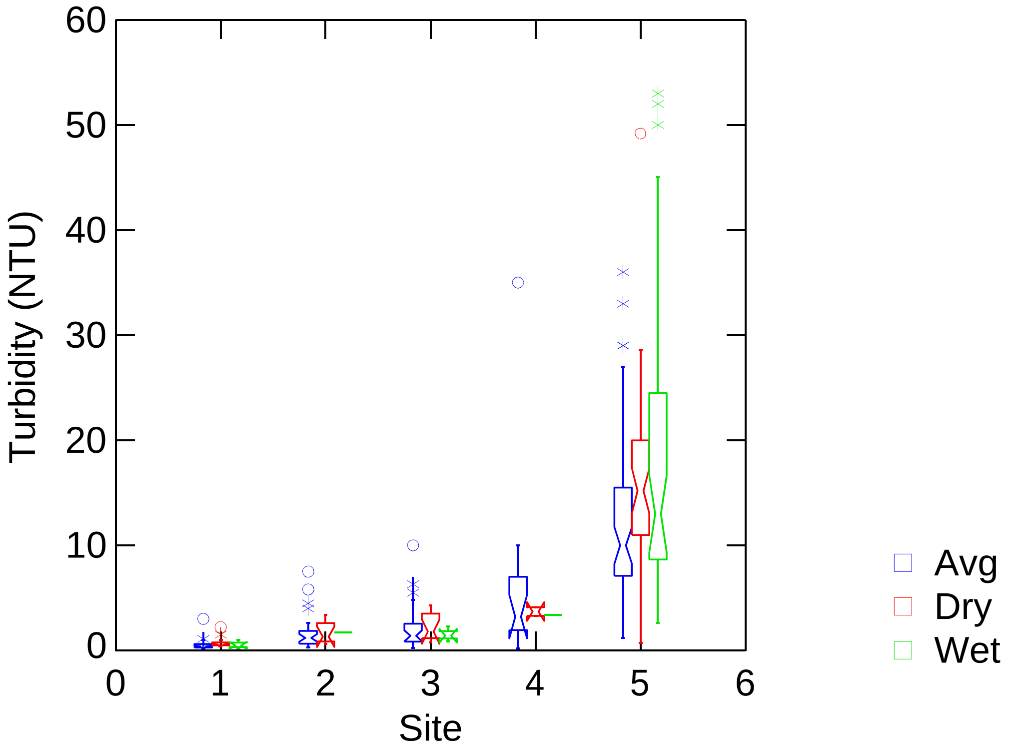


Figure 7.13. Turbidity during wet, average, and dry years at selected Beaver Lake sites.

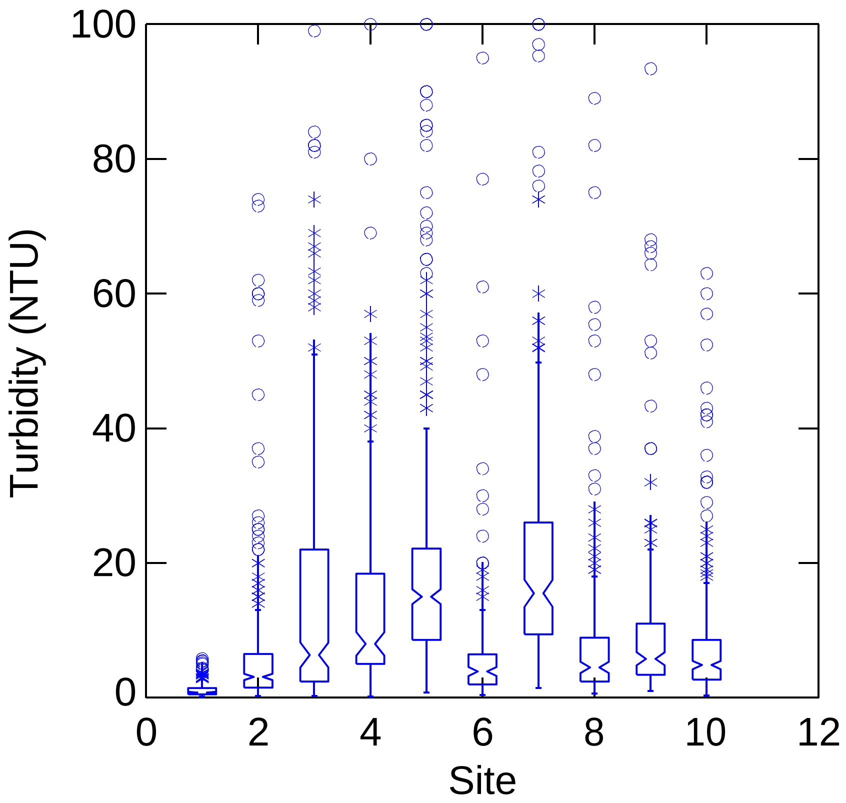
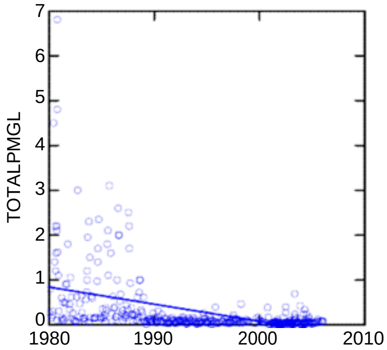


Figure 7.14. Turbidity levels at selected Beaver Lake and tributary sites.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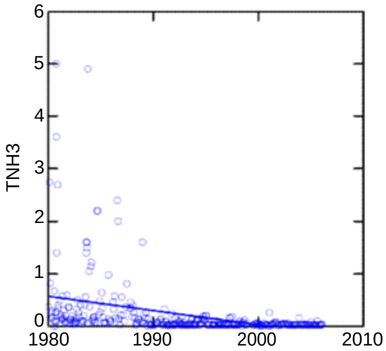
1990
2000
2010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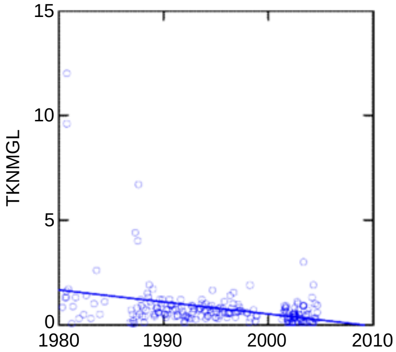
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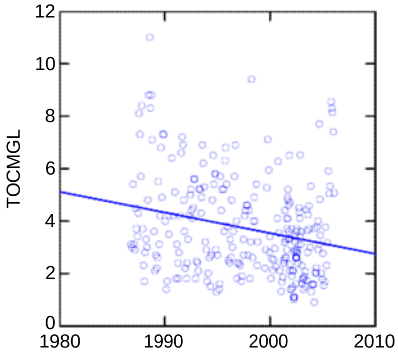
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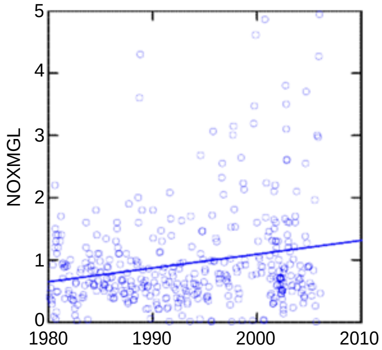
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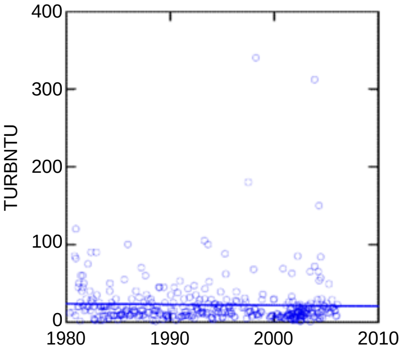
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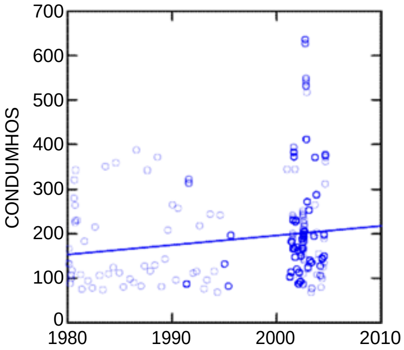
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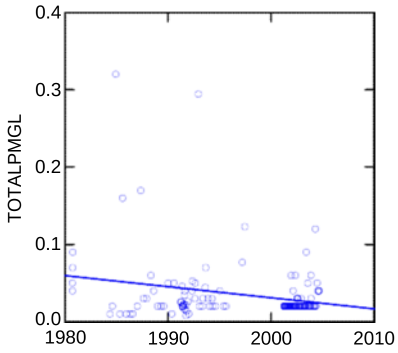
Figure 7.15. Water quality data for White River at Highway 45.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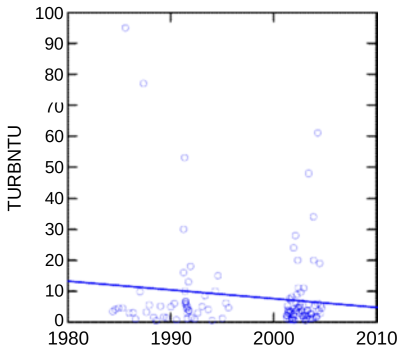
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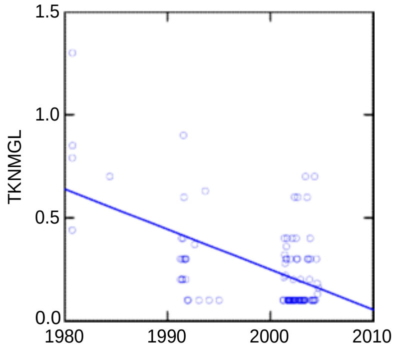
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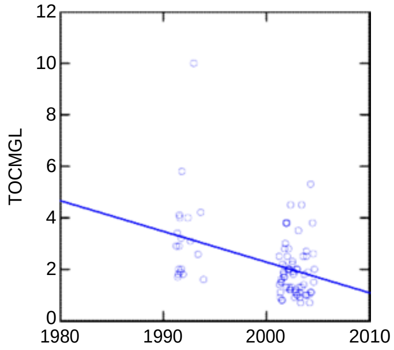
1.0
0.5
0.0
1980
1990
2000
2010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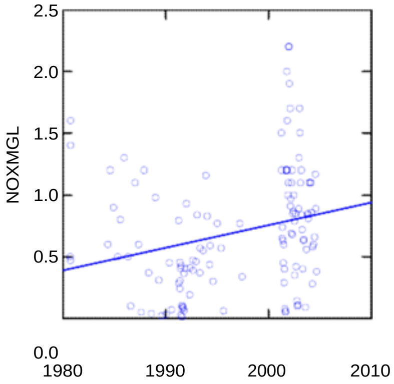
10
8
6
4
2
0
1980
1990
2000
2010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1980
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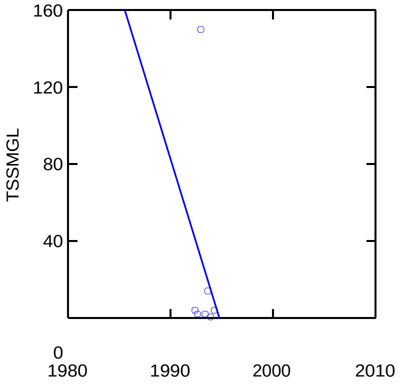
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40
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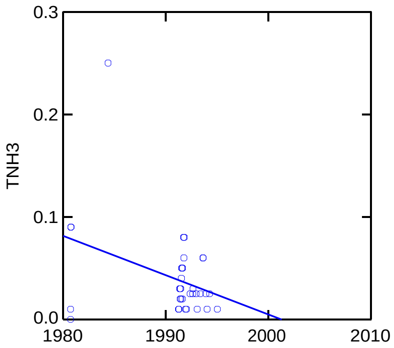
1990
2000
2010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1990
2000
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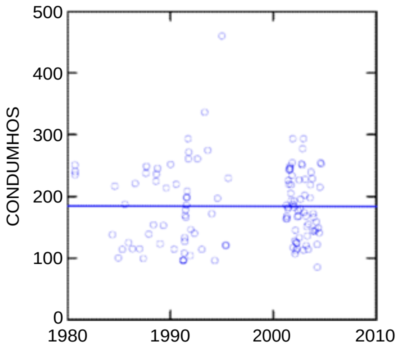
CONDUMHOS
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400
300
200
100
0
1980
1990
2000
2010

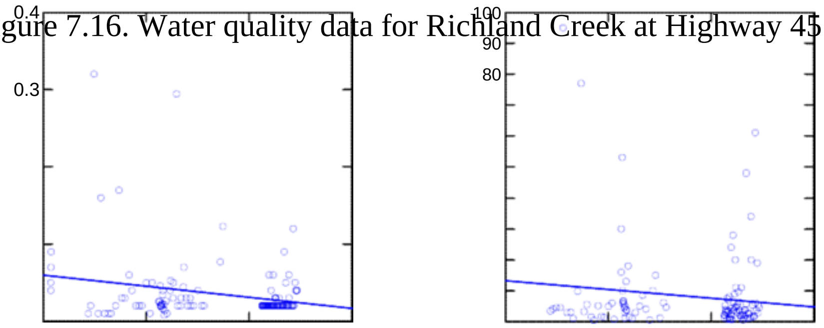
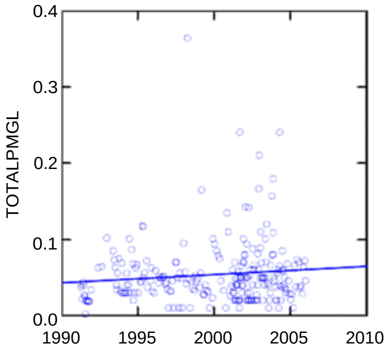


Figure 7.16. Water quality data for Richland Creek at Highway 45.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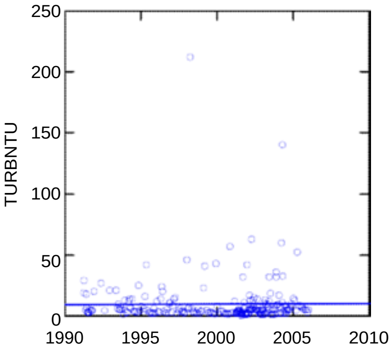
1995
2000
2005
2010


TURBNTU
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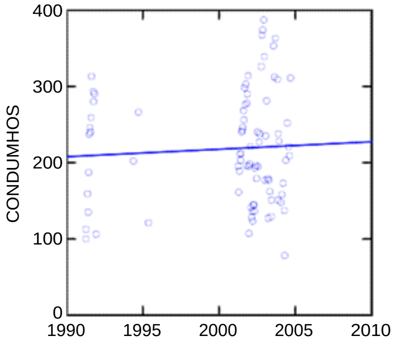
150
100
50
0
1990
1995
2000
2005
2010


CONDUMHOS
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300
200
100
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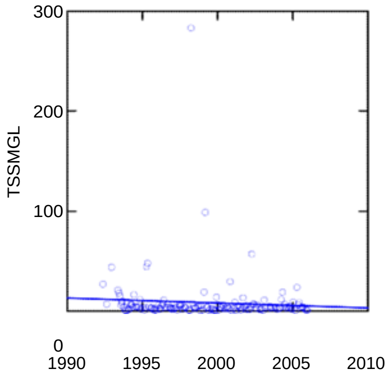
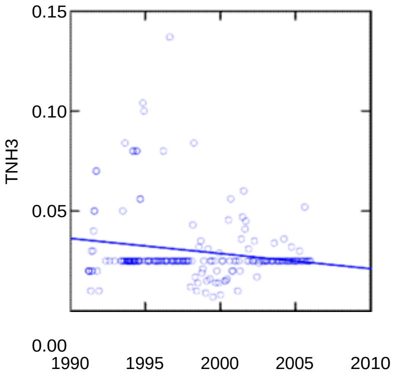
1990
1995
2000
2005
2010


TSSMGL
300
200
100
0
1990
1995
2000
2005
2010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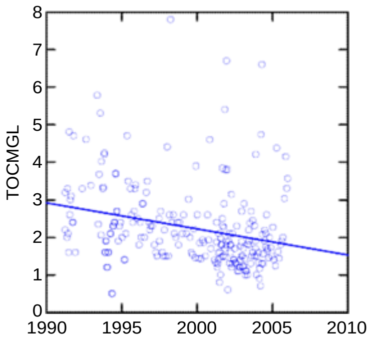
1995
2000
2005
2010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5
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2
1
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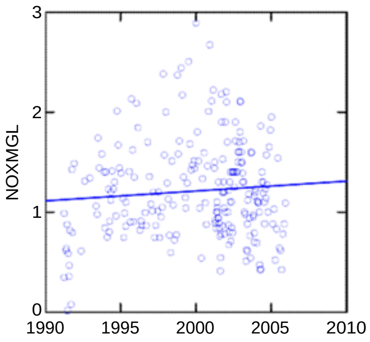
1990
1995
2000
2005
2010


NOXMGL
3
2
1
0
1990
1995
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2005
2010

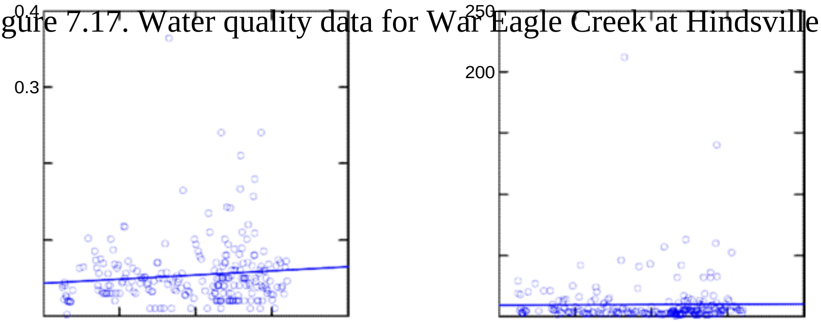


Figure 7.17. Water quality data for War Eagle Creek at Hindsville.

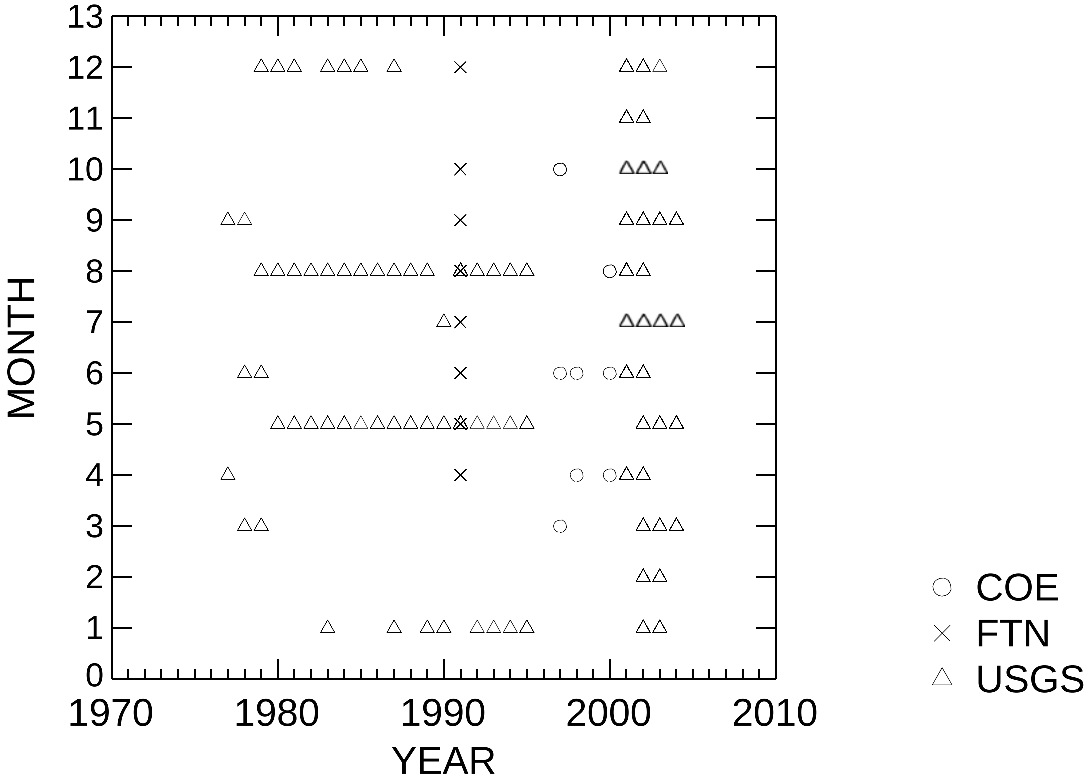


Figure 7.18. Months when dissolved oxygen data were collected by USGS, COE, and FTN.

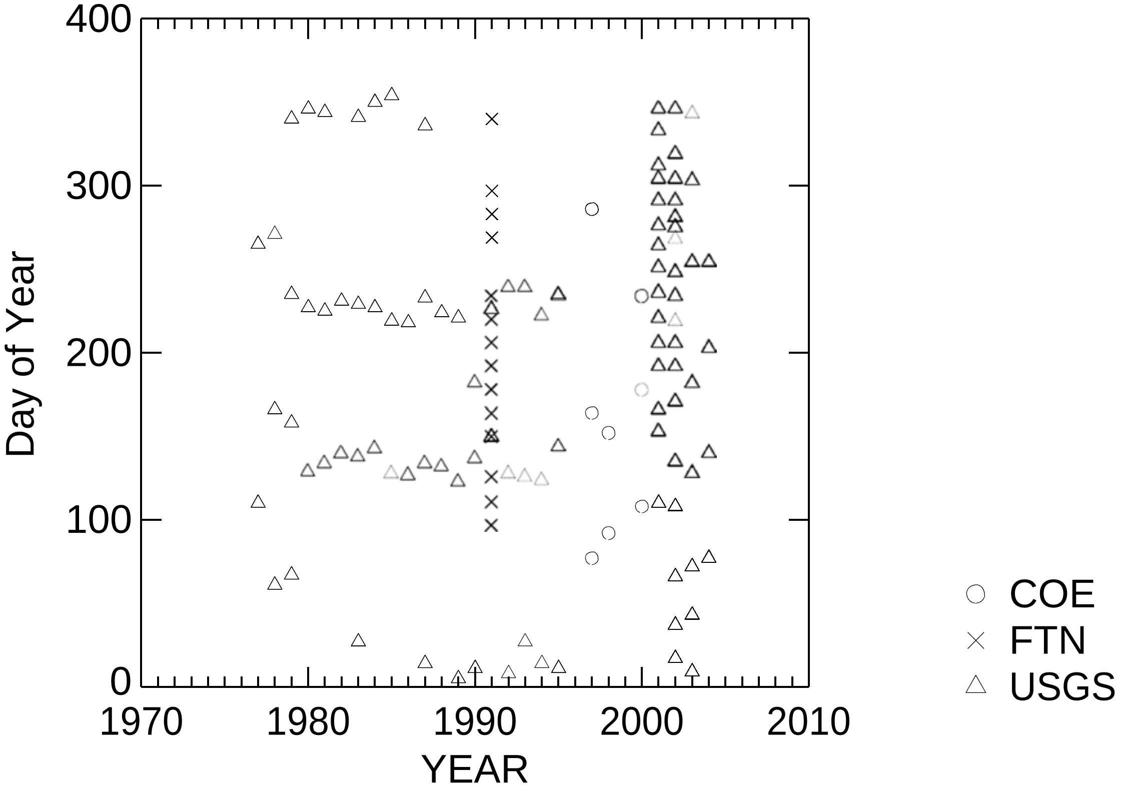


Figure 7.19. Days of year when dissolved oxygen data were collected by USGS, COE, and FTN.

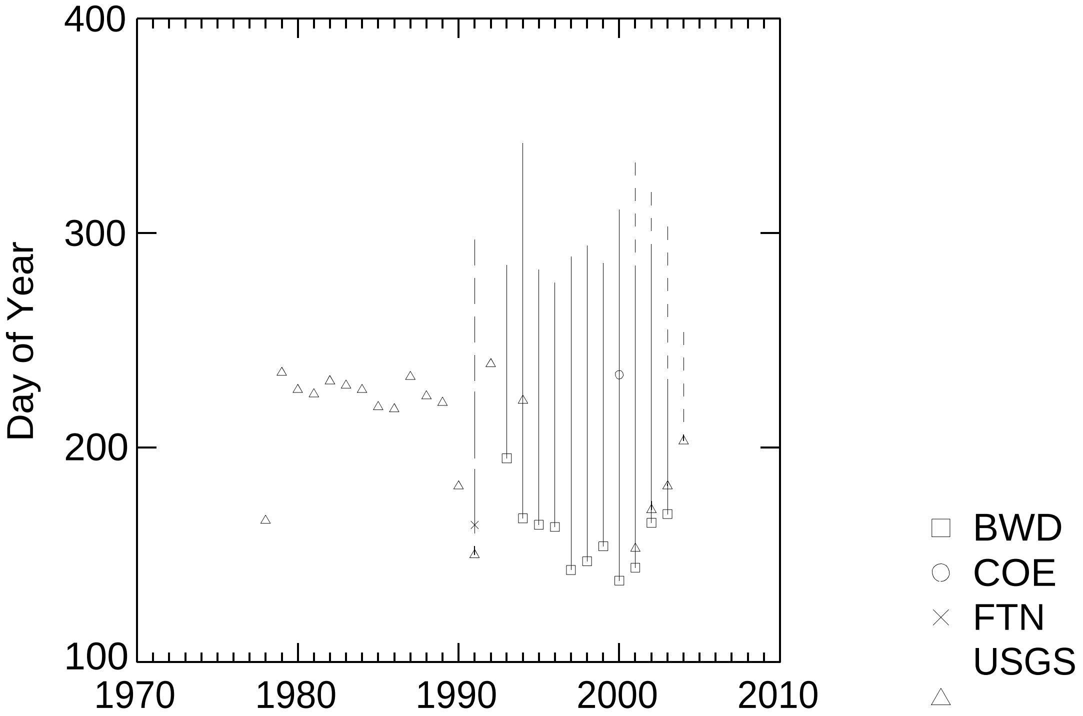


Figure 7.20. Days of year when dissolved oxygen values reported by various entities were less than 2 mg/L at Lowell.

