BEFORE THE
ILLINOIS POLLUTION CONTROL BOARD

AMEREN ENERGY GENERATING COMPANY, Petitioner, v. ILLINOIS ENVIRONMENTAL PROTECTION AGENCY Respondent.	)))))))))))	PCB 2009-038 (Thermal Demonstration)

PRE-FILED TESTIMONY OF ANN B. SHORTELLE, PH.D.

A. BACKGROUND AND QUALIFICATIONS

1. My name is Ann B. Shortelle, Ph.D. I am a Chief Scientist with MACTEC Engineering and Consulting, Inc. ("MACTEC"). I have a Bachelor of Science degree in biology from Mercer University and a Doctorate degree in limnology from the University of Notre Dame.

2. I have 24 years of professional experience in limnology and lake and reservoir management, including surface water quality monitoring and analysis. My Curriculum Vitae is attached hereto as Attachment 1.

B. TESTIMONY

1. In May 2009, Ameren Energy Generating Company ("Ameren") engaged MACTEC to prepare a report on the conditions of Coffeen Lake with regard to phosphorus and mercury. MACTEC evaluated the conditions in Coffeen Lake and the potential for impacts on phosphorus and mercury cycling from Ameren's proposed modification to the current site-specific thermal standards. The report is entitled "Evaluation of Effects of Revised Thermal

Standards on Phosphorus and Mercury Cycling in Coffeen Lake " and is provided as Attachment 2. I incorporate the evaluation as if fully set forth herein.

2. Our report concludes that significant increases in phosphorus loading or mercury methylation over current lake conditions will not result from higher thermal limits in May and October under Ameren's proposed modification. In addition, our evaluation indicates that there is no "dead zone" within Coffeen Lake. Below is a brief summary of the report's conclusions.

Impact on Phosphorus

3. MACTEC evaluated whether prolonged stratification from an increase in water temperature would result in an increase in phosphorus in Coffeen Lake. Internal phosphorus release from sediments can serve as a source of phosphorus in lakes. Seasonal stratification within the water column of a lake results in the development of an epilimnion (surface water) and hypolimnion (bottom water). Seasonal stratification can also result in anoxic conditions in the lower