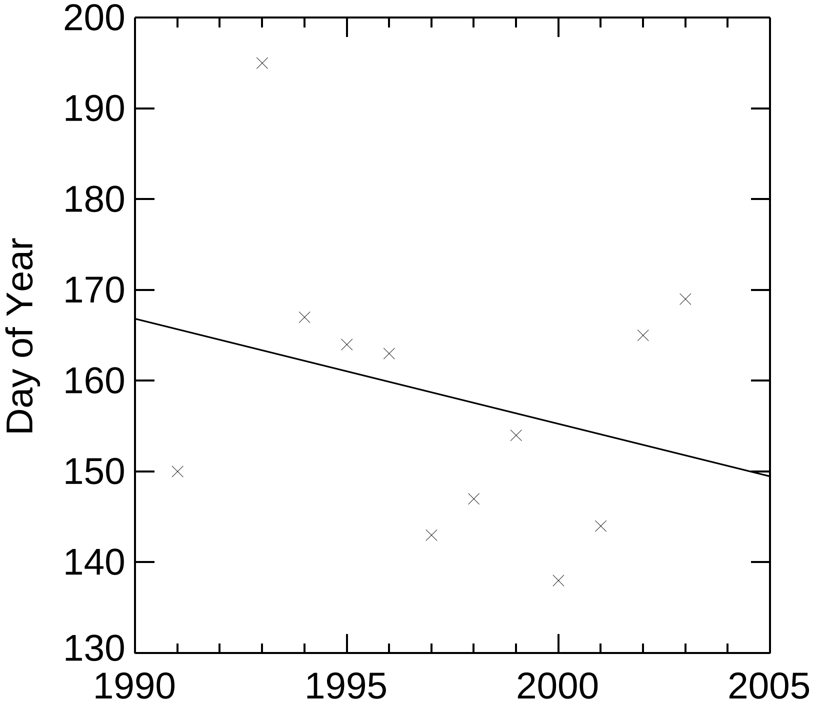


Figure 7.21. Decreasing trend evident in date of onset of hypoxia.

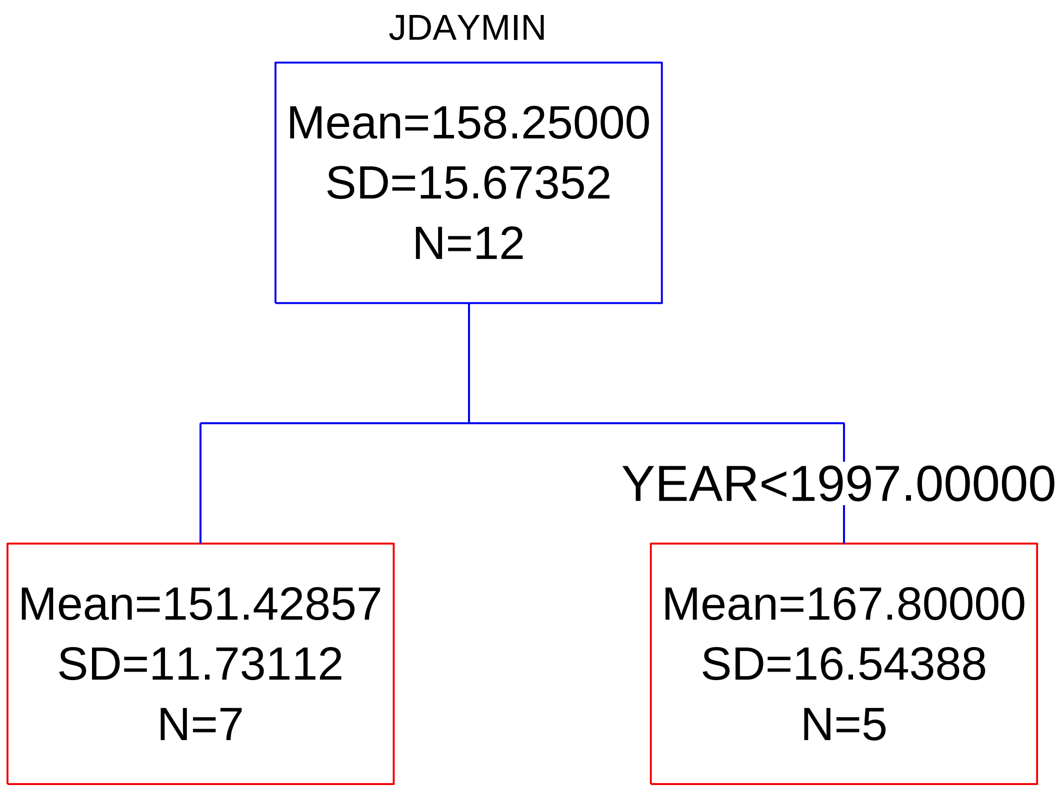


Figure 7.22. Tree analysis indicating change in date of onset of hypoxia after 1997.

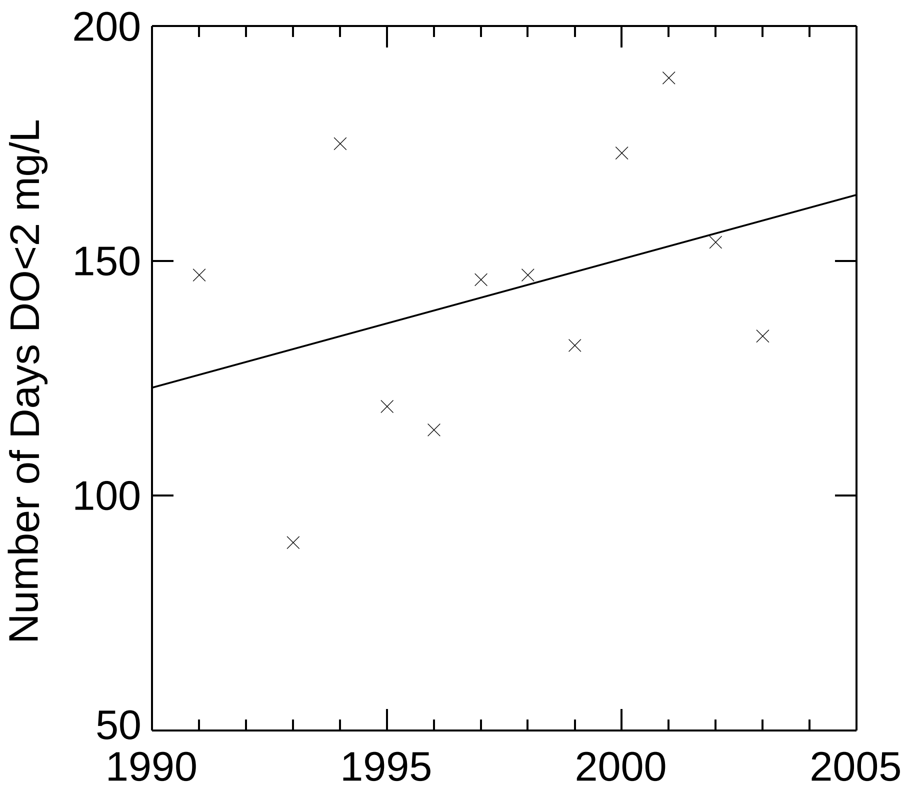


Figure 7.23. Possible increasing trend evident in number of days of hypoxia per year.

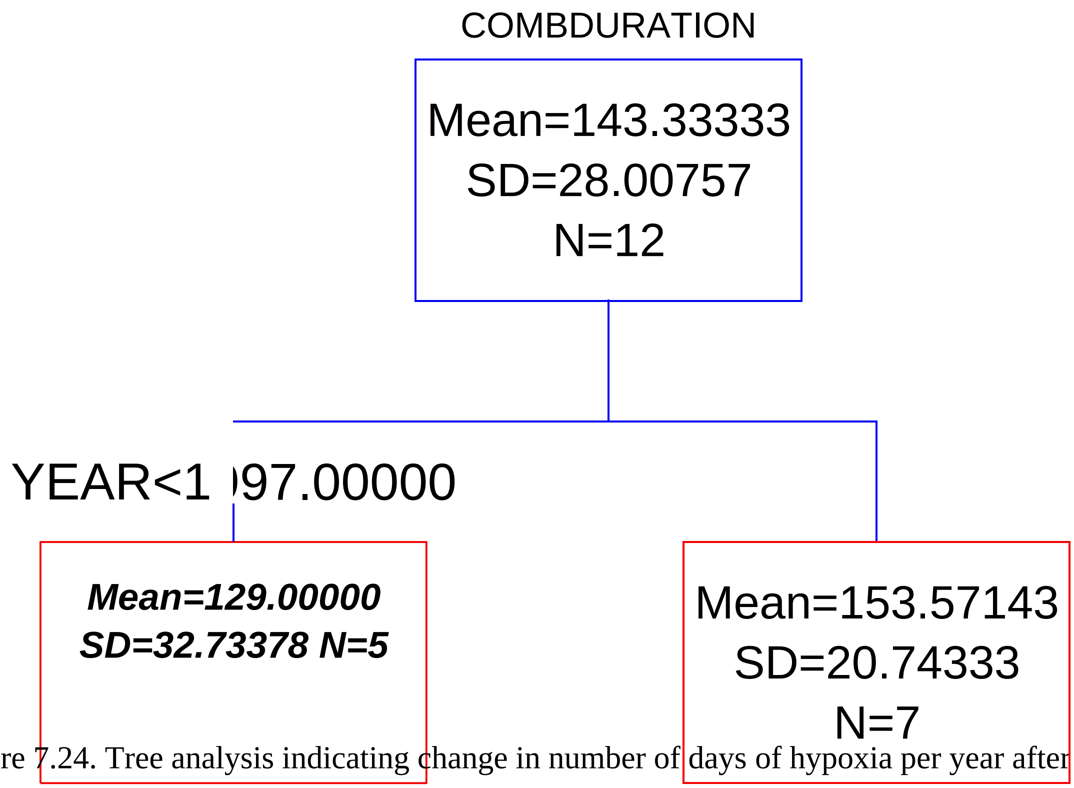


Figure 7.24. Tree analysis indicating change in number of days of hypoxia per year after 1997.

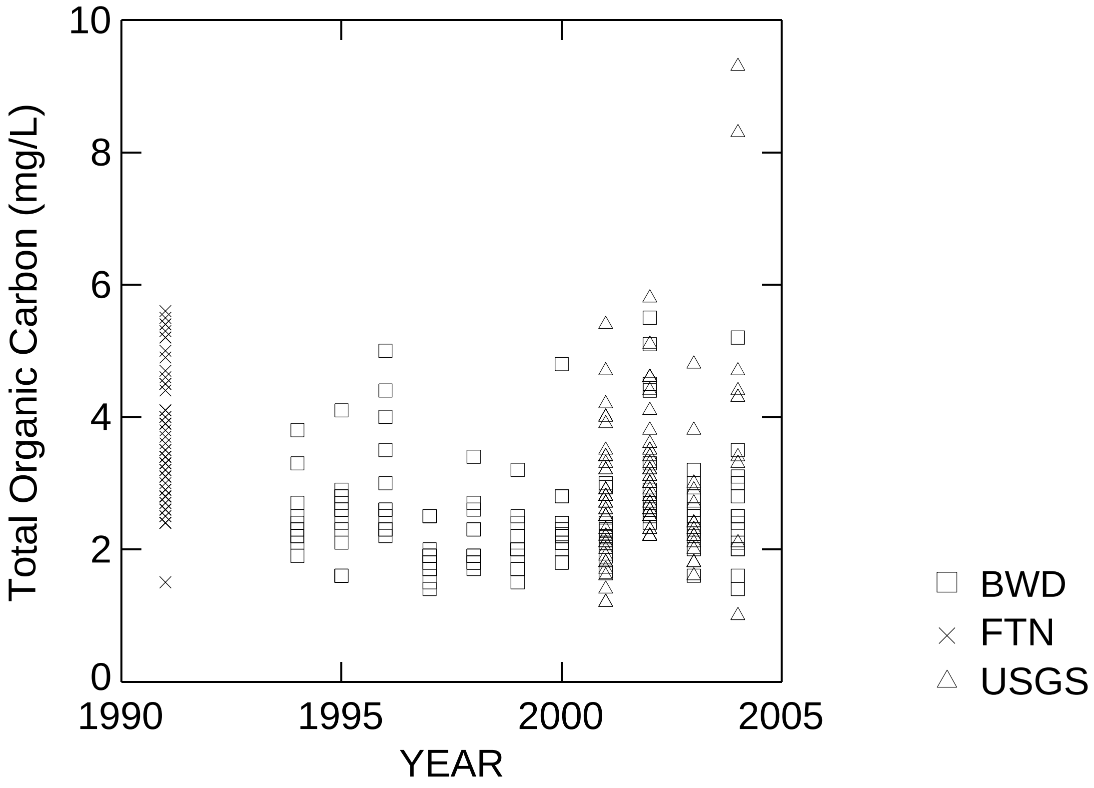


Figure 7.25. Total organic carbon values near Lowell reported by various entities.

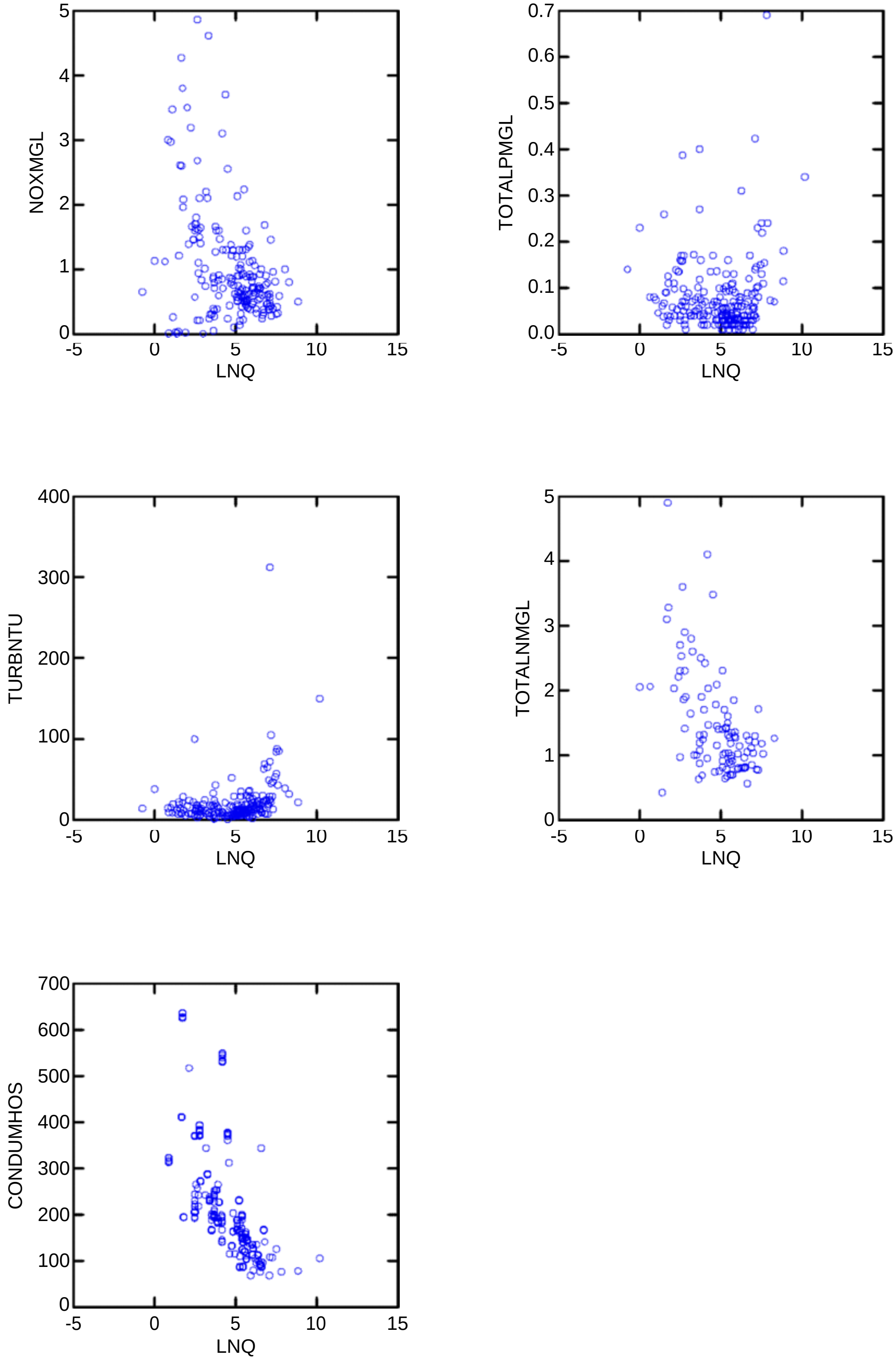


Figure 7.26. Water quality parameters plotted against flow for White River.

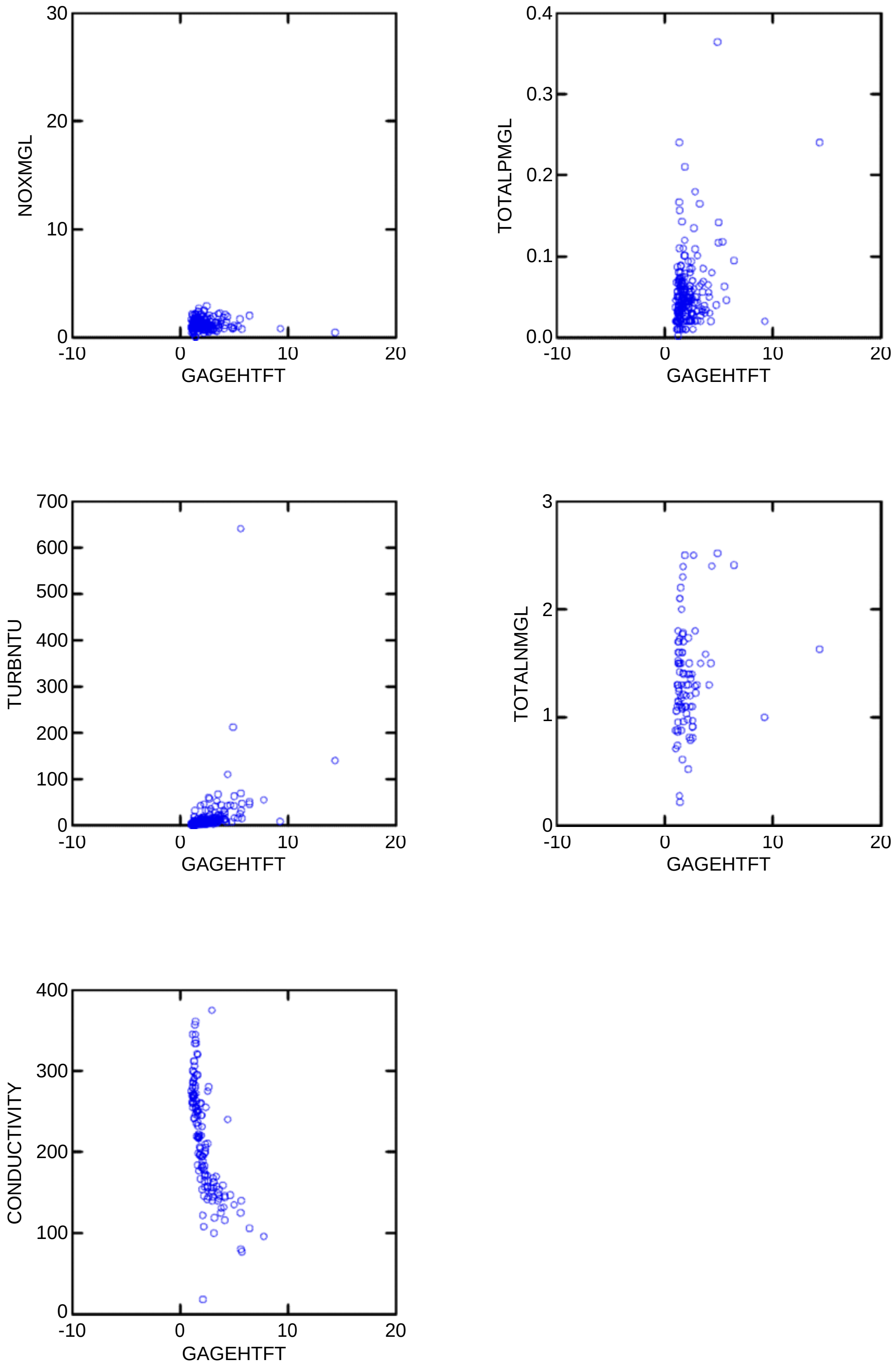


Figure 7.27. Water quality parameters plotted against gage height for War Eagle Creek.

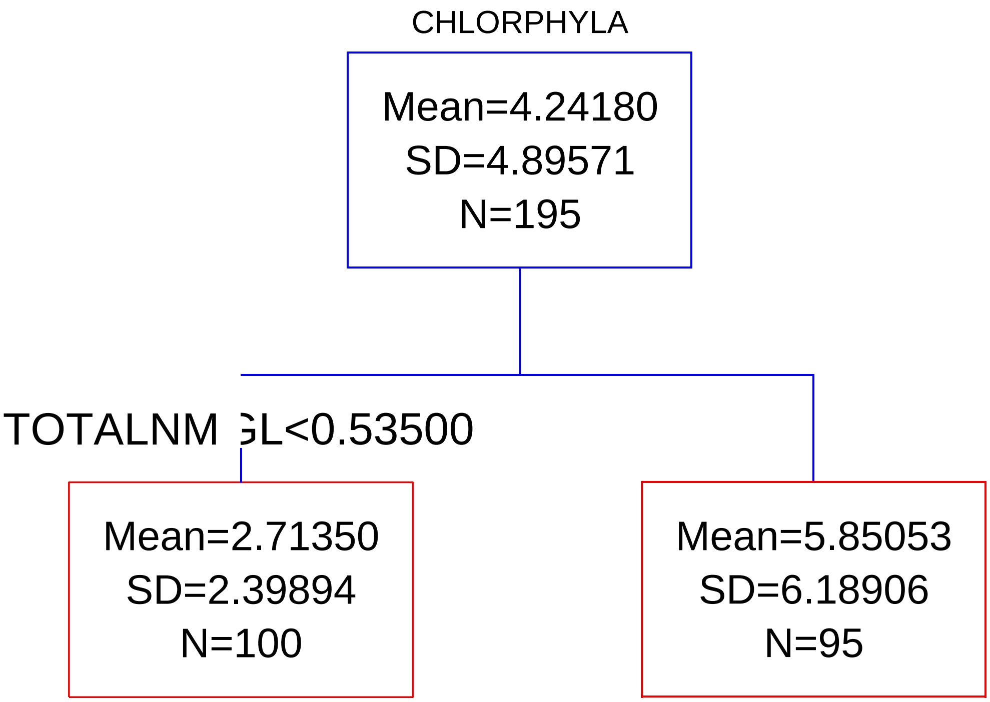


Figure 7.28. Tree model output for Beaver Lake chlorophyll a with total nitrogen showing change-point.

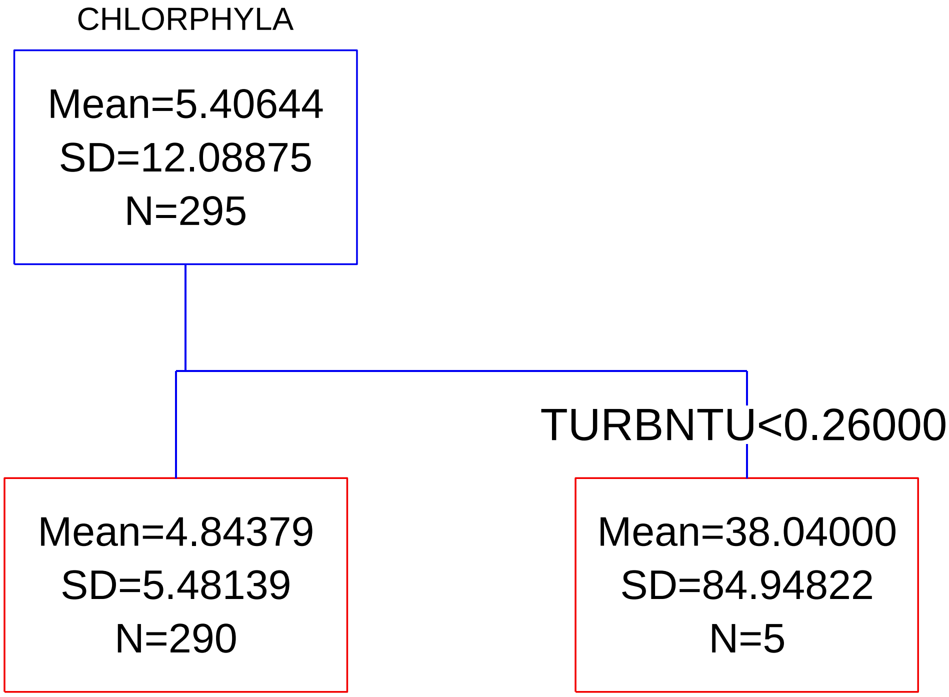


Figure 7.29. Tree model output for Beaver Lake chlorophyll a with turbidity showing change-point.

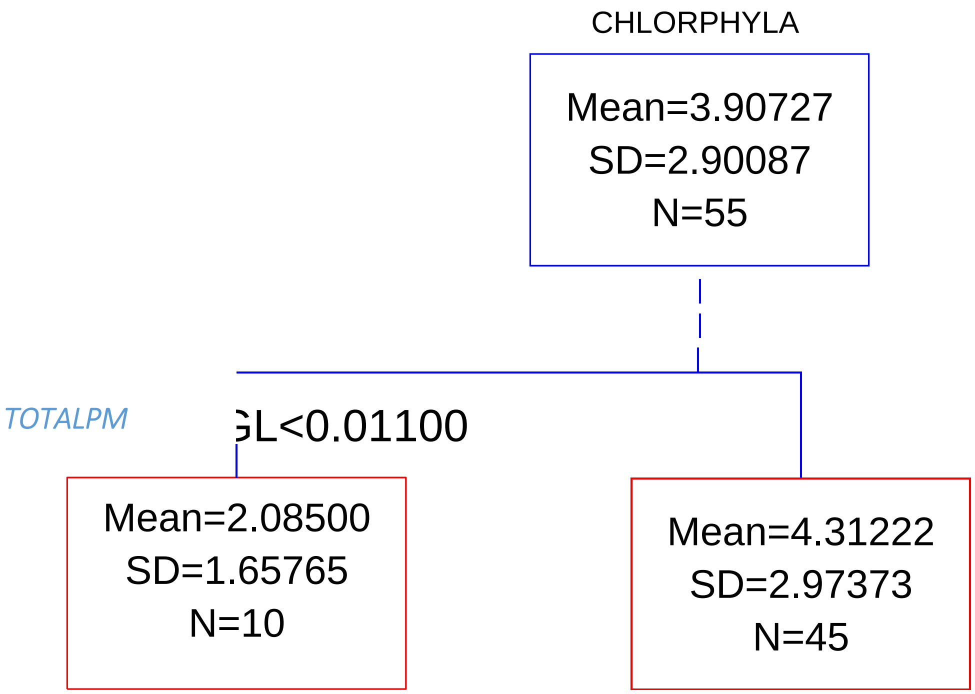


Figure 7.30. Tree model output for chlorophyll a with total phosphorus for Beaver Lake at Highway 12.

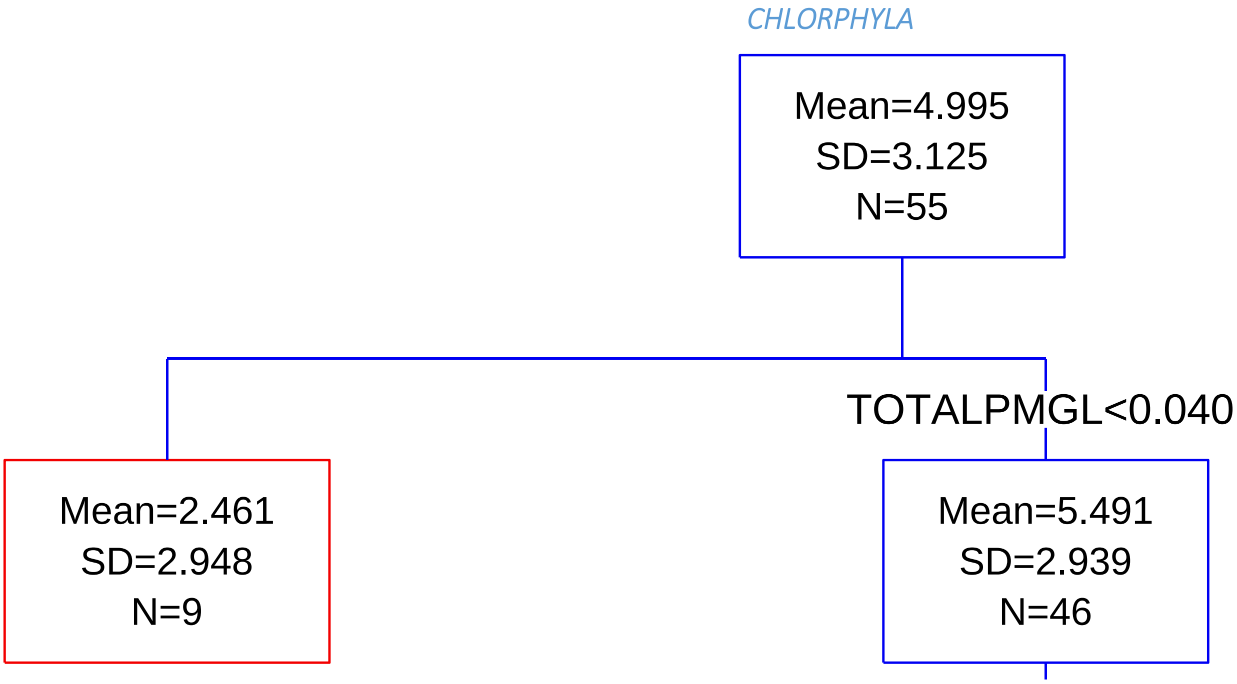


Figure 7.31. Tree model output for chlorophyll a with total phosphorus for Beaver Lake near Lowell.

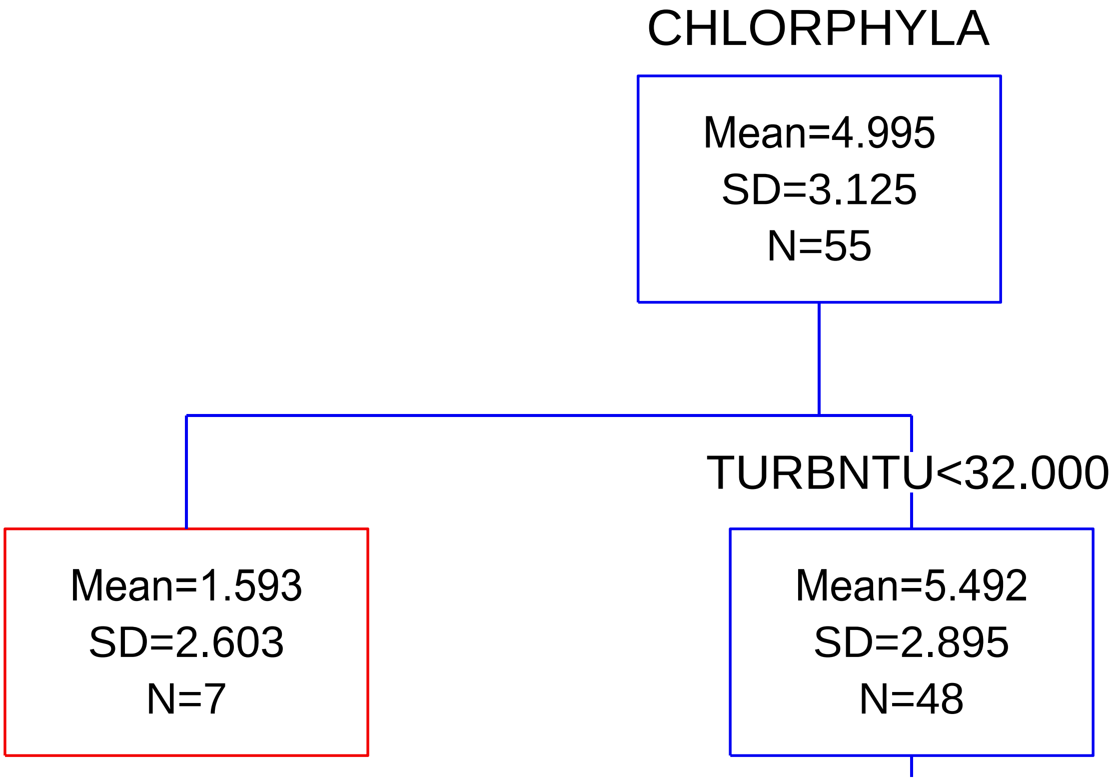


Figure 7.32. Tree model output for chlorophyll a with turbidity for Beaver Lake near Lowell.

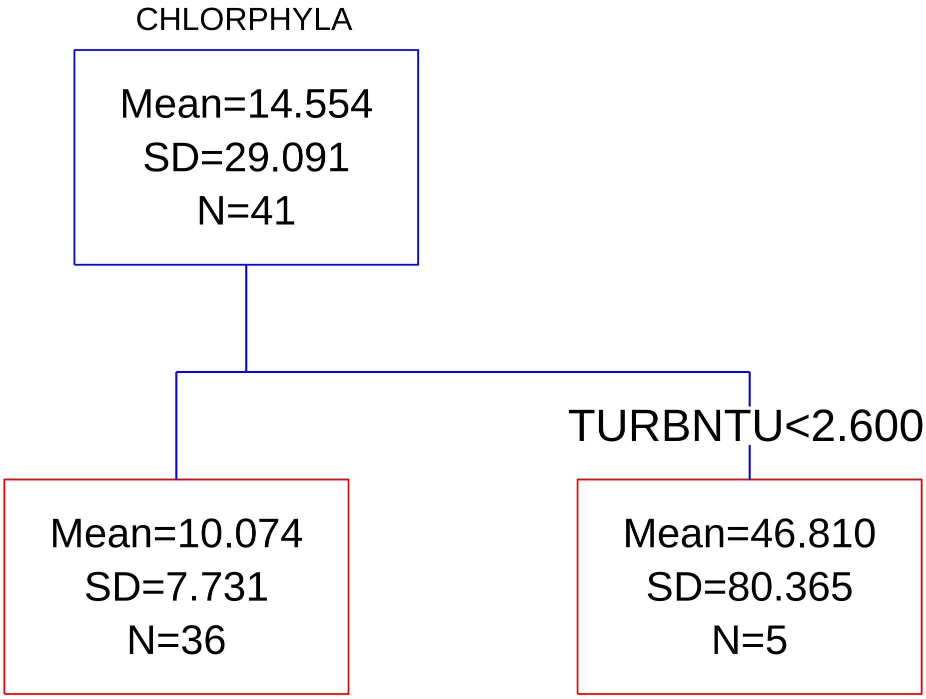


Figure 7.33. Tree model output for chlorophyll a with turbidity for Beaver Lake at Highway 412.

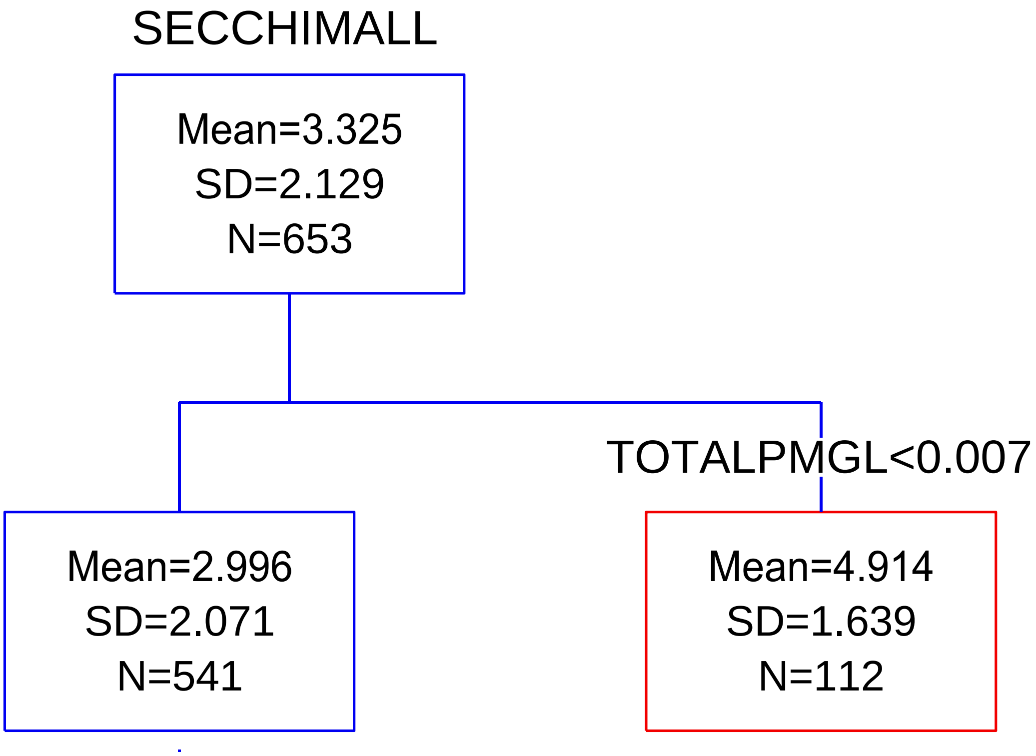


Figure 7.34. Tree model output for Beaver Lake Secchi transparency with all total phosphorus data.

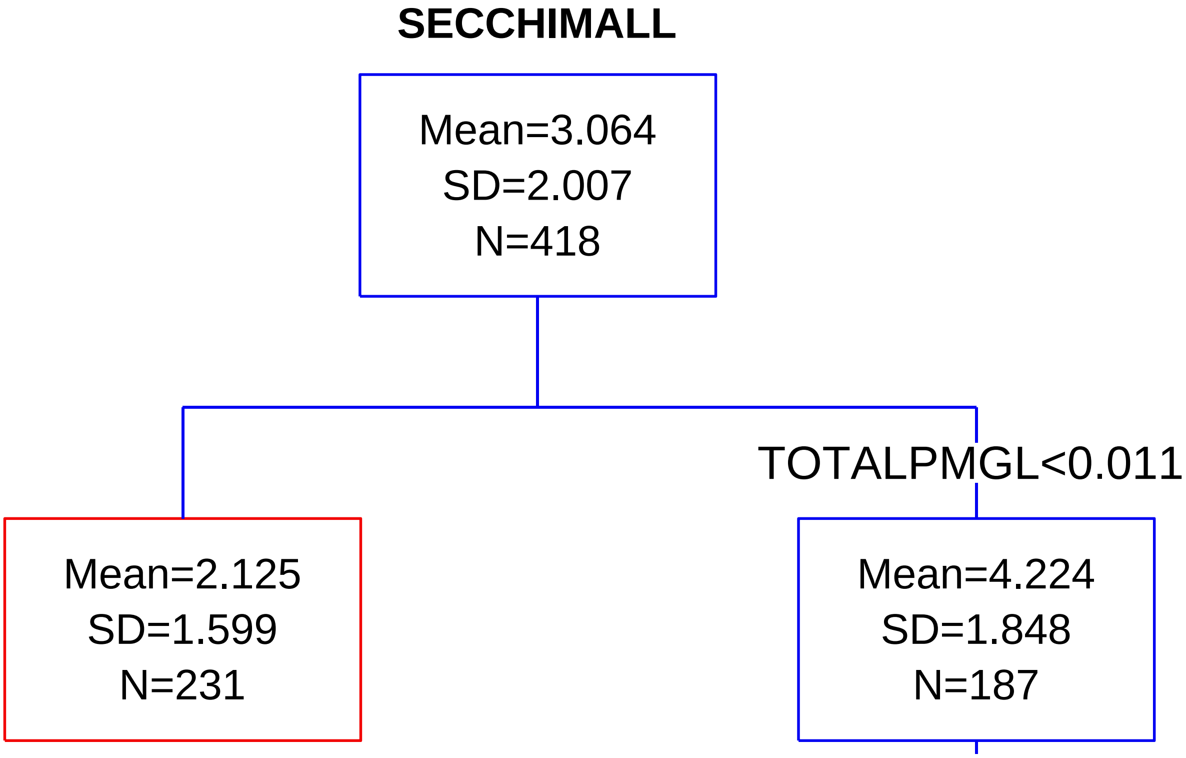


Figure 7.35. Tree model output for Beaver Lake Secchi transparency with reported total phosphorus values greater than detection.

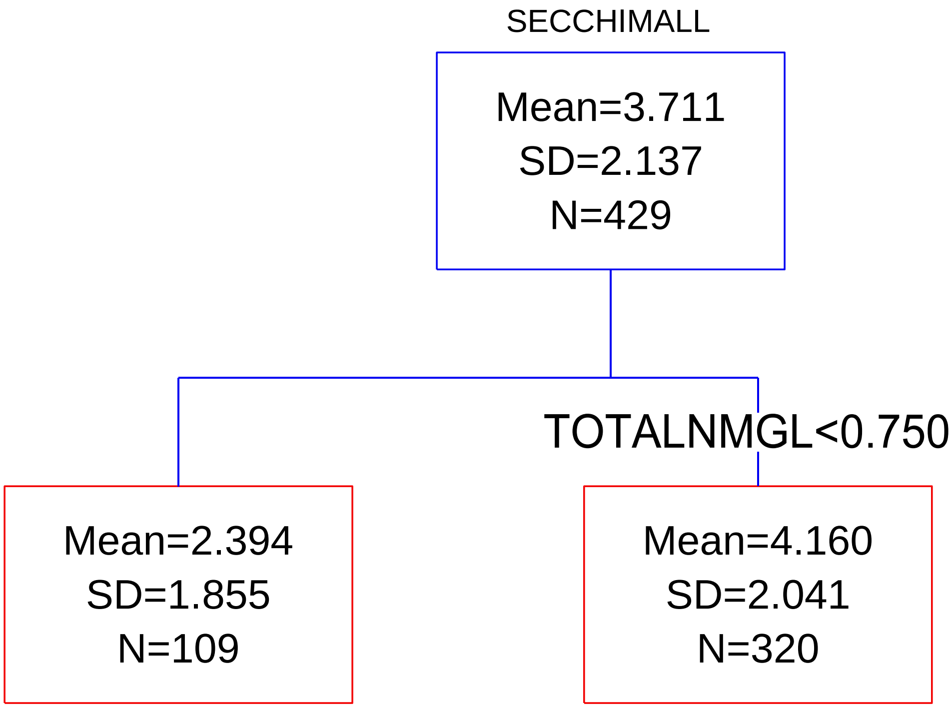


Figure 7.36. Tree model output for Beaver Lake Secchi transparency with total nitrogen data.

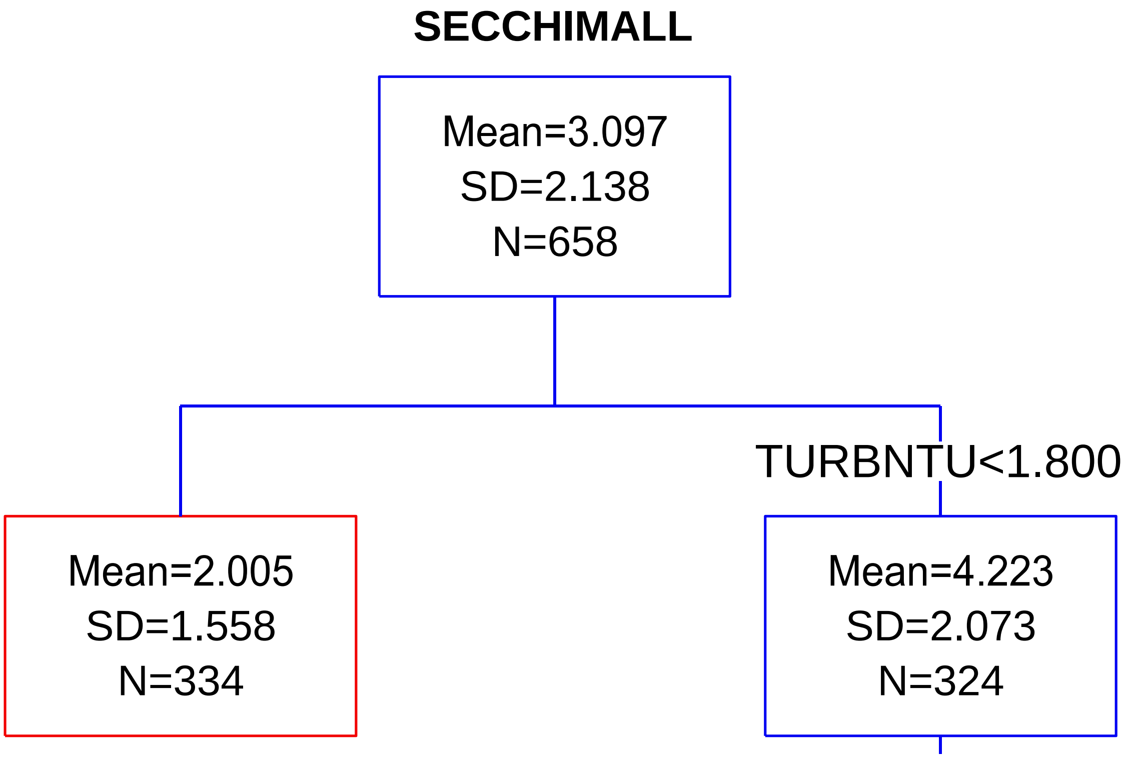
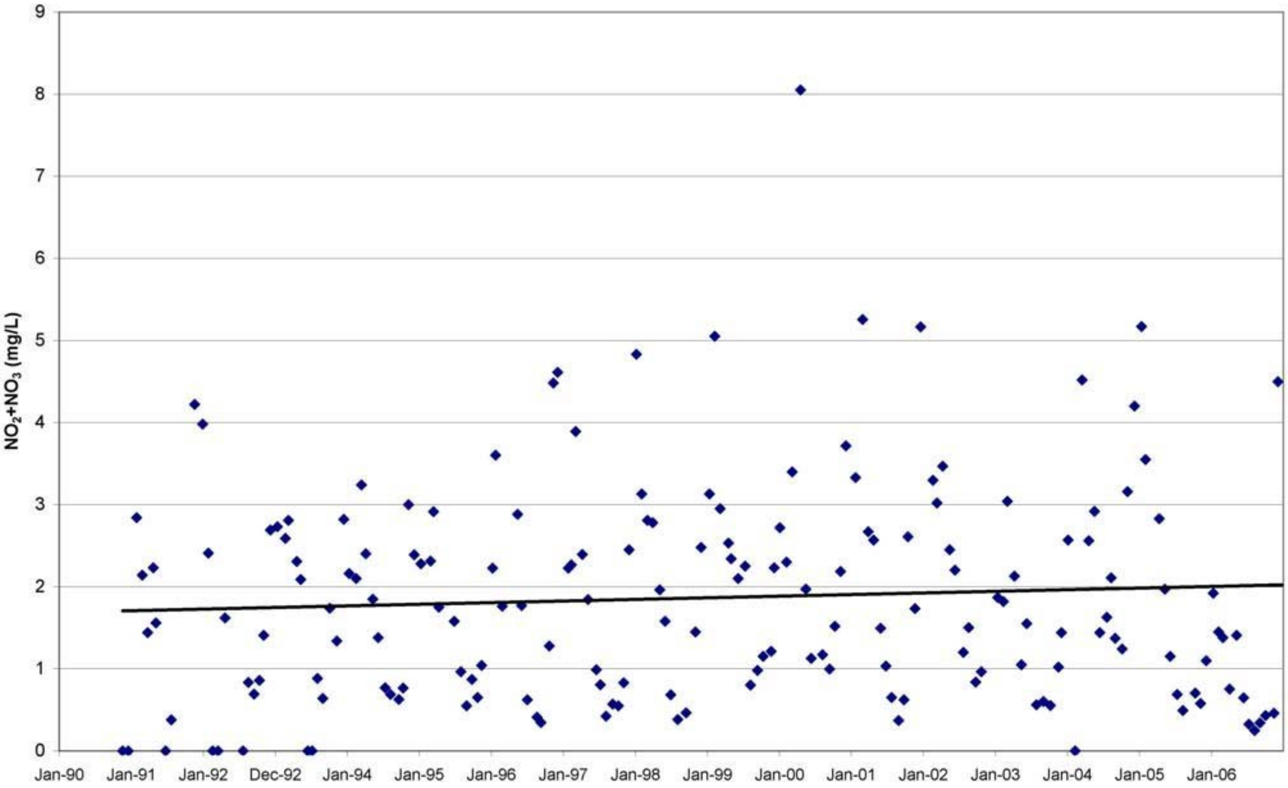


Figure 7.37. Tree model output for Beaver Lake Secchi transparency with turbidity data.



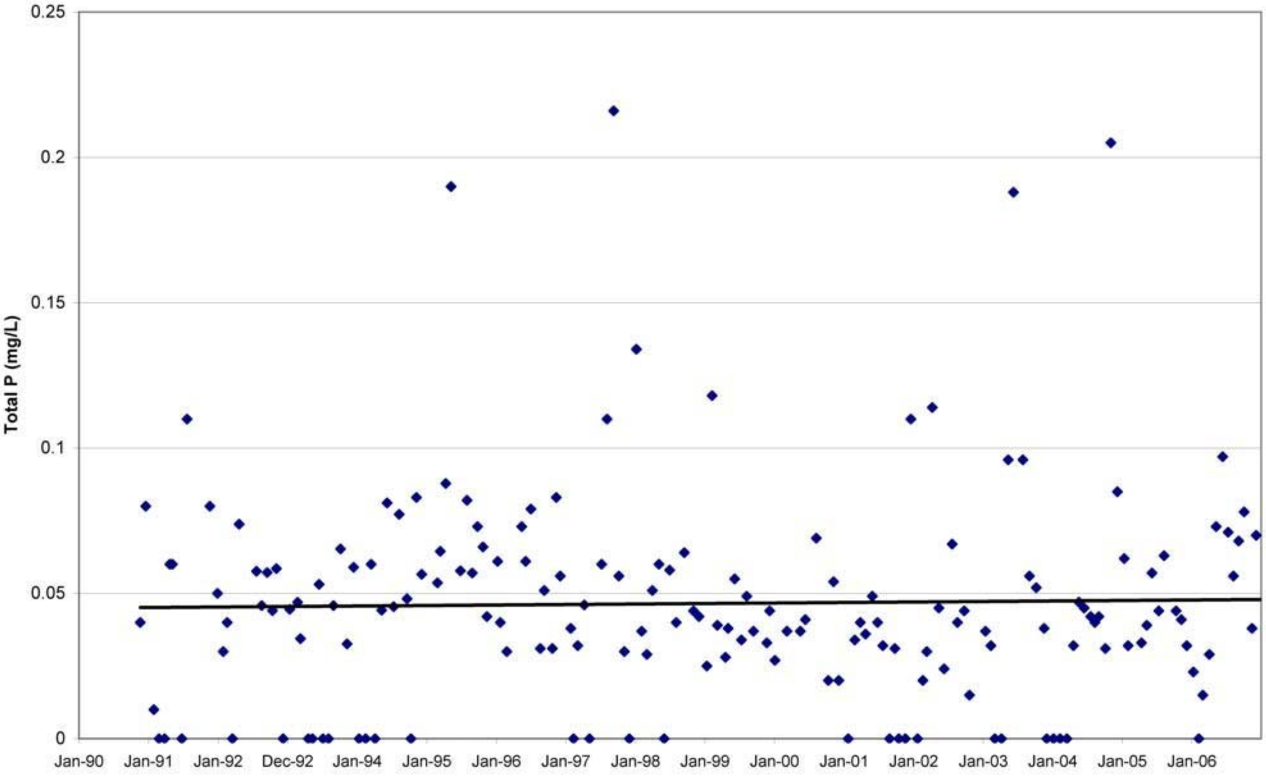
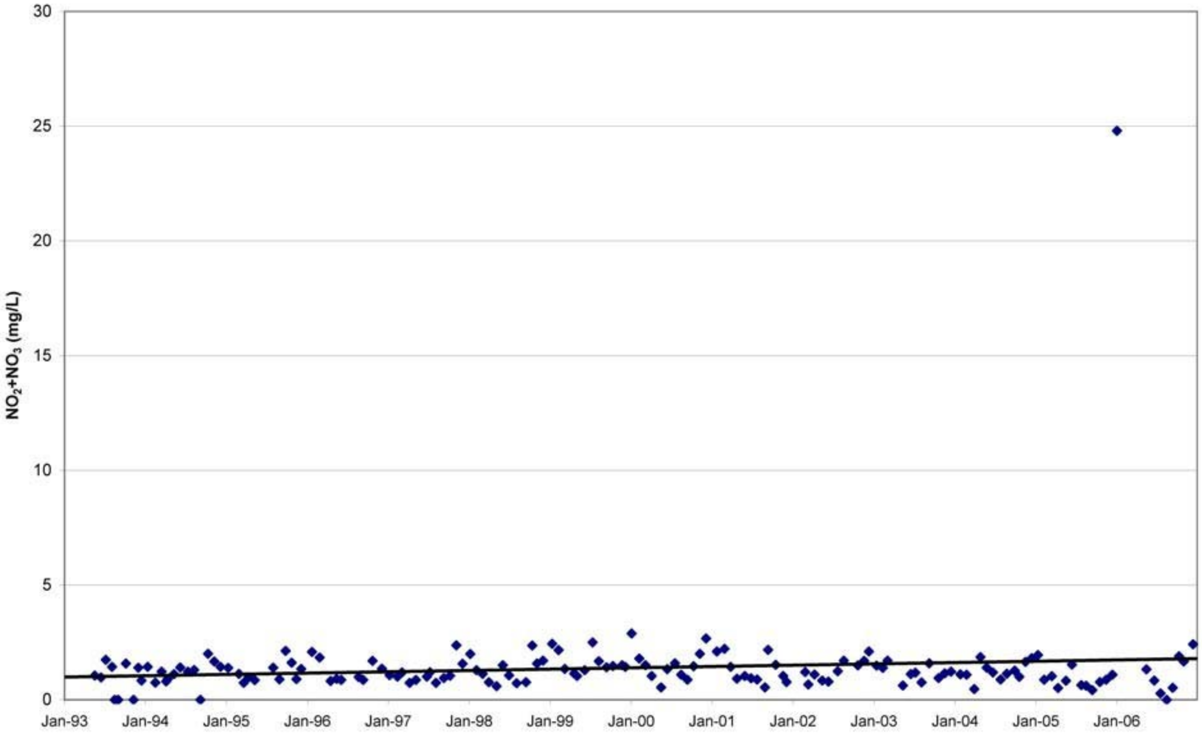


Figure 7.38. Flint Creek nutrient data over time.



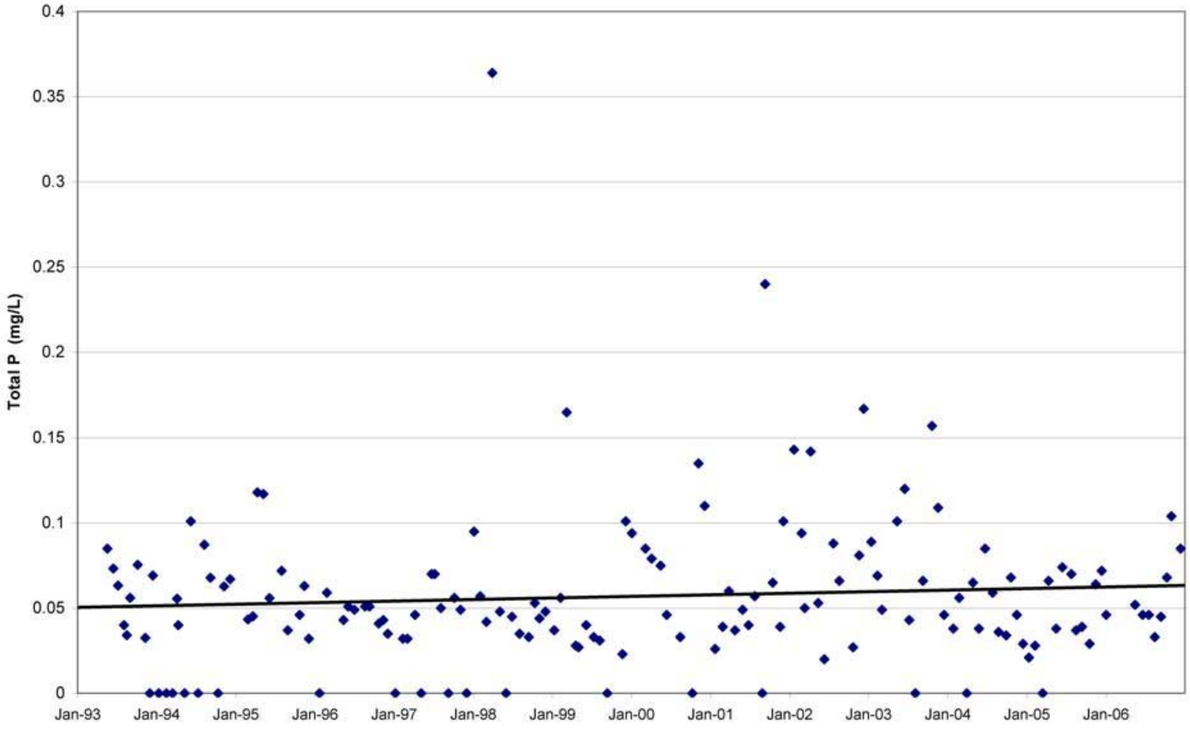


Figure 7.39. War Eagle Creek nutrient data over time.

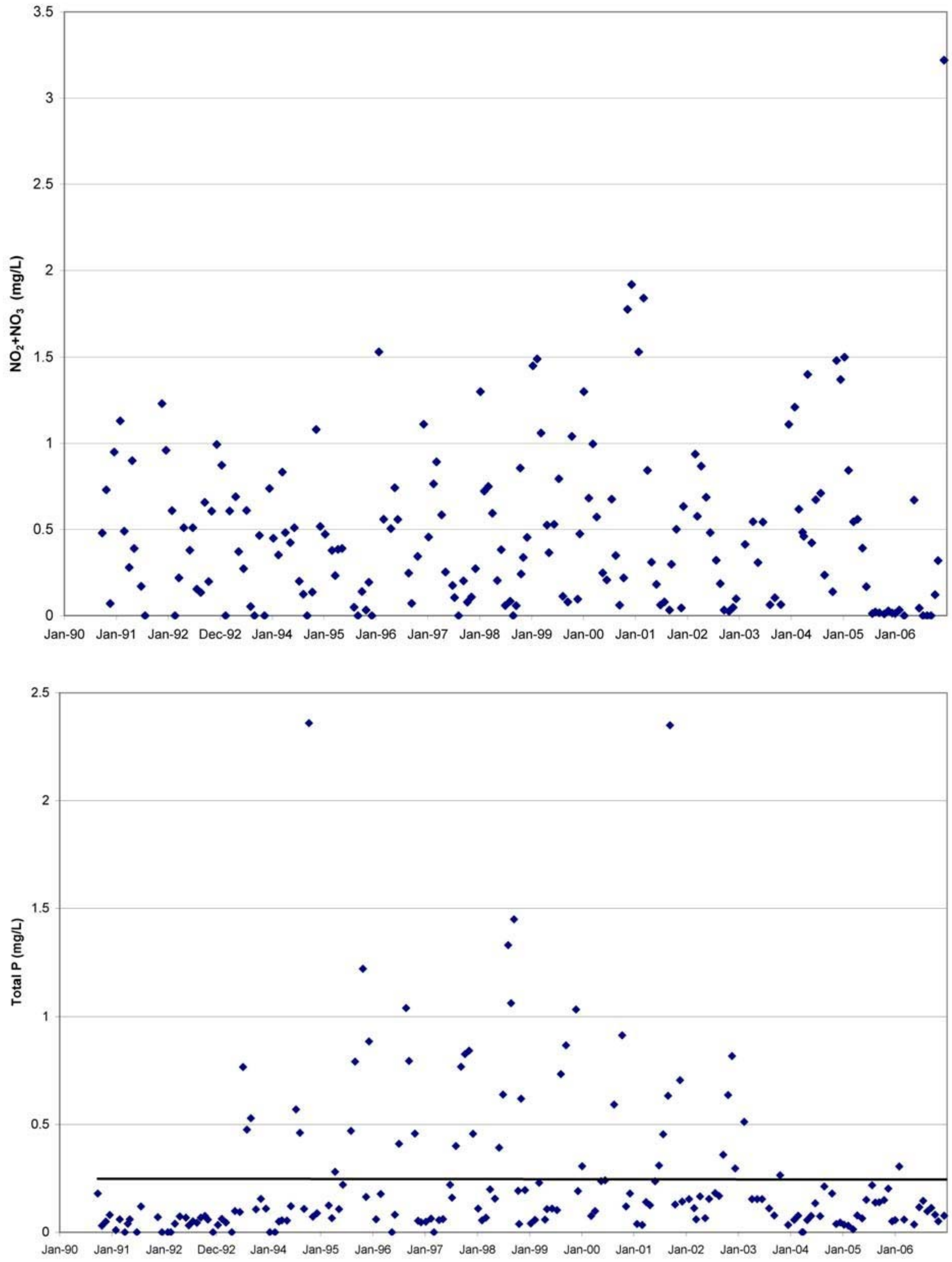
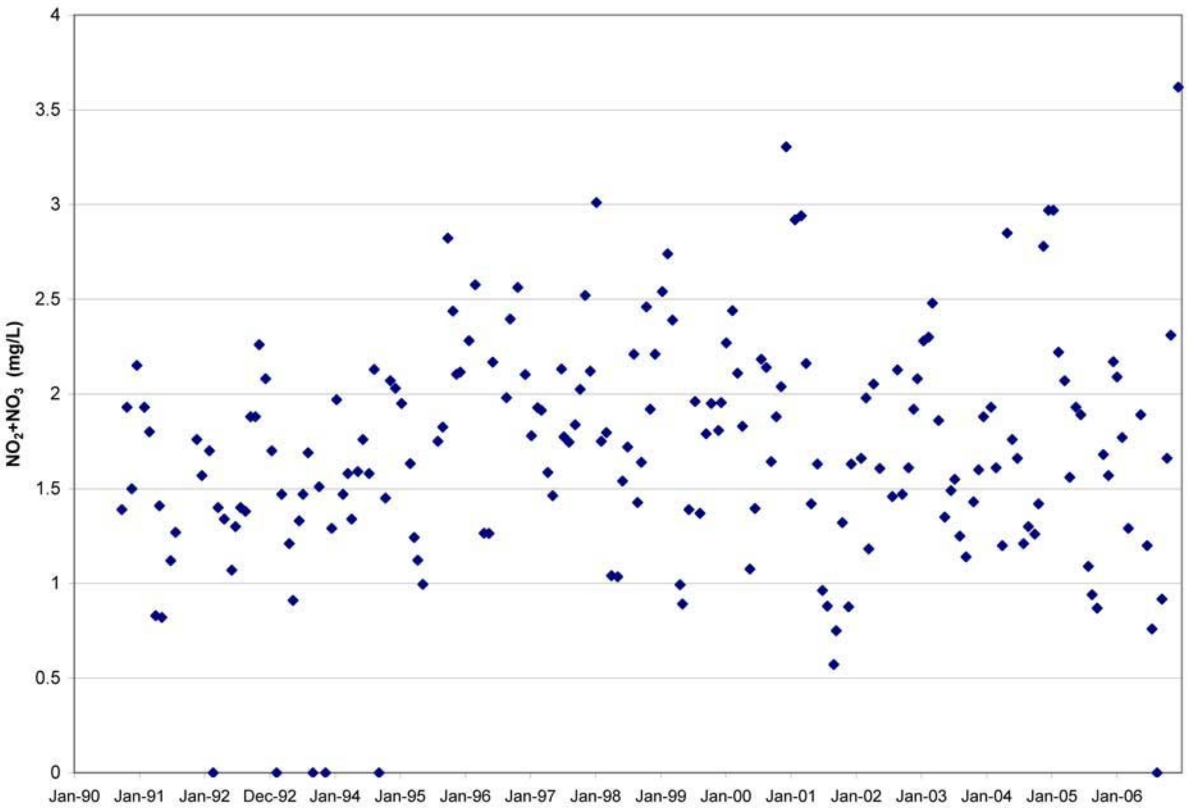


Figure 7.40. Kings River nutrient data over time.



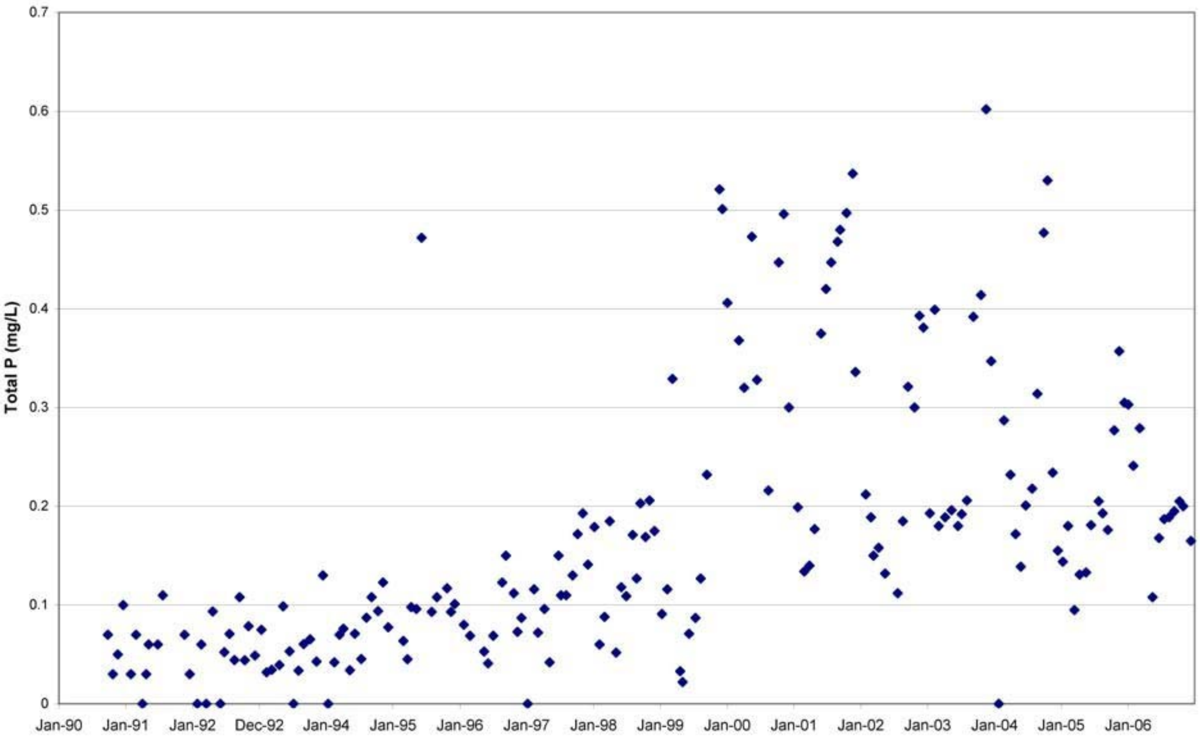


Figure 7.41. Long Creek nutrient data over time.

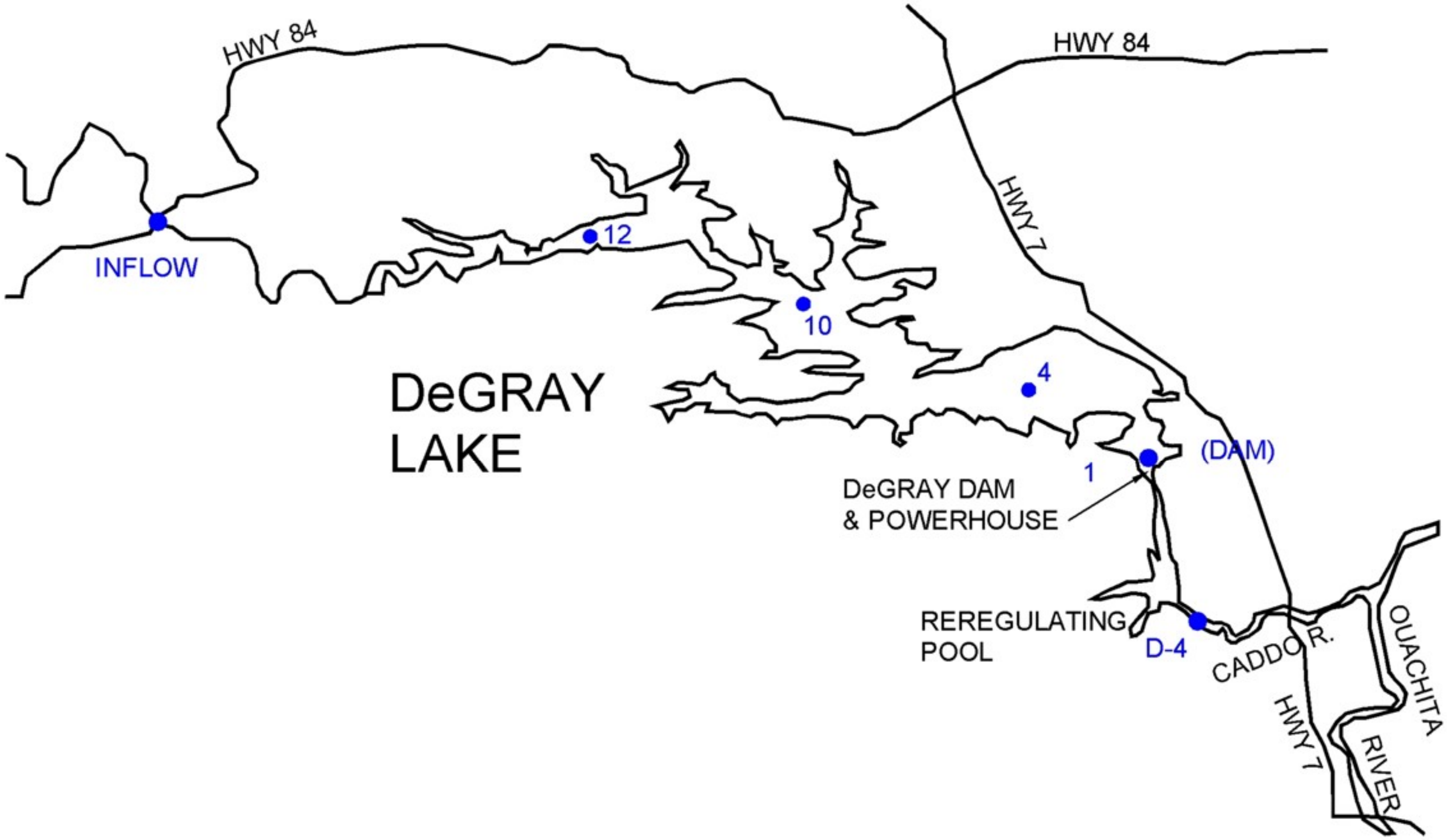


Figure 7.42. Categorization of DeGray Lake water quality sampling sites.

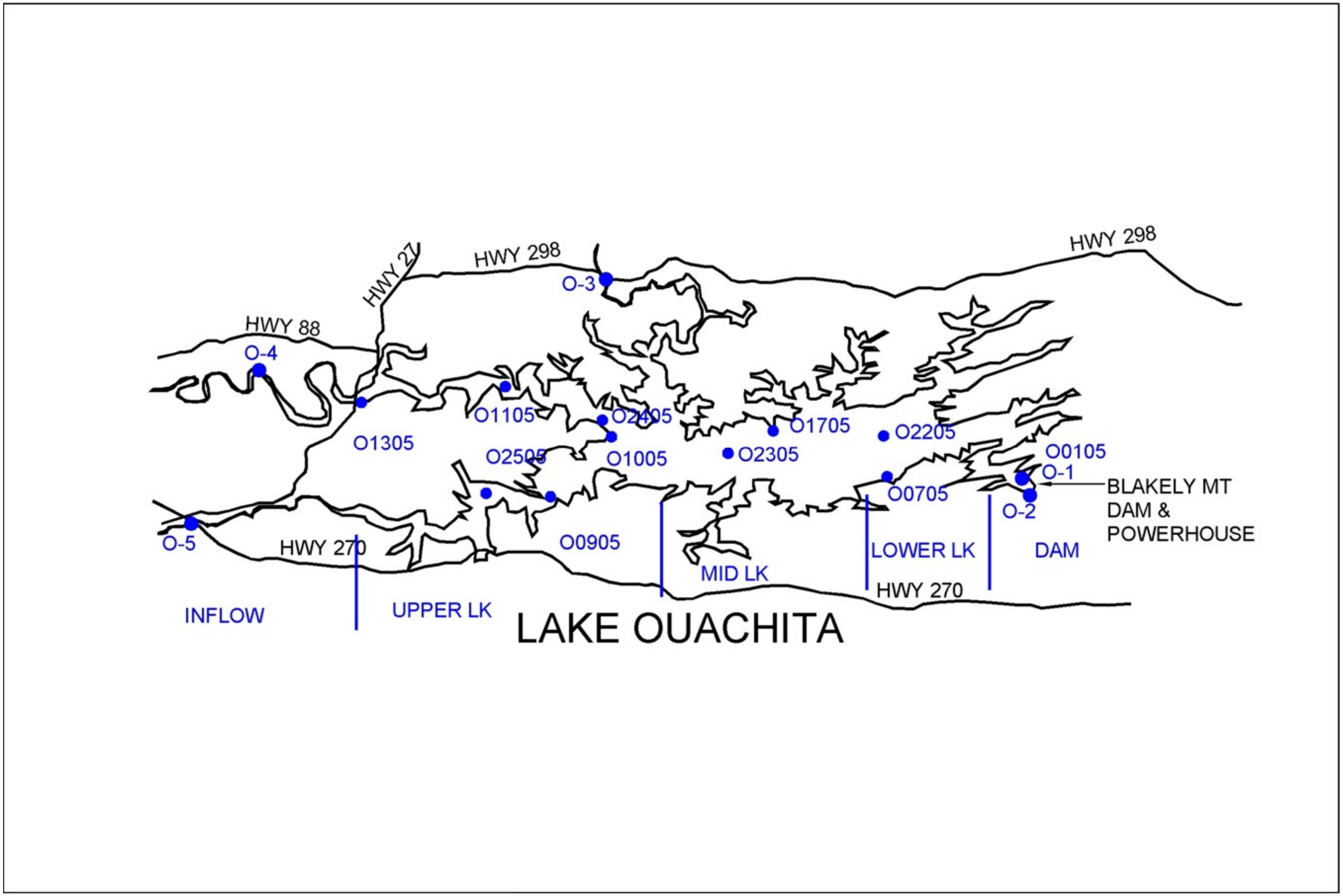


Figure 7.43. Categorization of Lake Ouachita water quality sampling sites.

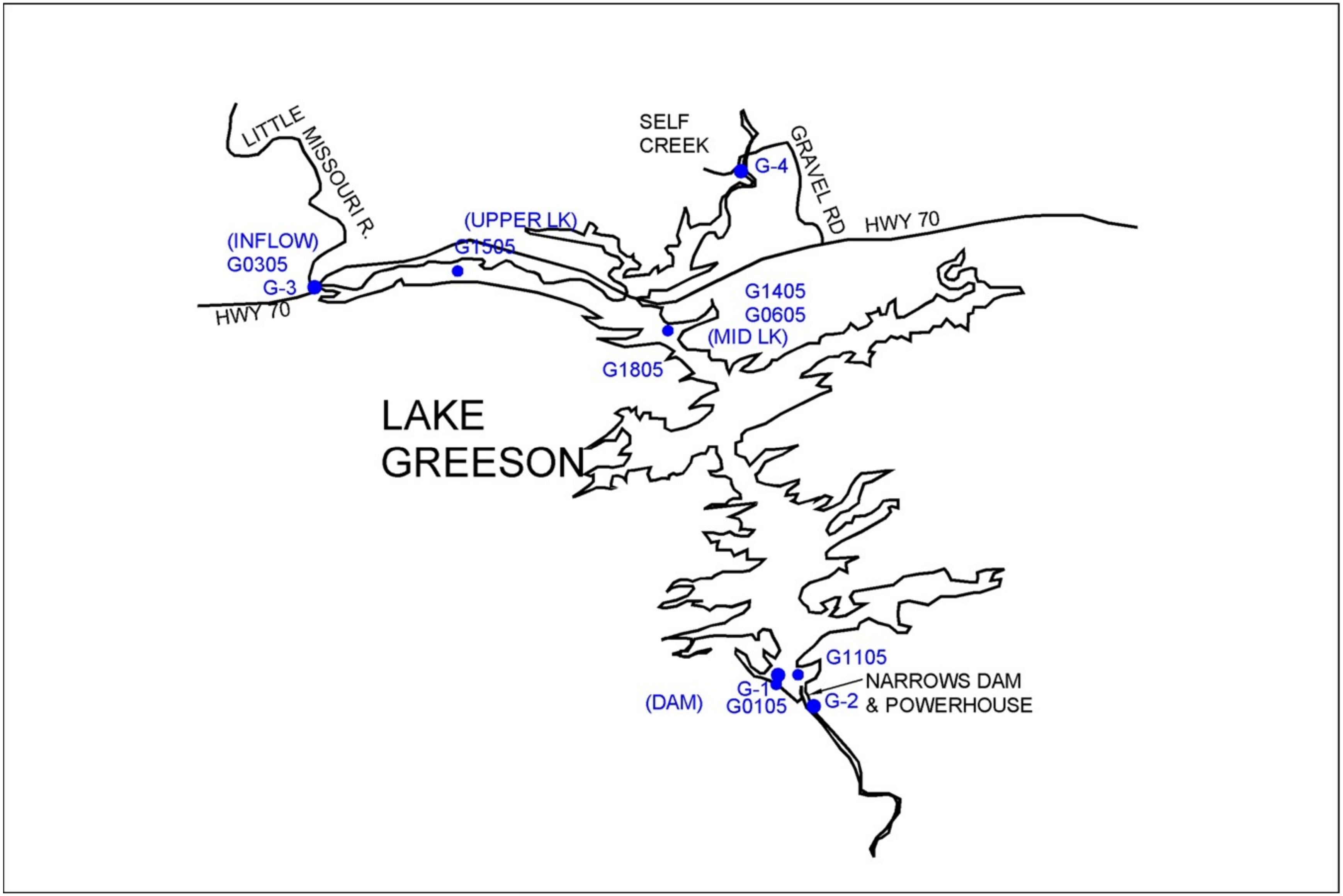


Figure 7.44. Categorization of Lake Greeson water quality sampling sites.

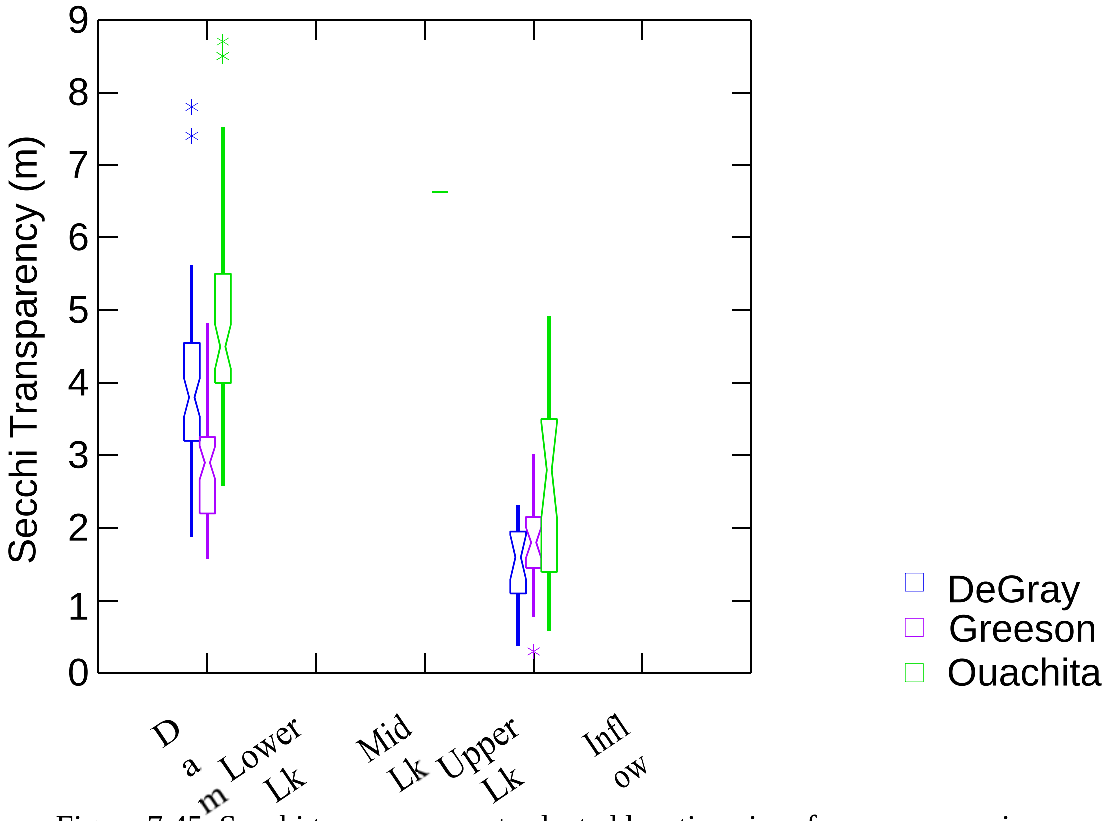


Figure 7.45. Secchi transparency at selected locations in reference reservoirs.

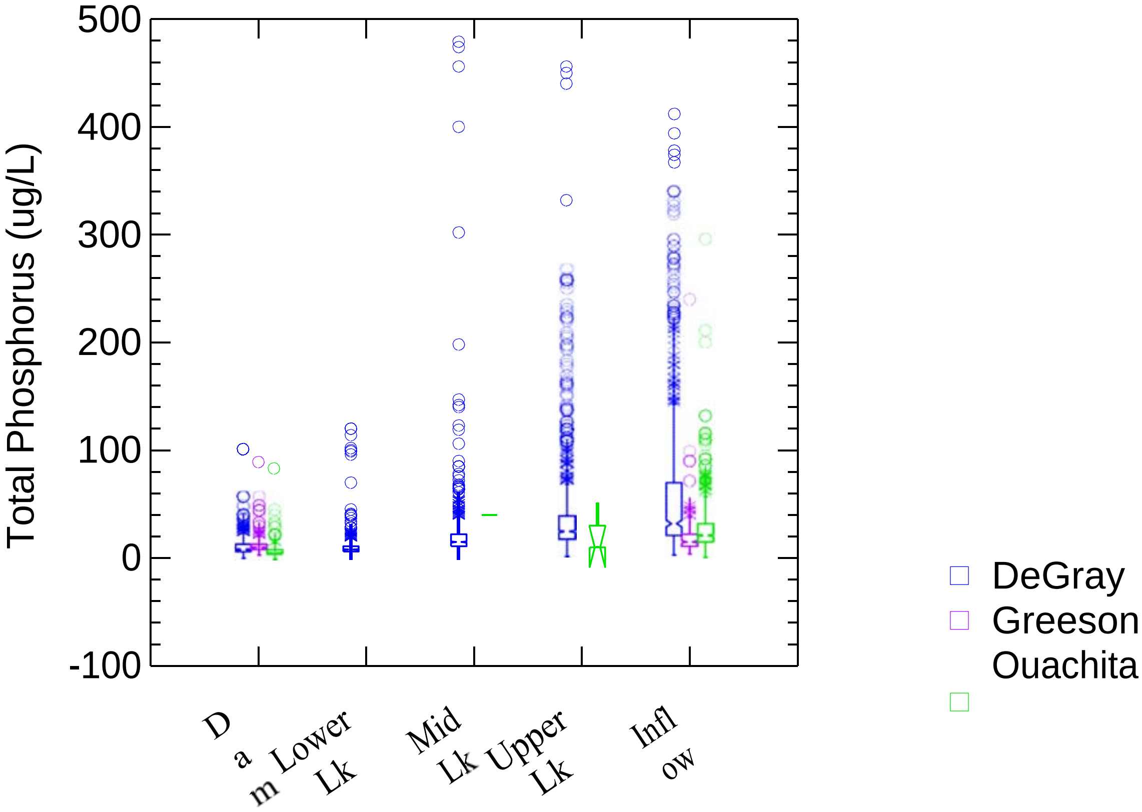


Figure 7.46. Total phosphorus concentrations at selected locations in reference reservoirs.

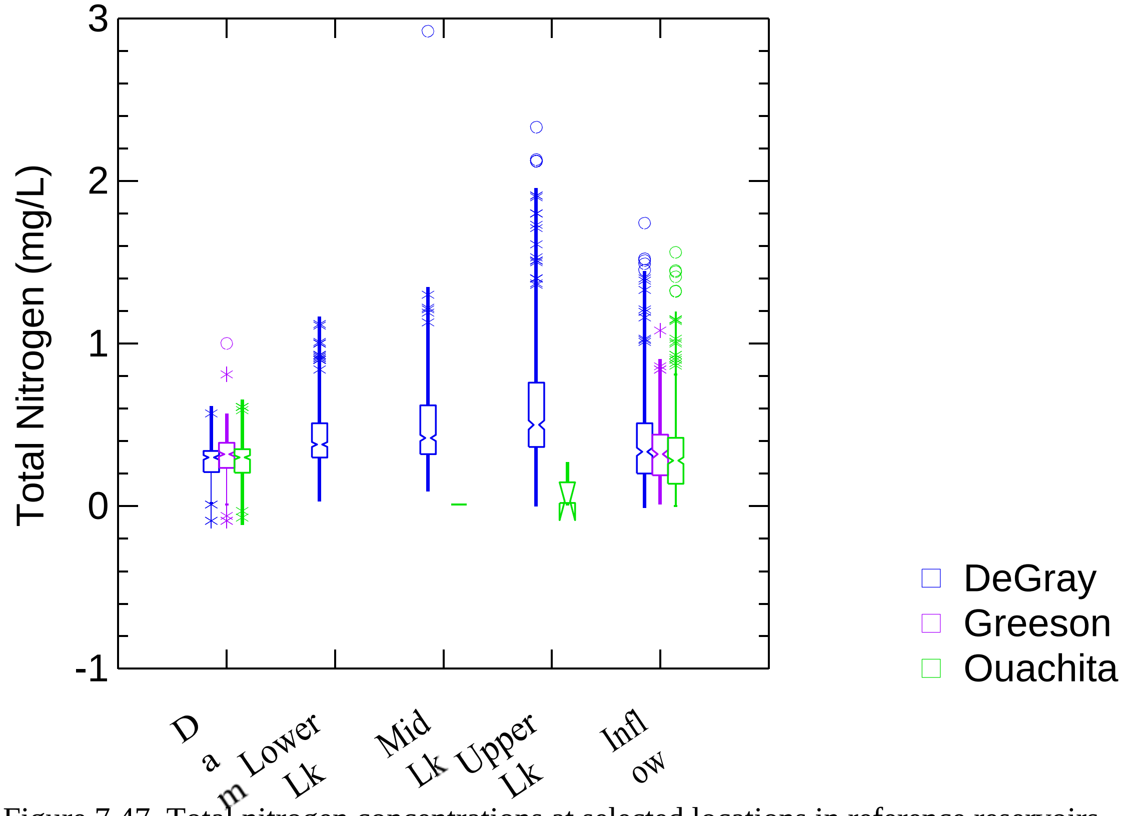


Figure 7.47. Total nitrogen concentrations at selected locations in reference reservoirs.

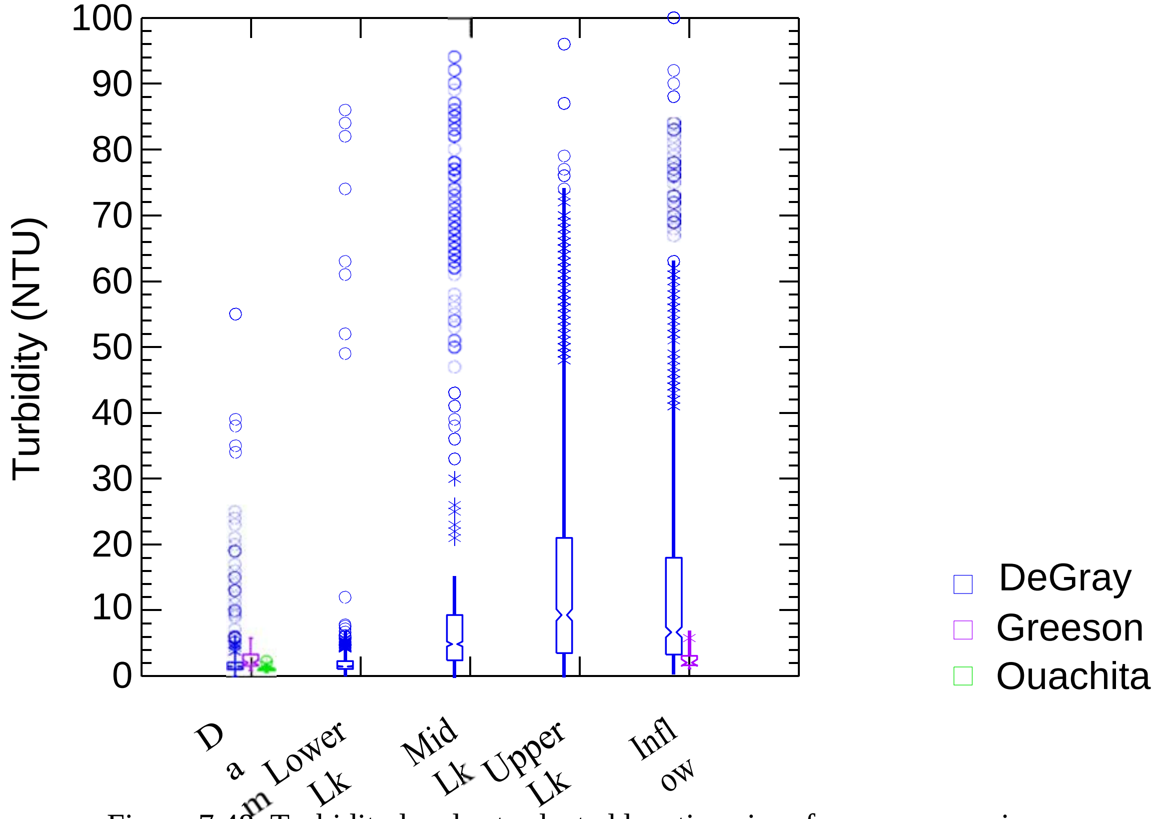


Figure 7.48. Turbidity levels at selected locations in reference reservoirs.

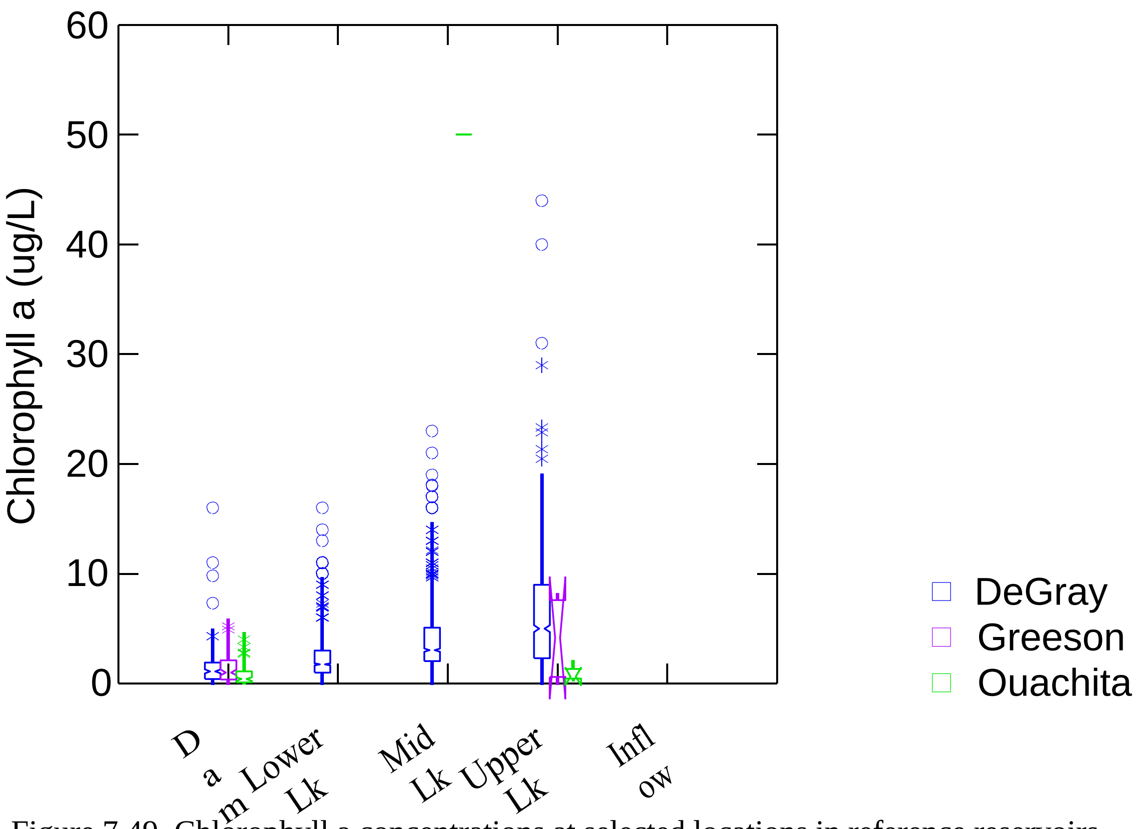


Figure 7.49. Chlorophyll a concentrations at selected locations in reference reservoirs.

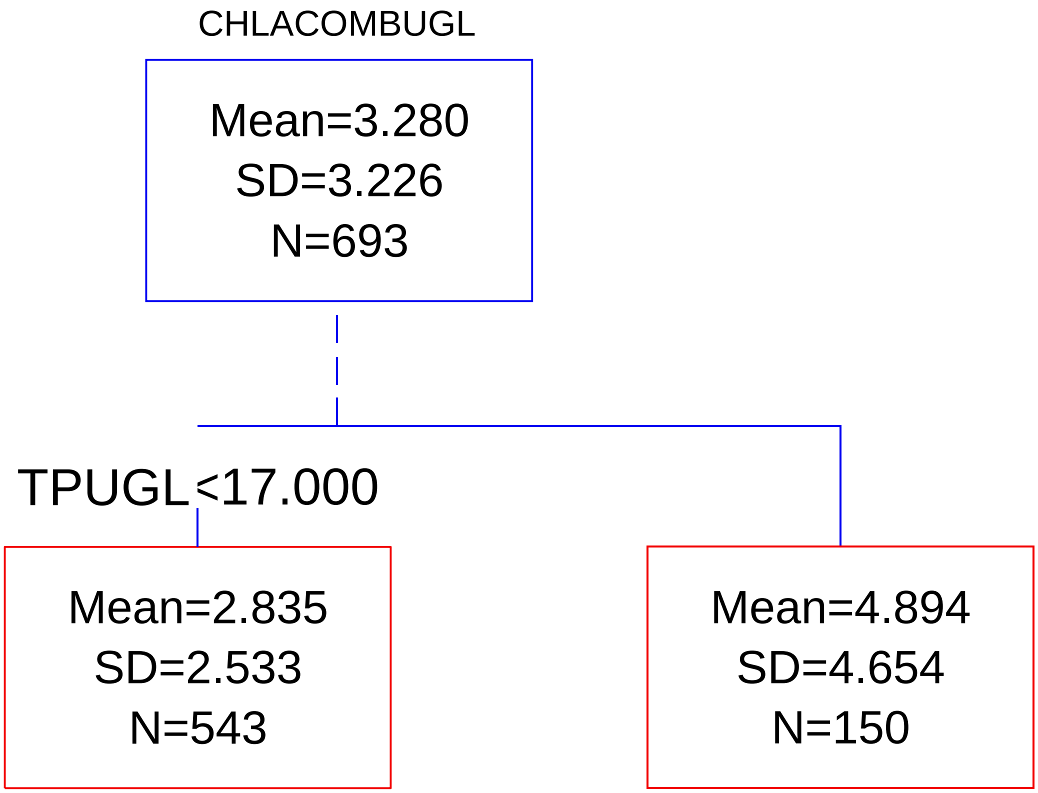


Figure 7.50. Tree analysis output for chlorophyll a with total phosphorus showing change-point.

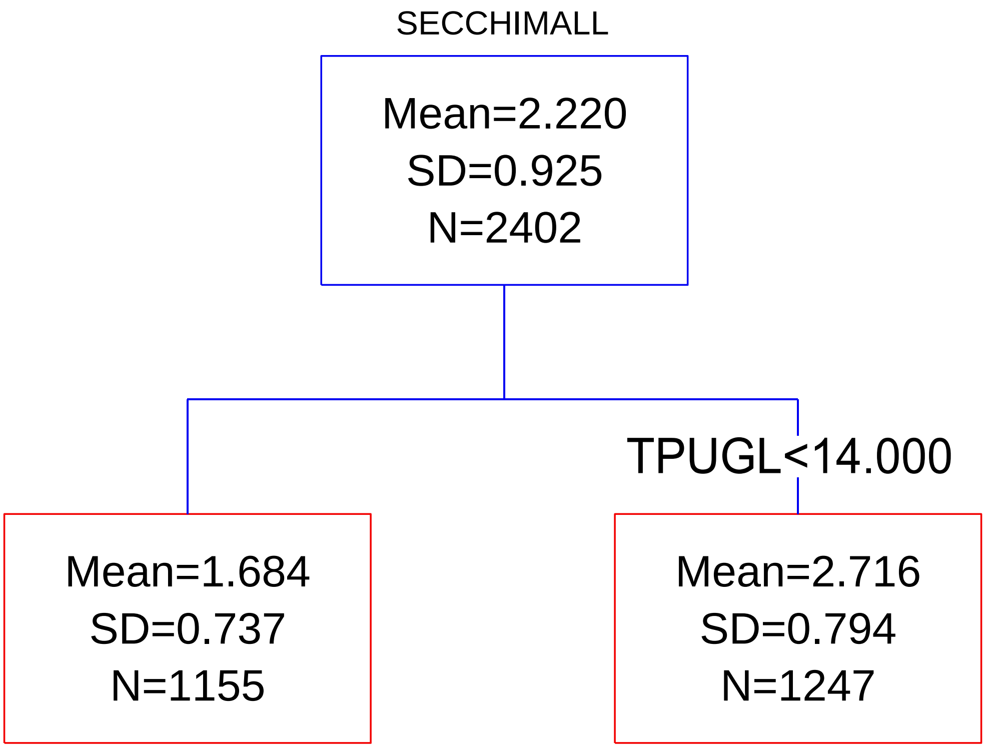


Figure 7.51. Tree analysis output for Secchi transparency with total phosphorus showing change-point.

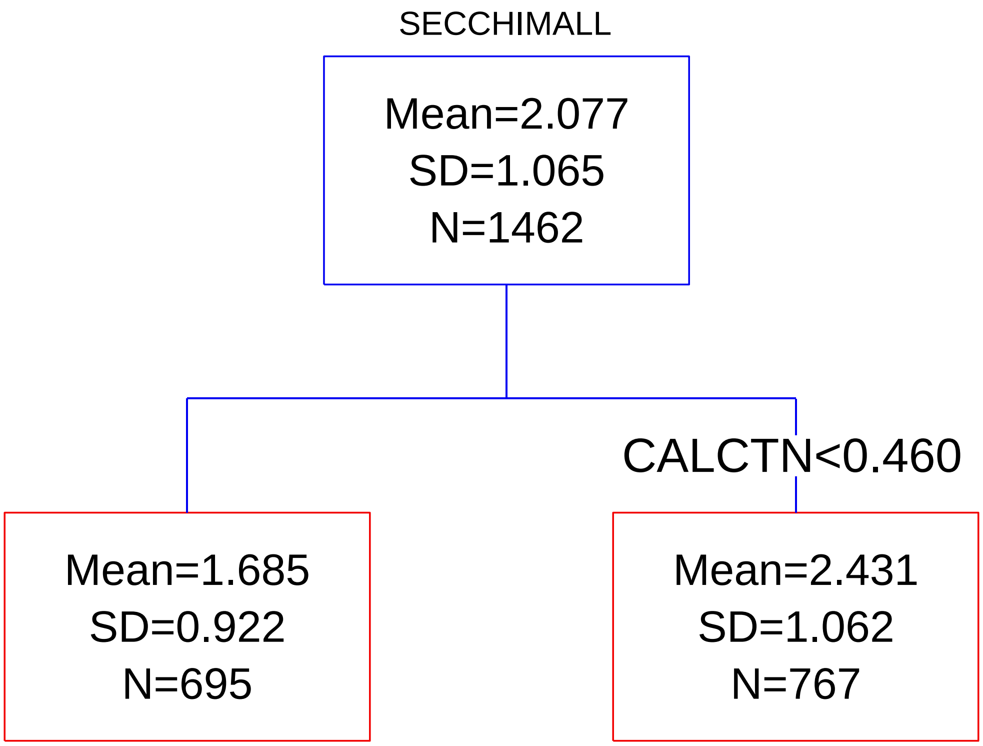


Figure 7.52. Tree analysis output for Secchi transparency with total nitrogen showing change-point.

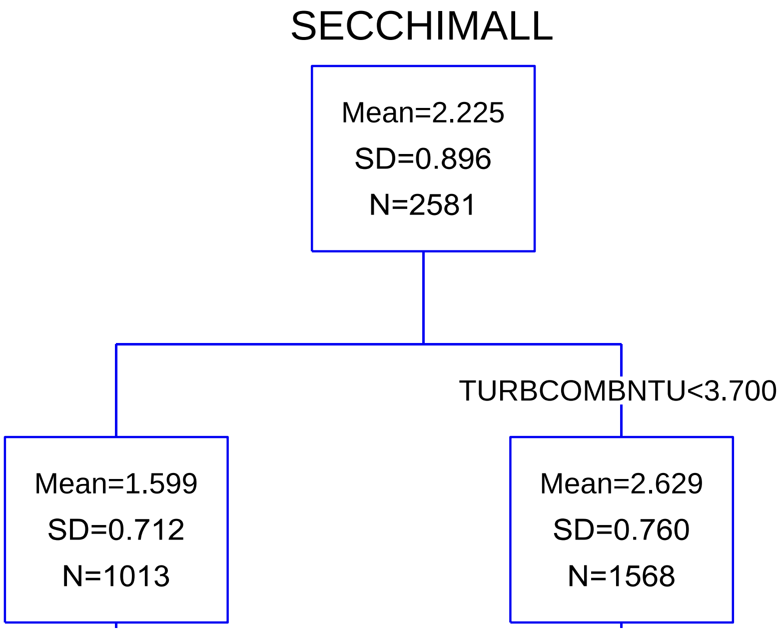


Figure 7.53. Tree analysis output for Secchi transparency with turbidity showing change-point.

8.1 Water Quality Modeling for Criteria Development

Both empirical and dynamic water quality models were used to evaluate the response of Beaver Lake to different nutrient scenarios under different flow regimes. While monitoring information provides the strongest base for evaluating water quality responses, modeling exercises provide information on possible water quality responses to different nutrient concentrations and for different lake locations than those monitored (e.g., Hickory Creek confluence). Nutrient responses were modeled using empirical relationships incorporated in a modeling platform developed for CE reservoirs and through the use of a dynamic model, CE-QUAL-W2, calibrated to Beaver Lake.

8.2 Nutrient Loading

TASTR is a modeling platform developed by the USACE Environmental Research and Development Center (ERDC) for simulating reservoir water quality using empirical relationships (ERDC 2007). TASTR uses Bathtub, a previously developed empirical modeling framework (Walker 1995), to estimate potential changes in reservoir water quality because of nutrient loading. The base case for Beaver Lake TASTR represents conditions observed during the NES. Changing total phosphorus inflow concentrations in the Beaver Lake Bathtub model resulted in the greatest changes in water quality in the upper reservoir (Table 8.1). While the current White River total phosphorus concentrations are greater than the TASTR baseline concentration, lower total phosphorus concentrations in Richland and War Eagle Creeks resulted in an overall lower average total phosphorus load under existing conditions. The TASTR Bathtub model of Beaver Lake predicted that this reduced phosphorus load would result in lower total phosphorus and chlorophyll a concentrations in the reservoir. The reduced phosphorus load did not result in any change in model predicted Secchi transparencies. Reducing the total phosphorus load also resulted in reductions in predicted Carlson’s Trophic State Indices (TSI). The Beaver Lake Bathtub model predicted maximum total phosphorus concentrations in Beaver Lake headwaters (the upper 10 km of the reservoir), with baseline and existing total phosphorus inputs. The

Beaver Lake Bathtub model predicted maximum chlorophyll a concentrations between 20 km and 30 km downstream of Highway 45. These predictions are consistent with results from the water quality monitoring program.

Table 8.1. TASTR Beaver Lake Bathtub model inputs and results.

Run	Baseline	Existing	Least-disturbed
White River, total phosphorus (µg/L)	73	81	45
Richland Creek, total phosphorus (µg/L)	181	45	45
War Eagle Creek, total phosphorus (µg/L)	76	54	45
Predicted Inflow Available Phosphorus Load (kg/yr)	116,307	106,425	95,451
Predicted Mean Headwater total phosphorus (µg/L)	49.4	44.1	37.1
Predicted Maximum Segment chlorophyll a (µg/L)	8.7	8.4	7.9
Predicted Minimum Segment Secchi transparency (m)	0.7	0.7	0.7
Area-weighted Mean Carlson TSI-P	48.1	47.5	46.7
Area-weighted Mean Carlson TSI-Chla	46.4	46.2	45.9
Area-weighted Mean Carlson TSI-Secchi	50.4	50.3	50.2

Mean total phosphorus concentrations for the four most recent years classified as dry, average, and wet were calculated for Richland and War Eagle Creeks (Table 8.2), and used in the TASTR Bathtub model of Beaver Lake. For the White River, only those years since 1989 classified as dry, average, and wet were used to calculate mean total phosphorus, because total phosphorus concentrations in the White River prior to 1990 were statistically different from mean total phosphorus concentrations after 1990. Treatment was upgraded in the Fayetteville wastewater treatment plant in 1987, which significantly decreased phosphorus point source discharges and loads to the White River. In addition, mean total phosphorus concentrations were also calculated from the data collected by USGS from 2001 through 2003 for their CE-QUAL-W2 modeling (Table 8.2). These phosphorus concentrations were also used in the TASTR Bathtub. The results of the TASTR Bathtub runs using these mean concentrations are shown in Table 8.3.

Table 8.2. Total phosphorus concentration statistics for White River, Richland Creek, and War Eagle Creek.

Condition	Statistic	White River at Hwy 45 (mg/L)	Richland Creek at Hwy 45 (mg/L)	War Eagle Creek at Hwy 45 (mg/L)
Dry	N	38	20	39
	Mean	0.090	0.036	0.061
	Median	0.046	0.020	0.050
Average	N	80	41	87
	Mean	0.062	0.023	0.056
	Median	0.040	0.020	0.040
Wet	N	29	15	10
	Mean	0.102	0.057	0.056
	Median	0.080	0.030	0.060
CE-QUAL-W2	N	56	57	57
	Mean	0.065	0.025	0.048
	Median	0.030	0.020	0.040

Table 8.3. TASTR/Bathtub results for Beaver Lake, changing only total phosphorus concentrations in White River, Richland Creek, and War Eagle Creek.

Run	TASTR Baseline	Dry	Average	Wet	CE-QUAL-W2
White River, total phosphorus (µg/L)	73	90	62	102	65
Richland Creek, total phosphorus (µg/L)	181	36	23	57	25
War Eagle Creek, total phosphorus (µg/L)	76	61	56	56	48
Predicted Inflow Available Phosphorus Load (kg/yr)	111,691.9	104,739.8	95,705.4	108,450.0	95,362.2
Predicted Mean Headwater, total phosphorus (µg/L)	49.4	45.6	38.9 (20-30 km)	49.3	39.4
Predicted Maximum Segment, chlorophyll a (µg/L)	8.7 (20-30 km)	8.5 (20-30 km)	8.2 (20-30 km)	8.6 (20-30 km)	8.1 (20-30 km)
Area-weighted Mean Carlson TSI-P	48.1	47.6	47.0	47.9	47.0
Area-weighted Mean Carlson TSI-Chla	46.4	46.3	46.0	46.4	46.0
Area-weighted Mean Carlson TSI-Secchi	50.4	50.3	50.2	50.3	50.2

The maximum chlorophyll concentrations were predicted to occur 20 to 30 km downstream of Highway 45. The Highway 412 monitoring site is 18 to 20 km downstream of Highway 45. This is consistent with the longitudinal profiles of chlorophyll observed from the monitoring program. The CE-QUAL-W2 loads also resulted in maximum chlorophyll concentrations in the same area. The predicted maximum segment chlorophyll concentration was 8.1 µg/L while the median chlorophyll concentrations observed during 2001-2003 at the

Highway 412 site were 12.5 µg/L. The observed median chlorophyll concentrations, however, were within the error for predicted chlorophyll concentrations (" 7 µg/L).

8.3 Dynamic Water Quality Modeling

In addition to using empirical modeling relationships, USGS calibrated a two-dimensional, laterally-averaged, hydrodynamic and water quality model, CE-QUAL-W2, to Beaver Lake. The model was calibrated at four sites in the reservoir for the period from April 2001 through April 2003 (Galloway and Green 2006). The four sites were based on location of monitoring stations in Beaver Lake: Highway 412 station near Sonora, the station near Lowell, Highway 12 site near Rogers, and at the dam station near Eureka Springs. Following calibration, the model was used to evaluate the effects of different nutrient loading scenarios on Beaver Lake water quality.

Nitrogen and phosphorus loadings were decreased by half, and increased two, four, and ten times the calibrated daily input concentrations in the three tributaries simultaneously and for each individual tributary (Galloway and Reed 2007). In addition, nitrogen and phosphorus concentrations were increased simultaneously as well as independently. In general, the chlorophyll response to increased phosphorus or nitrogen was not as great as when both nitrogen and phosphorus were increased.

The greatest response to nutrient load changes was in the upper portions of the Beaver Lake (Galloway and Green 2007). For example, a ten-fold increase in nitrogen and phosphorus concentrations in the three major tributaries (White River, Richland Creek, and War Eagle Creek) resulted in a four-fold increase in total nitrogen at the Highway 412 station and a two-fold increase at the dam station. The ten-fold increase in both nitrogen and phosphorus in the three major tributaries resulted in a total phosphorus concentration increase of about nine-fold at the station near Lowell. A ten-fold increase in nitrogen and phosphorus in the three major tributaries also resulted in about a 10 µg/L increase in chlorophyll concentrations at the station near Lowell. A doubling of the nitrogen/phosphorus daily concentrations in the three major tributaries resulted in about a 2 µg/L increase in chlorophyll concentrations at the Highway 12 station and less than a 1 µg/L increase in chlorophyll concentration at the dam station.

Decreasing both nitrogen and phosphorus daily concentrations in the three major tributaries by half resulted in about a 1 µg/L decrease in chlorophyll concentrations at the Highway 412 station and about a 0.5 µg/L decrease at the dam station.

8.4 Modeling Conclusions

Both empirical and dynamic modeling results indicated that the greatest change to increased or decreased nutrient loading would occur in the upper portions of the reservoir, with significantly lower responses in the lower portion of the reservoir, consistent with monitoring results. The mean of observed chlorophyll concentrations in Beaver Lake during 2001 to 2003 were 15.6 µg/L at Highway 412 and 5.4 µg/L at the station near Lowell. The empirically predicted chlorophyll concentrations near the Highway 412 station were 9.8 µg/L compared with dynamic model mean chlorophyll concentration predictions of 5.8 µg/L at the Highway 412 station during 2001 to 2003. Dynamic model chlorophyll concentrations at the station near Lowell averaged 5.4 µg/L compared with monitored concentrations of 5.4 µg/L and the empirical model mean concentration of 7.0 µg/L. The root mean square error (RMSE) associated with dynamic model predictions of chlorophyll concentrations for the Highway 412 station was 7.3 µg/L, and 3.3 µg/L for the station near Lowell. This means that the mean concentration predicted by the model could be " RMSE, as shown in Table 8.4. Chlorophyll concentrations predicted by the empirical model at Highway 412 and the station near Lowell varied by 40% to 37% about the estimated mean chlorophyll concentrations of 10 and 7.0 µg/L, respectively.

Table 8.4. Comparison of observed chlorophyll a data and model results.

Location	**Observed 2001 – 2003 (µg/L)**	**Bathtub (µg/L)**	**CE-QUAL-W2 (µg/L)**
Highway 412	15.6	9.8	5.8 ± 7.3
Lowell	5.4	7.0	5.4 ± 3.3

The mean of observed total phosphorus concentrations in Beaver Lake during 2001 to 2003 were 26 µg/L at Highway 412 and <20 µg/L (the detection limit) at the station near Lowell. The mean empirically predicted total phosphorus concentration near the Highway 412 station was 59 µg/L compared with dynamic model mean total phosphorus concentration prediction of 61 µg/L at the Highway 412 station during 2001 to 2003. Dynamic model total phosphorus concentrations at the station near Lowell averaged 36 µg/L compared with monitored concentrations of <20 µg/L and the empirical model mean concentration of 35 µg/L. The RMSE associated with dynamic model predictions of total phosphorus concentrations for the stations at Highway 412 near Lowell was 40 µg/L for both stations. This means that the mean concentration predicted by the model could be " RMSE, as shown in Table 8.5. Total phosphorus concentrations predicted by the empirical model at Highway 412 and the station near Lowell varied by 41% and 37%, respectively, about the estimated mean total phosphorus concentrations of 61 and 36 µg/L.

Table 8.5. Comparison of observed total phosphorus data and model results.

Location	**Observed 2001 – 2003 (µg/L)**	**Bathtub (µg/L)**	**CE-QUAL-W2 (µg/L)**
Highway 412	26	58.8	61 ± 40
Lowell	<20	34.6	36 ± 40

9.0 WEIGHT OF EVIDENCE

9.1 Location

Some WQS are established to be applicable any time, anywhere in the waterbody. It is recommended that reservoir WQS be established for a specific location or locations within the waterbody because of the complexity and dynamic processes in these ecosystems. Previous chapters have described the distinct longitudinal gradients in water quality constituents with most constituent concentrations decreasing from the headwater to the dam (Secchi depth, or water clarity, increases from the headwater to the dam). If water quality criteria were established for a location in the upper portion of the reservoir, then, designated uses downstream from this location should be protected, and numeric water quality criteria should be attained. There are two primary considerations for establishing this location: plunge point and dominant tributary inflow.

Because the area or zone downstream from the plunge point is typically the most dynamic region in the reservoir for most water quality constituents, including chlorophyll, this zone might be considered for establishment of the location to monitor and assess the attainment of the water quality criteria. The riverine zone typically does not exhibit the greatest chlorophyll concentrations because of light limitation, and chlorophyll and other constituent concentrations are significantly lower downstream from the plunge point. Although dynamic, the plunge point typically occurs just upstream from the Highway 412 monitoring site (See Table 6.4 and Figure 6.11).

Loading from major tributaries is the second consideration in establishing a location for monitoring and assessing water quality attainment. If there are several major inflows to a reservoir, multiple locations might be established below the plunge point for each major tributary. Alternatively, a single location below the confluence of all major tributaries might be established. The Highway 412 location integrates the inflows from the White River and Richland Creek, but is upstream from the confluence of War Eagle Creek inflows. The location at Lowell integrates the inflow from all three major tributaries. One of the disadvantages of the Lowell monitoring site location is that it provides limited buffer for episodic excursions above the water quality criterion to protect the drinking water designated use.

An alternative location, which is not currently a monitoring site, but does have access and is below the confluence of all three major inflows, is a site near Hickory Creek. Advantages of the Hickory Creek site include: 1) there is a boat ramp at this location; 2) it is below the confluence of all three major tributaries and should integrate the loadings from these three tributaries; and 3) it is upstream from the location of a major drinking water intake, so it should provide protection from episodic excursions of chlorophyll and suspended sediment in the transition zone.

The proposed location for the monitoring and assessment site, therefore, is over the thalweg at the Hickory Creek site in Beaver Lake, between the current Highway 412 and Lowell monitoring sites (Figure 9.1). Rationale includes:

1. It integrates the loadings from all three major tributaries – White River, Richland and War Eagle Creeks;
2. It is typically below the plunge point in the transition zone of the reservoir, which has the greatest water quality dynamics;
3. It provides some buffer from episodic excursions for the downstream drinking water intake, which represents one of the highest designated uses for Beaver Lake;
4. Water quality typically improves significantly for all constituents downstream from this location so downstream designated uses should be protected;
5. Subsequent tributary numeric WQS for nutrients and other constituents should protect Beaver Lake designated uses from minor tributary loadings downstream of the site;
6. Water quality constituent concentrations can be extrapolated from the Highway 412 and Lowell sites to estimate concentrations at the Hickory Creek site until sufficient data can be established at the Hickory Creek site to assess water quality status and trends; and
7. The Beaver Lake Watershed Management Plan should assist in moving toward restoration of tributaries that are currently not meeting WQS and provide protection of both upstream and downstream areas from degradation. The DA/SA ratio described in Chapter 5 indicated that best management practices implemented anywhere in the watershed should result in improved water quality conditions in Beaver Lake.

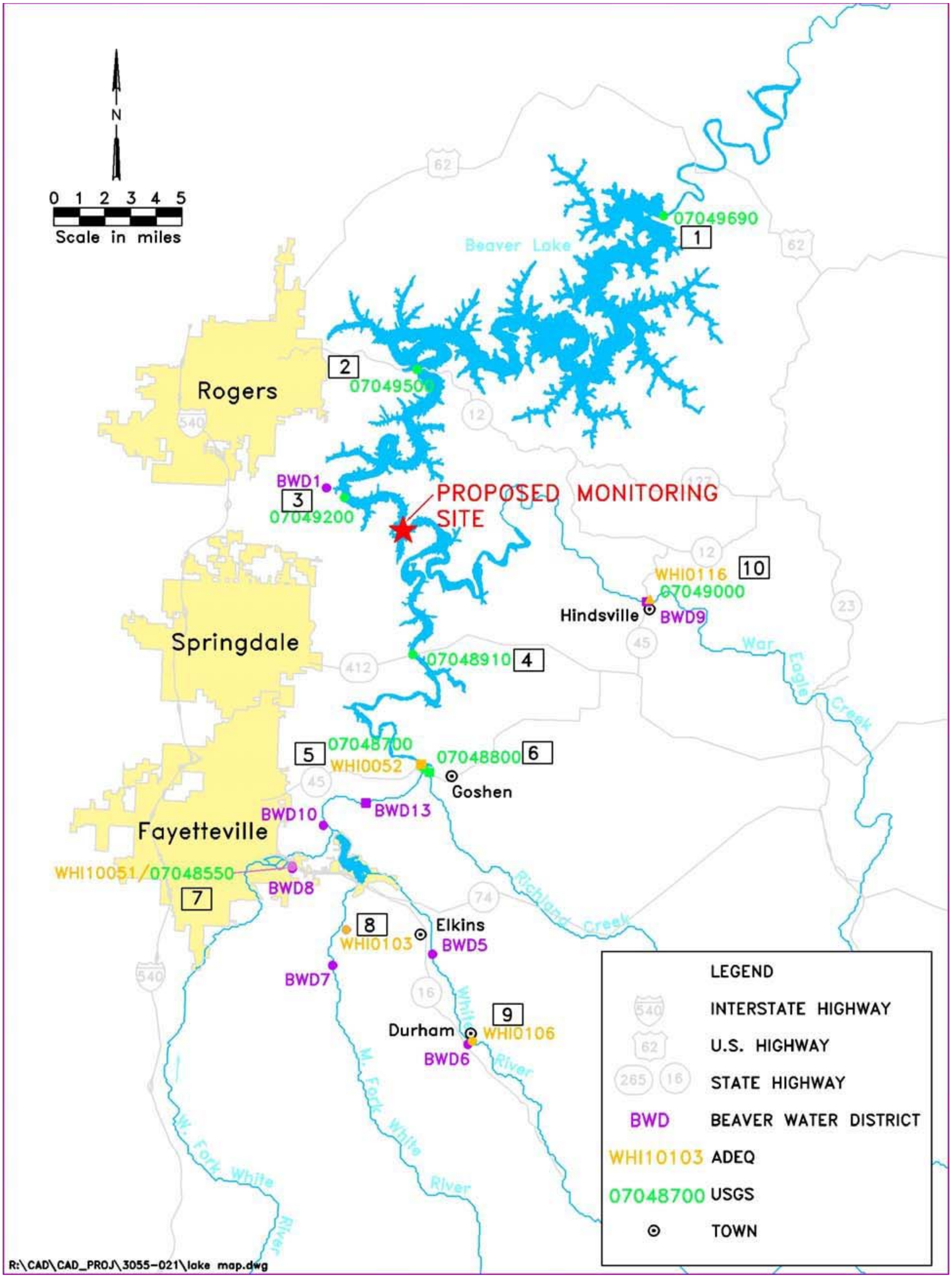


Figure 9.1. Proposed Hickory Creek monitoring site for assessing WQS attainment.

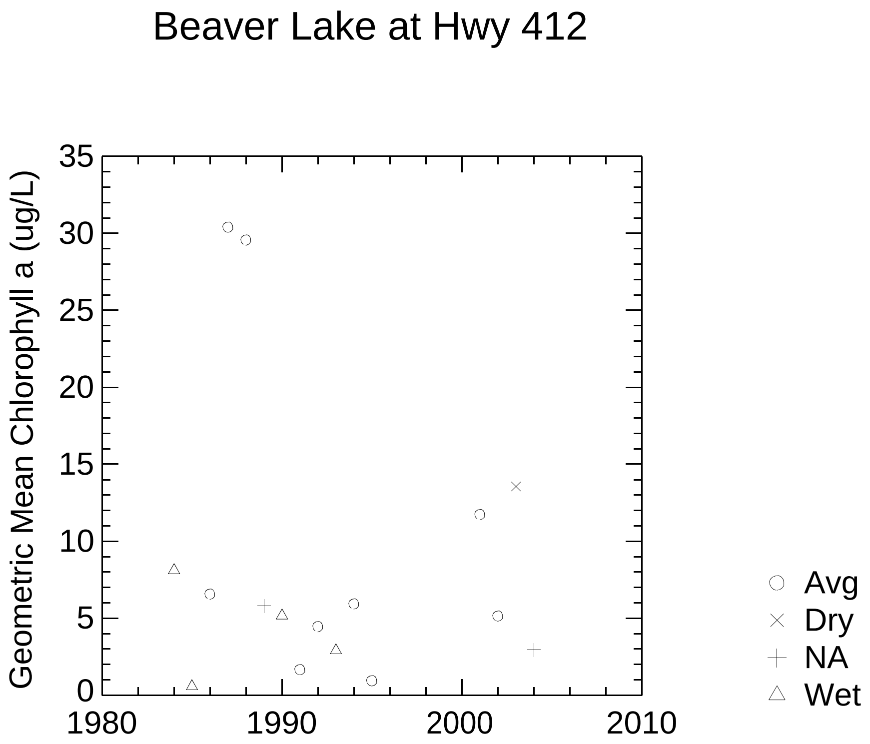
9.2 Frequency, Duration, and Magnitude

The emphasis has been on developing effects-based criteria that can be directly related to the designated uses for Beaver Lake. The two effects-based criteria are chlorophyll a (aquatic life, drinking water, recreation designated uses), and Secchi transparency or water clarity (drinking water, recreation designated uses). Both of these constituents are dynamic and vary episodically, seasonally, and annually, based on hydrology and in-lake processes. Therefore, the development of water quality criteria needs to consider not only magnitude, but also frequency and duration in constituent concentrations.

Chlorophyll data are traditionally quite variable with time scales of about a week. A comparison of seasonal means for chlorophyll collected at the same site by Beaver Water District and USGS for 2001-2005 illustrates this variability (Table 9.1) Because Secchi transparency is an indicator of water clarity, it also is affected by algal biomass as well as inorganic particulate concentrations. Geometric means are typically used to estimate conditions for constituents with highly variable concentrations. Geometric means of growing season (May – October) chlorophyll concentrations and annual average Secchi depth values in Beaver Lake at the Highway 412 and Lowell stations, along with hydrologic year classification, are shown in Figures 9.2 and 9.3.

Table 9.1. Comparison of growing season geometric chlorophyll means (μg/L) collected by USGS and Beaver Water District at the site near Lowell, Arkansas.

Agency	**Growing Season Geometric Chlorophyll Mean (μg/L)**				
	2002	**2003**	**2004**	**2005**	**2006**
USGS	4.6	4.9	1.1	3.4	4.2
BWD	5.3	4.8	7.2	3.8	1.3



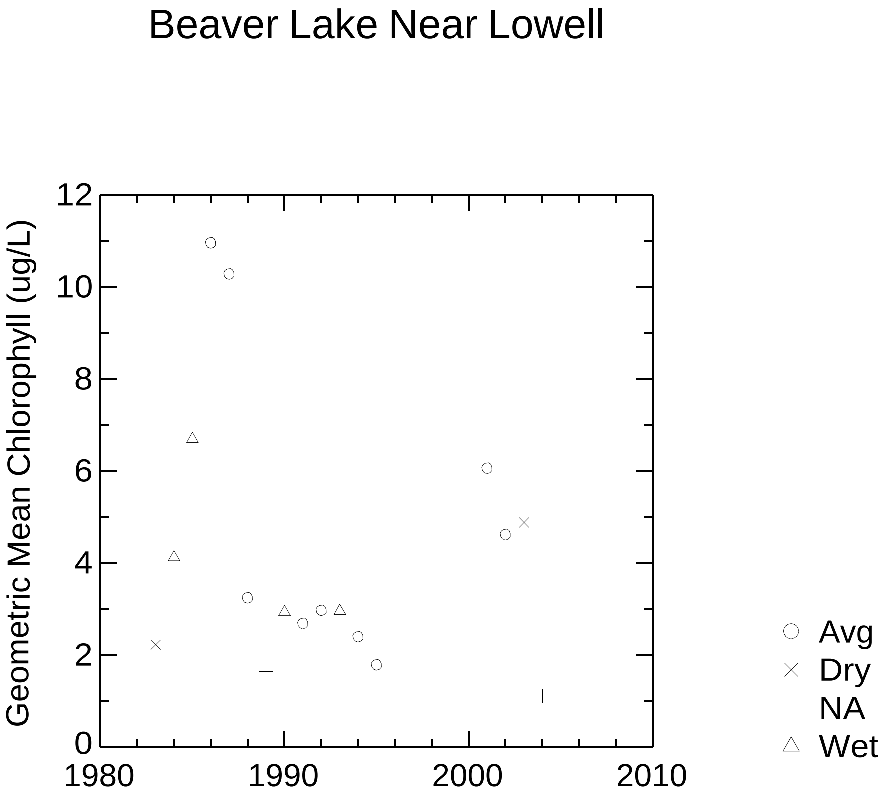
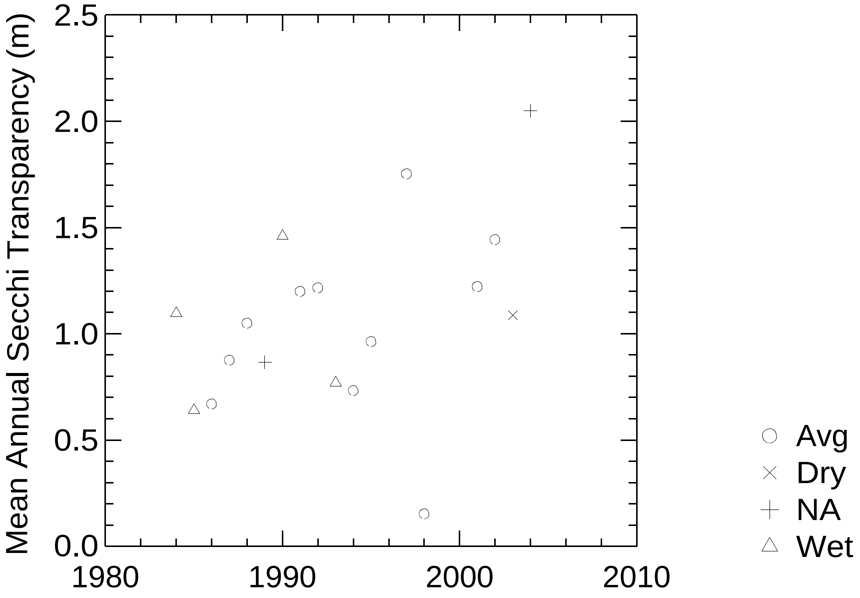


Figure 9.2. Growing season geometric chlorophyll means as a function of hydrologic category at the Highway 412 (top graph) and Lowell (bottom graph) sites. No apparent hydrologic patterns were noted. NA indicates that hydrologic classification based on precipitation was different from the classification based on

flow. Beaver Lake at Hwy 412


Beaver Lake at Hwy 412

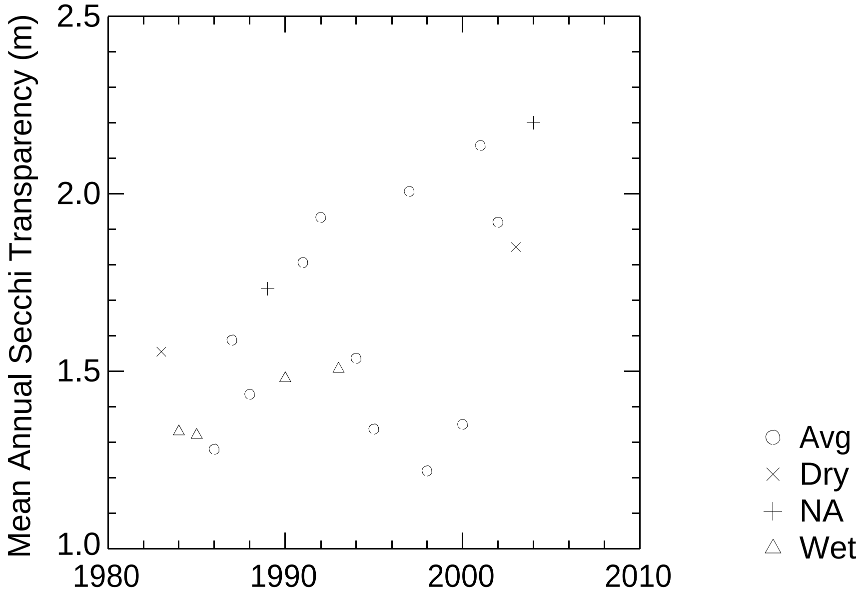

Beaver Lake Near Lowell

Figure 9.3. Average annual Secchi transparency values as a function of hydrologic category at the Highway 412 (top graph) and Lowell (bottom graph) sites. No apparent hydrologic patterns were noted, but there has been an increasing trend in water clarity at both sites over time. NA indicates that hydrologic classification based on precipitation was different from the classification based on flow.

9.3 Weight of Evidence

A weight of evidence approach was used to develop and derive numeric water quality criteria for Beaver Lake. This included considerations of:

1. Surrounding state numeric criteria for chlorophyll, Secchi transparency, total phosphorus, and total nitrogen values;
2. Ecoregion values;
3. Percentile values based on both reference lakes and extant values for Beaver Lake;
4. Statistical analyses of Beaver Lake and reference lake data;
5. Empirical nutrient loading relationships; and
6. Dynamic modeling results.

Results from these various lines of evidence are shown in Table 9.2 for chlorophyll a, Secchi depth, total phosphorus, and total nitrogen. Each of these constituents are discussed below.

Table 9.2. Weight of evidence comparison of analytical approaches for Beaver Lake water quality criteria.

Constituent	Station Standard	Percentile Distributions					
		75th Percentile		25th Percentile			
		DeGray	Ouachita	Highway 412	Lowell	Ecoregion 38	Ecoregion 39
Chlorophyll a (µg/L)	10	9	--	2.6	2.4	6.6	6.1
Secchi depth (m)	0.45 (a)	0.9	1.7	2.0	2.4	1.8	2.0
Total phosphorus (µg/L)	90 (a)	38	17	20	13	5	24
Total nitrogen (mg/L)	1.0 (a)	0.76	0.33	0.65	0.39	0.12	0.5

Constituent	Change-Point Analyses						Historical				
	Chlorophyll			Secchi Transparency			Lowell		Dam		
	DeGray	Hwy 412	Lowell	DeGray	Hwy 412	Lowell	CLS	2001/2	NES	CLS	2001/2
Chlorophyll a (µg/L)	--	--	--	--	--	--	3.9	5.9	2.7	0.8	1.9
Secchi depth (m)	--	--	--	--	--	--	1.7	2.0	4.2	5.2	5.7
Total phosphorus (µg/L)	28	60	15	21	40	48	17	20	11	5	20
Total nitrogen (mg/L)	0.42	0.5	0.31	0.52	0.5	--	0.59	0.68	0.35	0.49	0.35

Notes: (a) Recommended criteria for MS reservoirs, not WQS.

9.3.1 Chlorophyll a

The drinking water criterion for chlorophyll adopted by Oklahoma Water Resources Board (OWRB) is 10 µg/L, which is the chlorophyll concentration associated with increased risk of blue-green bacteria blooms for drinking water supplies. None of the other lines of evidence resulted in concentrations that exceeded this criterion value. DeGray was the only reference lake for which distributional (75th percentile) analysis could be performed for a station in the upper portion of the reservoir (see Figure 7.42). The distributional concentration for DeGray Lake at this upper reservoir station was 9 µg/L (Table 9.2). Distributional analyses on extant data for Beaver Lake (25th percentile) at both the Highway 412 and Lowell sites were similar – 2.4 to 2.6 µg/L (Table 9.2). Distributional analyses on extant data for Ecoregions 38 and 39 (see Section 3.2) ranged from 6.6 to 6.1 µg/L (Table 9.2). The approach recommended by USEPA (2000) was to use distributional analyses for reference lakes, when possible. Therefore, greater weight was given to the DeGray Lake chlorophyll concentration. There was no significant change in historic chlorophyll concentrations at either the Lowell station or dam station in Beaver Lake, although there was an apparent increase in chlorophyll concentrations at the Lowell station after 1991 (Figure 9.2).

Geometric mean chlorophyll concentrations were computed for the Highway 412 and Lowell stations for the period from the early 1980s through 2004 (Figure 9.2). The long-term growing season geometric means at the Highway 412 and Lowell sites were 5.2 and 3.5 µg/L, respectively. While the highest chlorophyll means occurred in the 1980s, several means greater than the long-term average have also occurred since 2000 at both sites. There was a statistical relationship, albeit a weak relationship, between growing season geometric mean chlorophyll concentrations at the Highway 412 and Lowell stations ($R^2 = 0.11$, $p < 0.1$). Increased chlorophyll concentrations at Lowell were generally associated with increased chlorophyll concentrations at the Highway 412 station (Figure 9.4). The War Eagle confluence with Beaver Lake downstream from the Highway 412 station likely confounds this relationship. If the Hickory Creek site was established in Beaver Lake, it might be expected that chlorophyll concentrations at the Hickory Creek site would be correlated with similar, but lower chlorophyll concentrations at the downstream Lowell station.

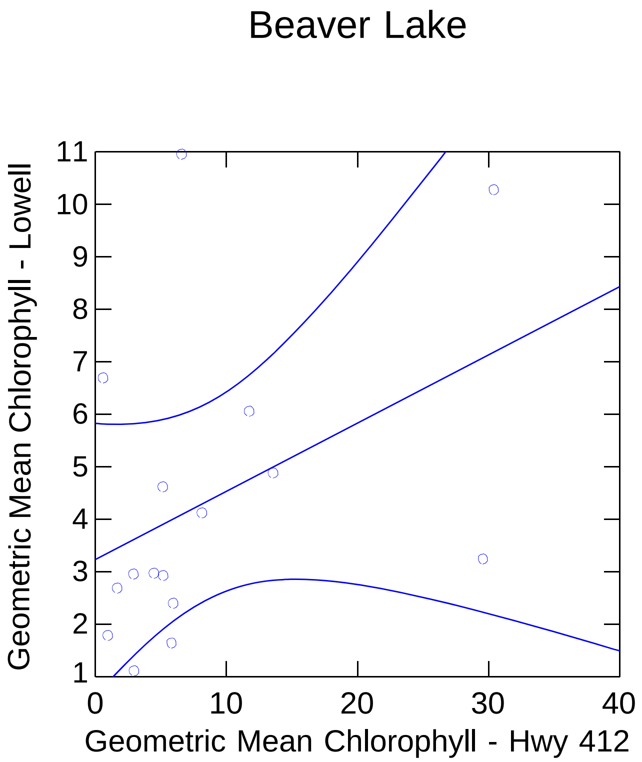


Figure 9.4. Regression relationship with 95% confidence interval between growing season geometric chlorophyll means at Highway 412 and Lowell sites (gmchl Lowell = 0.13 * gmchl 412 + 3.23; $R^2 = 0.11$, $p \leq 0.1$).

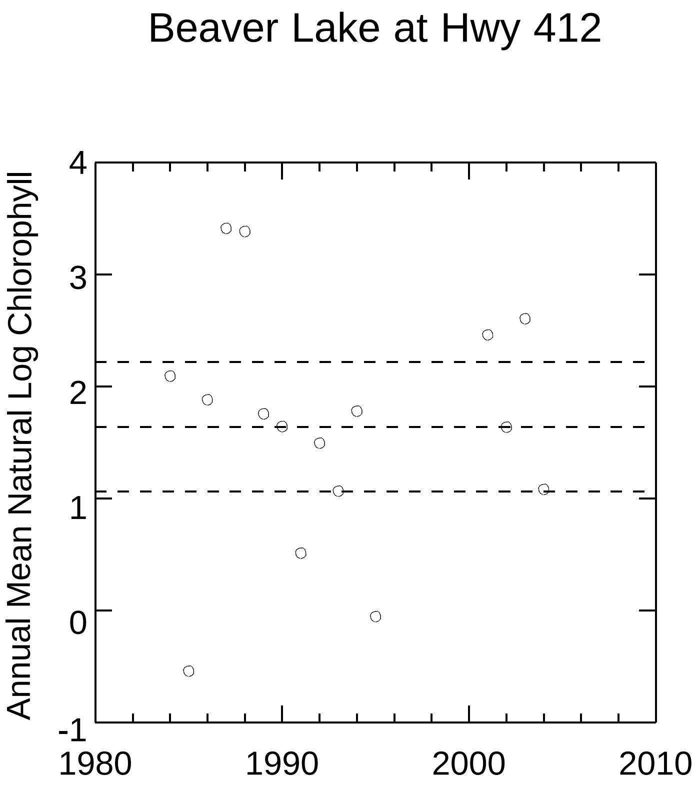
The likelihood of exceeding various geometric mean chlorophyll concentrations at the Highway 412 and Lowell sites was evaluated by considering hydrologic frequency and probability of exceedance. Initially, it was assumed there might be a direct relationship between increased nutrient loading during wet years and chlorophyll concentrations. However, there was no apparent relationship between hydrology (i.e., wet, dry, and average years) and geometric chlorophyll means or annual Secchi depth means at either the Highway 412 or Lowell stations (Figure 9.2). In some cases, chlorophyll concentrations were higher during dry years than during wet years.

A long-term geometric chlorophyll mean, with a 95% confidence interval, was determined for both the Highway 412 and Lowell stations. Geometric means and confidence interval, as log values, are shown on Figure 9.5. Variance or confidence intervals cannot be transformed into arithmetic values because of nonlinear relations in the variance estimates. The growing season geometric chlorophyll mean associated with the 95% confidence interval at the Highway 412 and Lowell stations are 9.2 and 4.8 μg/L, respectively.

The chlorophyll regression equation was used to estimate concentrations at Lowell, and subsequently at the Hickory Creek site by averaging the values from the Highway 412 and Lowell sites. The Hickory Creek site is located about half the way between Highway 412 and Lowell. A growing season geometric mean chlorophyll concentration of 10 and 12 μg/L at Highway 412 results in a predicted geometric chlorophyll mean of 4.5 and 4.8 μg/L at Lowell, with the upper 95% geometric means at Lowell estimated as 6.5 and 6.9 μg/L, respectively. The associated Hickory Creek growing season geometric chlorophyll means estimated for the Hickory Creek site were 7.5 and 8.5 μg/L, respectively. The DeGray reference lake chlorophyll concentration was 9 μg/L, which is consistent with this estimated value.

Drinking water supply is one designated use, but aquatic life and fishable are also designated uses for Beaver Lake. Chlorophyll, as an indicator of productivity, relates not only to the drinking water use, but also to Beaver Lake sport fisheries. In general, greater productivity in a reservoir results in greater sport fish standing stocks. Game fish biomass is greatest in the upper reservoir and lowest near the dam (data from AGFC 2004) (Figure 9.6). This longitudinal pattern is similar to the longitudinal patterns of nutrients and chlorophyll a in Beaver Lake. Arkansas Game and Fish Commission uses regression equations to describe relationships between fishery condition and water quality metrics. Information for Beaver Lake was used to estimate changes in sport fish standing stock that might result if chlorophyll concentrations were decreased from 7 μg/L to 3 μg/L. Sport fish standing stock would be expected to decline as chlorophyll a concentrations decrease (Figure 9.7).

There are potential conflicts between criterion values that protect drinking water while increasing fish support/recreational fishing uses of Beaver Lake. Lower chlorophyll and nutrient levels, which would be preferable for the drinking water use, can reduce productivity and the sport fishery use. There are trade-offs that must be acknowledged and considered.


Beaver Lake at Hwy 412

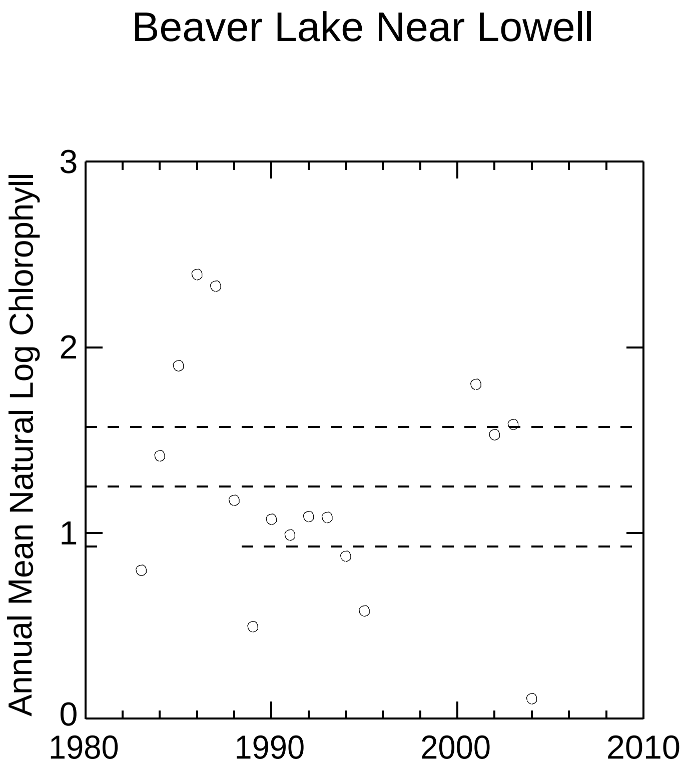

Beaver Lake Near Lowell

Figure 9.5. Long-term growing season geometric chlorophyll mean, with 95% confidence interval, for Highway 412 (top graph) and Lowell (bottom graph) sites.

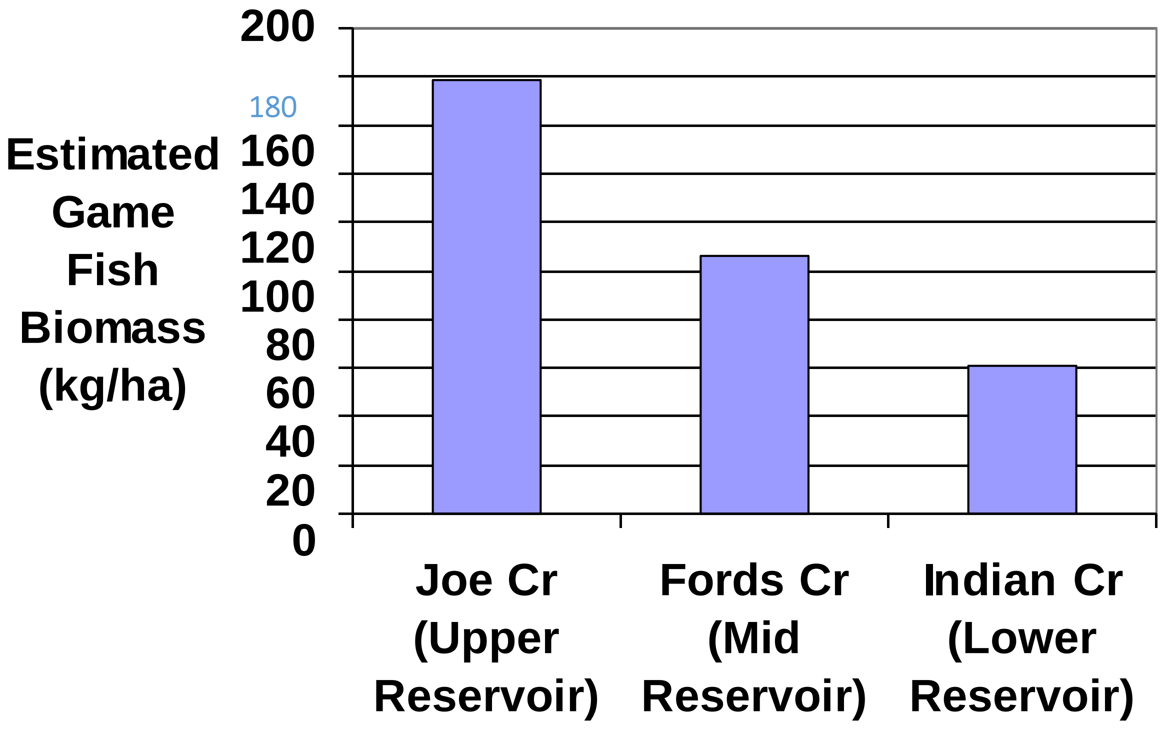


Figure 9.6. Longitudinal gradient in Beaver Lake game fish biomass.

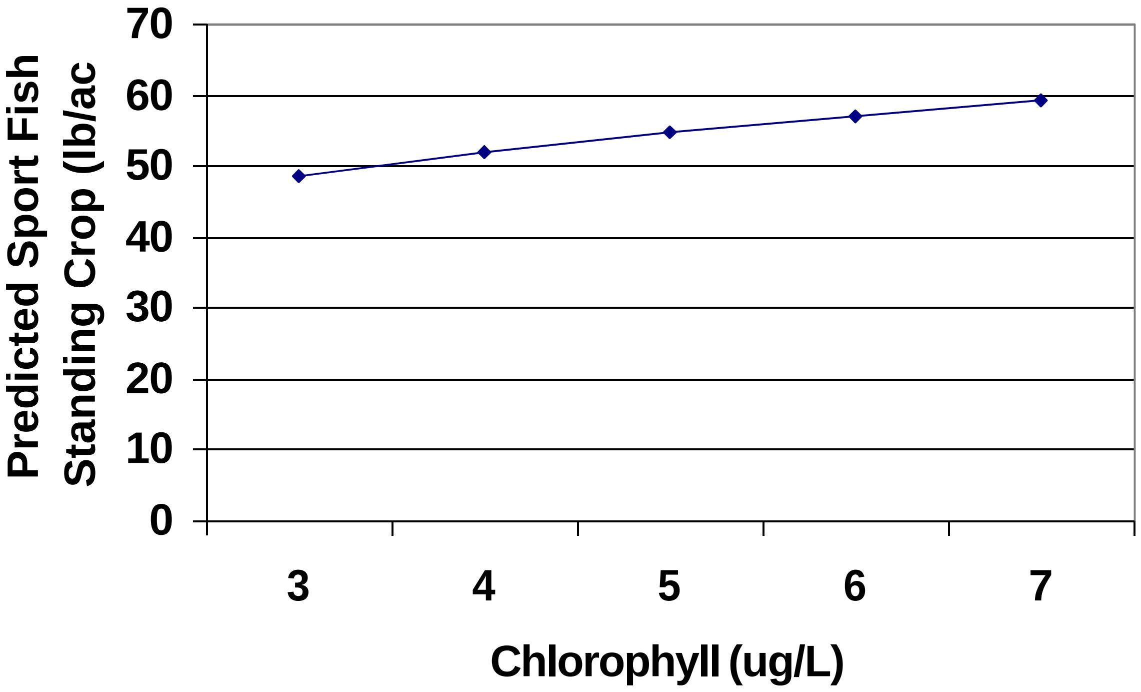


Figure 9.7. Predicted change in sport fish standing crop resulting from changes in chlorophyll concentrations.

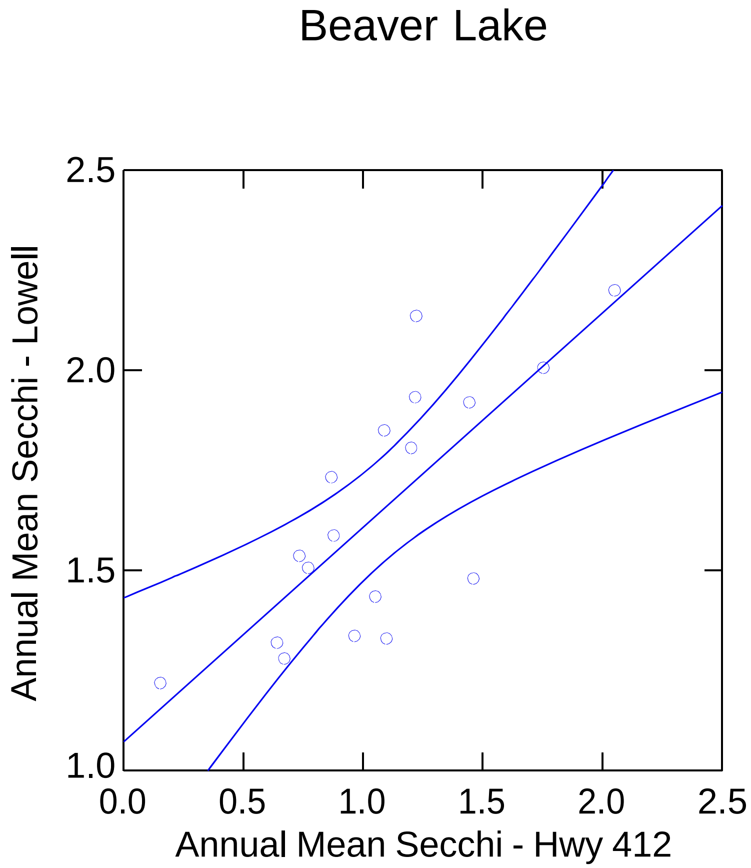


Figure 9.8. Regression relationship, with 95% confidence intervals, between average annual Secchi transparency values at the Highway 412 and Lowell sites (AM Secchi Lowell = 0.54 * AM Secchi 412 + 1.07; $R^2 = 0.55$, $p < 0.001$).

9.3.2 Secchi Depth

Secchi depth values ranged from 0.9 to 2.4 meters for upstream reservoir site locations (Table 9.2). The highest upstream reservoir Secchi values were noted at the Lowell station. DeGray Lake and Lake Ouachita Secchi depth values for upstream sites (see Figures 7.42 and 7.43) were 0.9 and 1.7 meters, respectively. Because these are reference systems, greater weight was given to these values. There has been a statistically significant increase in Secchi transparency since the 1980s at both the Lowell and Highway 412 stations (Figure 9.3). In addition, there is a statistically significant relationship between Secchi depth values are Highway 412 and the Lowell stations (Figure 9.8; $R^2 = 0.55$, $p < 0.001$).

The long-term annual average Secchi transparency values for both the Highway 412 and Lowell stations, with 95% confidence interval, are shown on Figure 9.9. The annual average Secchi transparency value associated with the lower 95% confidence interval at the Highway 412 and Lowell stations are 0.85 and 1.5 meters, respectively.

The Secchi transparency regression equation was used to estimate Secchi transparencies at Lowell, and subsequently at the Hickory Creek site. Secchi transparency values of 0.8 and 1.0 meters at the Highway 412 site resulted in predicted Secchi transparency values of 1.5 and 1.6 meters at Lowell, with the 95% estimate at Lowell of 1.3 and 1.5 meters, respectively. The estimated values at Hickory Creek were 1.15 and 1.3 meters, respectively. The DeGray Lake and Lake Ouachita Secchi transparency values ranged from 0.9 to 1.7 meters, with an average value of 1.3 meters, which is consistent with the estimated values at Hickory Creek.

9.3.3 Total Phosphorus

Total phosphorus concentrations for upstream stations in Arkansas reservoirs ranged from 13 to 60 μg/L (Table 9.2). Total phosphorus concentrations at the two upstream stations in the reference lakes were 17 μg/L and 38 μg/L (Table 9.2). Change-point analyses for total phosphorus using either the chlorophyll or Secchi depth response variable ranged from 15 to 48 μg/L at the Lowell site and 40 to 60 μg/L at the Highway 412 site (Table 9.2). No apparent patterns were revealed in bivariate plots of annual average total phosphorus concentrations with growing season geometric chlorophyll means and annual Secchi depth means (Figure 9.10). Computation of nitrogen to phosphorus ratios for Beaver Lake indicate that it is typically phosphorus-limited, with nitrogen limitation during late summer. However, the limited relationship between total phosphorus and chlorophyll or Secchi depth indicates that increased or decreased total phosphorus loads might or might not elicit an associated response in chlorophyll concentrations or Secchi depth. Therefore, establishing a total phosphorus criterion might not be warranted and should be approached with caution.

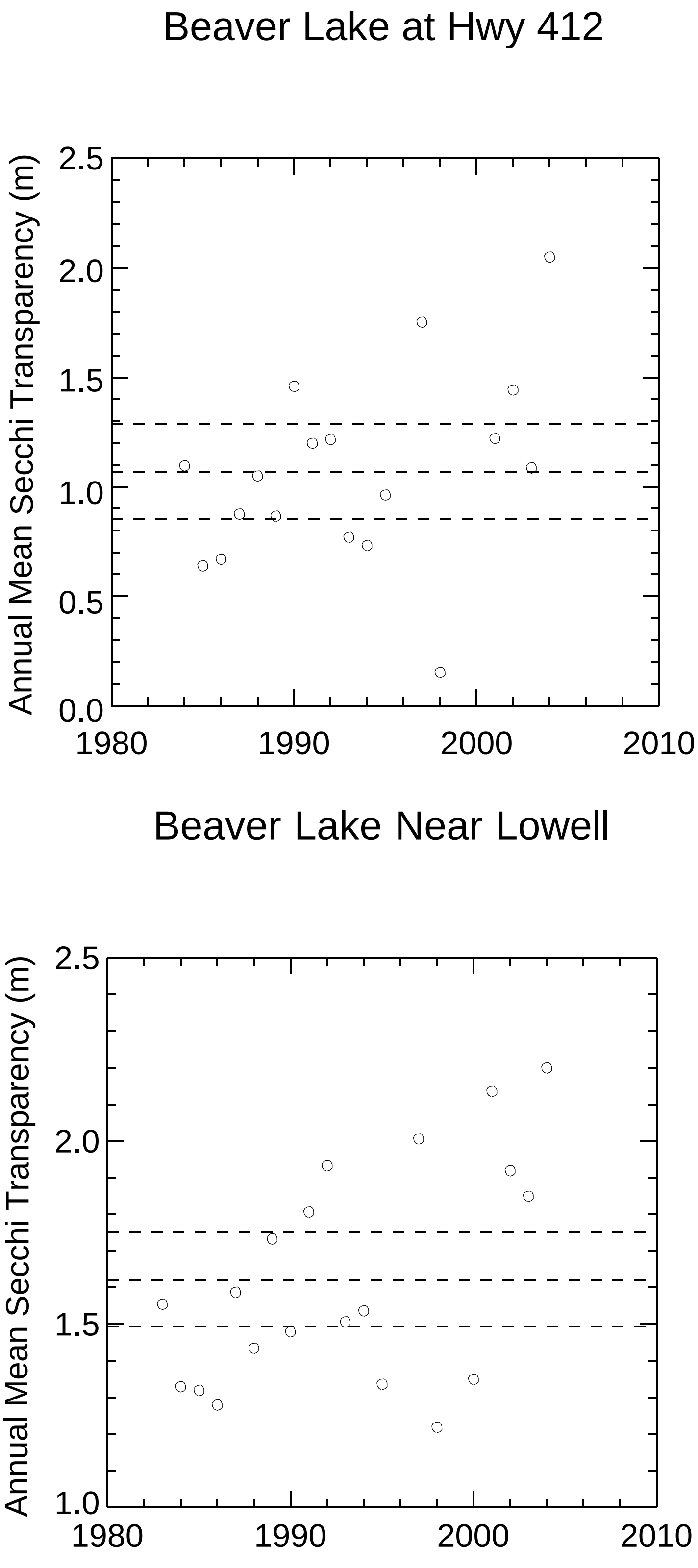


Figure 9.9. Long-term average annual Secchi transparency, with 95% confidence interval, at the Highway 412 (top graph) and Lowell (bottom graph) sites.

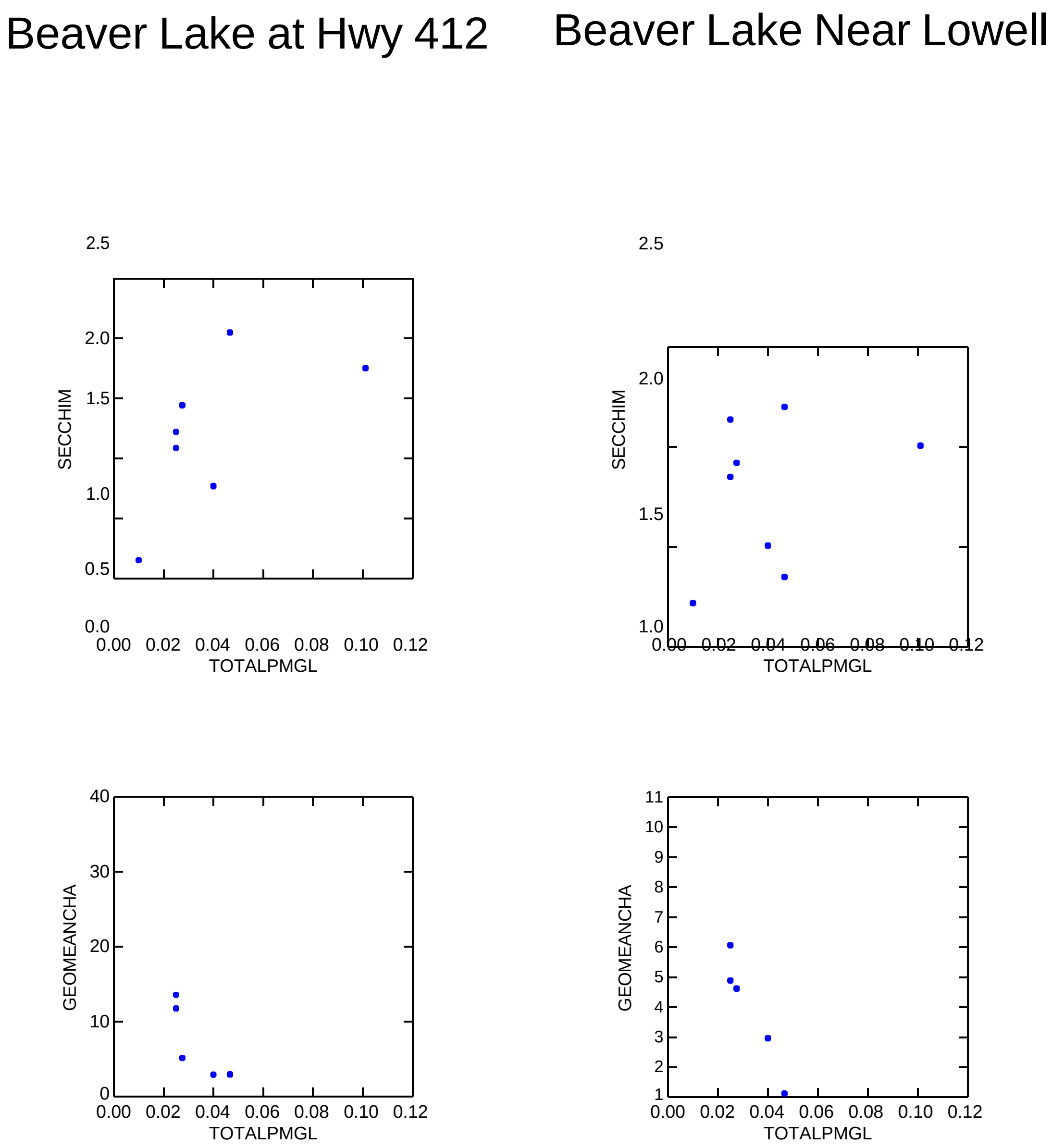


Figure 9.10. No apparent relationships were observed between annual average total phosphorus means and annual average Secchi or growing season geometric chlorophyll means at either the Highway 412 (left column) or Lowell (right column) sites.

Nutrient-loading relationships for chlorophyll and Secchi transparency were used to back-calculate the total phosphorus concentration associated with a chlorophyll value of 8 μg/L and a Secchi transparency value of 1.1 meters. These annual average total phosphorus concentrations were 40 and 30 μg/L, respectively.

9.3.4 Total Nitrogen

Total nitrogen concentrations ranged from 0.31 to 0.76 mg/L for upstream stations in Arkansas reservoirs (Table 9.2). Total nitrogen concentrations in the two reference reservoirs were 0.33 and 0.76 mg/L (Table 9.2). Based on nitrogen to phosphorus ratios, nitrogen limitation does appear to occur in late summer in Beaver Lake. There was no pattern revealed in bivariate plots of annual average total nitrogen concentrations with growing season geometric chlorophyll means and annual Secchi depth means (Figure 9.11). Increased or decreased total nitrogen loads might or might not elicit an associated response in chlorophyll concentrations or Secchi depth. Therefore, establishing a total nitrogen criterion might not be warranted and should be approached with caution.

There are few nutrient loading relationships between total nitrogen and chlorophyll or Secchi transparency. Therefore, an upper estimate of the optimal Redfield ratio (10:1 based on mass) was used to estimate a total nitrogen concentration of 0.4 and 0.3 mg/L at the Hickory Creek site.

9.4 Recommended Criteria

The site-specific effects-based numeric water quality criteria recommended for the Hickory Creek site in Beaver Lake are:

- Growing season geometric chlorophyll a concentration: 8 μg/L; and
- Secchi transparency: 1.1 meters

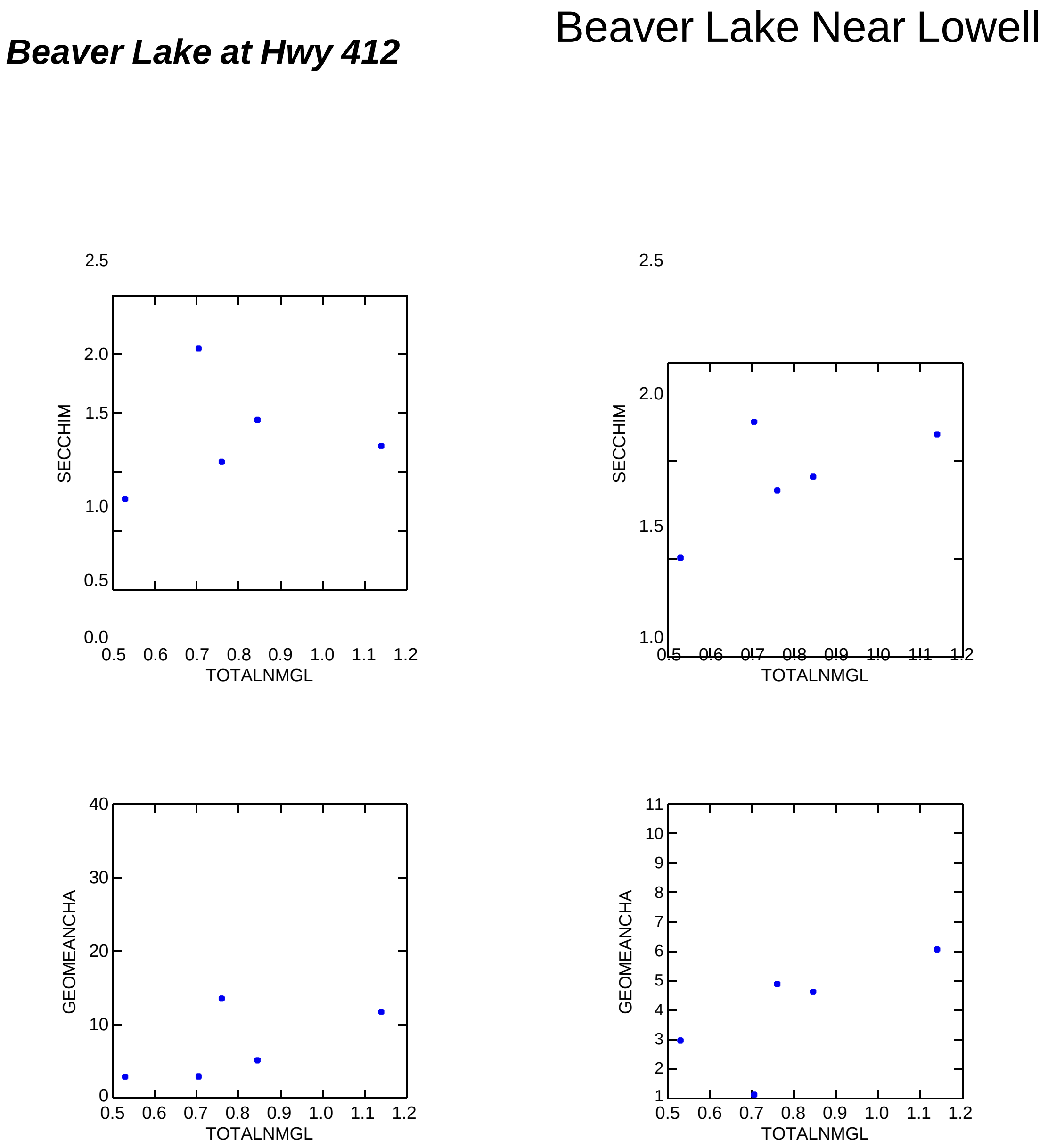


Figure 9.11. No apparent relationships were observed between annual average total nitrogen means and annual average Secchi or growing season geometric chlorophyll means at either the Highway 412 (left column) or Lowell (right column) sites.

Total phosphorus and total nitrogen criteria are not recommended because the effects-based criteria above integrate the total phosphorus, total nitrogen, and other contributing factors in their response. Total phosphorus and total nitrogen targets for the Hickory Creek site in Beaver Lake might be:

- Total phosphorus nutrient target: 40 μg/L; and
- Total nitrogen nutrient target: 0.4 mg/L.

A relative risk analysis was conducted using the proposed effects-based criteria and the nutrient targets to estimate the likelihood of exceedances based on these criteria.

9.4.1 Relative Risk of Exceedance

Relative risk analyses were used to estimate possible exceedance/attainment ratios for growing season geometric chlorophyll and annual Secchi means at Lowell based on possible chlorophyll and Secchi criteria values at the Hickory Creek site (Table 9.3). Because monitoring has not occurred at the Hickory Creek site, it is not possible to directly evaluate attainment of the recommended water quality criteria. However, using the regression equations showing on Figures 9.4 and 9.8, and assuming that Hickory Creek values were equivalent to the average of Highway 412 and Lowell values, chlorophyll and Secchi values at Hickory Creek were used to estimate corresponding values at Highway 412 and the Lowell site. The 95th percentile for the growing season geometric chlorophyll (i.e., 11 μg/L) and average annual Secchi mean (i.e., 0.8 meter) calculated for the Highway 412 site were used to derive the Lowell chlorophyll (6.7 μg/L) and Secchi means (1.5 meters) corresponding to the Hickory Creek targets.

A range of target values were evaluated to determine the relative risk of exceeding these values. The intent was to protect the designated resource uses without overly stringent water quality criteria. The relative risk of exceeding the 95th percentile value at Lowell associated with the recommended criteria at Hickory Creek (chlorophyll = 8 μg/L and Secchi = 1.1 meters) was about 10%. More stringent chlorophyll and Secchi criteria at Hickory Creek resulted in exceedances ranging from 20% for chlorophyll to 40% for Secchi at the downstream Lowell station, based on historical means for these constituents (Figures 9.4 and 9.8).

Table 9.3. Exceedance/attainment ratios (and relative risk) of exceeding different growing season geometric chlorophyll means and average annual Secchi transparency values at Lowell based on potential water quality targets for Hickory Creek.

Parameter	Station			
	Hickory Creek	Highway 412	Lowell	
	Targets	Targets	Targets	Exceedances
Chlorophyll a (μg/L)	9	12	7	2/17 (0.12)
	8	11	6.7	2/17 (0.12)
	7.5	10	6.5	3/17 (0.18)
	7	9.5	6.3	3/17 (0.18)
	6	7.8	6.1	3/17 (0.18)
Secchi transparency (m)	0.8	0.3	1.0	0
	1.0	0.6	1.2	0
	1.1	0.8	1.3	2/22 (0.09)
	1.2	0.9	1.4	6/22 (0.27)
	1.25	1.0	1.5	9/22 (0.41)
	1.4	1.1	1.5	9/22 (0.41)

The recommended chlorophyll and Secchi mean criteria at Hickory Creek are considered sufficient to protect the downstream designated resource uses without being overly restrictive for current and historical watershed activities.

9.4.2 Rationale for Criteria

Rationale for the recommended criteria are:

1. The growing season geometric chlorophyll mean of 8 μg/L at Hickory Creek provides protection for the downstream drinking water supply intakes in Beaver Lake;
2. The growing season geometric chlorophyll mean is less than the OWRB 10 μg/L criterion established to protect drinking water sources;
3. The chlorophyll and Secchi transparency mean values are considered conservative and protective of the designated uses, but should not result in frequent non-attainment assessments;
4. The recommended criteria are consistent with concentrations and values found in the reference lakes, change point and other statistical analyses and were developed through a weight of evidence approach;
5. The criteria can be related directly to the designated uses of the waterbody;

6. The criteria can be related to nutrient targets if nutrient TMDLs might be required at some future date because of non-attainment;
7. The location within the plunge point represents a dynamic area of the reservoir where attainment of the WQS should result in attainment of downstream designated uses in Beaver Lake; and
8. The criteria provide a reference frame for subsequent development of tributary numeric WQS and for discussion of watershed management practices that will protect upstream and downstream designated uses in Beaver Lake.

9.4.3 Sampling Location and Frequency

The sampling location for monitoring is recommended as the **Hickory Creek site over the old thalweg**, below the confluence of War Eagle Creek and the White River. **Monthly sampling,** including nutrient sampling in the photic zone, is recommended because it is consistent with the current ADEQ monitoring program, and it provides sufficient information for estimating growing season chlorophyll geometric means and annual Secchi transparency means.

10.0 REFERENCES

Arkansas Department of Pollution Control and Ecology. 1987. Physical, Chemical, and Biological Characteristics of Least-Disturbed Streams in Arkansas' Ecoregions: Volume 1 – Data Compilation. WQ87-06-1. Arkansas Department of Pollution Control and Ecology. Little Rock, AR.

Bureau of the Census. 1991. Census of Population and Housing, 1990: Summary Tape File 3A, Arkansas. US Department of Commerce Bureau of the Census. Washington, DC.

Bureau of the Census. 2002. Census 2000 SF3 Demographic Profiles, Arkansas. US Department of Commerce Bureau of the Census. Washington, DC.

Chapra, S.C., R.P. Canale, and G.L. Amy. 1997. Empirical models for disinfection by-products in lakes and reservoirs. Journal of Environmental Engineering. 123(7):714-715.

Downing, J.A., S.B. Watson, and E. McCauley. 2001. Predicting cyanobacteria dominance in lakes. Can. J. Fish. Aquat. Sci. 58: 1905-1908.

Fischer, H.B., E.J. List, R.C.Y. Koh, J. Imberger, and N.H. Brooks. 1979. Mixing in inland and coastal waters. Academic Press. New York.

Ford, D.E., and M.C. Johnson. 1983. An Assessment of Reservoir Density Currents and Inflow Processes. Technical Report E-83-7. U.S. Army Corps of Engineers Waterways Experiment Station. Vicksburg, MS.

FTN Associates, Ltd. 2005. Compilation of Lake and Reservoir Nutrient Criteria and Nutrient-Endpoint Relationships. Mississippi Department of Environmental Quality. Jackson, MS.

Häkanson, L. 1982. Lake bottom dynamics and morphometry: the dynamic ratio. Water Resour. Res. 18:1444–1450.

Jirka, B.H., and D.R.F. Harleman. 1979. Cooling impoundments: Classification and analyses. ASCE Jour. Hyd. Div. 106:701–715.

Kimmel, B.L., O.T. Lind, and L.J. Paulson. 1990. Chapter 6: Reservoir primary productivity. In Cole, T.M. and H.H. Hannah (eds).

Mueller, K.K., D.C. Croft, R.L. George, P.L. Johnson, and R.A. Robine. 1981. Guidelines for studies of potential eutrophication. Water Quality Planning Technical Memorandum. Bureau of Reclamation. Denver, CO.

National Climatic Data Center. 1968. Climate Atlas of the United States.

Paul, M.J., and J.L. Meyer. 2001. Streams in the urban landscape. Annual Review of Ecology and Systematics. 32:333-365.

Qian, S.S., R.S. King, and C.J. Richardson. 2003. Two statistical methods for the detection of environmental thresholds. Ecological Modeling 166:87-97.

Roy, A.H., A.D. Rosemond, M.J. Paul, D.S. Leigh, and J.B. Wallace. 2003. Stream macroinvertebrate response to catchment urbanization. Freshwater Biology 48(2): 329-346.

Savage, S.B., and J. Brimberg. 1975. Analysis of plunging phenomena in water reservoirs. J. Hydraulic Research. 13(2):187-204.

Thornton, K.W., R.H. Kennedy, J.H. Carroll, W.W. Walker, R.C. Gunkel, and S. Ashby. 1980. Reservoir sedimentation and water quality—an heuristic model in Proceedings of the Symposium on Surface Water Impoundments. ASCE. Vol. I. pp. 654–661.

Thornton, K.W., B.L. Kimmel, and F.E. Payne, eds. 1990. Reservoir limnology: Ecological perspectives. John Wiley & Sons, Inc. New York.

Walker, W.W. 1983. Significance of eutrophication in water supply reservoirs. Journal AWWA. 75(1): 38-42.

Wetzel, R.G. 1983. Limnology, 2nd edition. Saunders College Publishing. Chicago, IL.

Williams, D.T., G.R. Drummond, D.E. Ford, and D.L. Robey. 1980. Determination of light extinction coefficients in lakes and reservoirs. In H.G. Stefan, Ed. ASCE Proc. Surface Water Impoundments. II:1329–1335.

Younos, T., J.L. Walker, and C.E. Zipper. 2007. Nutrients in Lakes and Reservoirs – A Literature Review for Use in Nutrient Criteria Development. Special Report SR34-2007. Virginia Polytechnic Institute and State University. Blacksburg, VA.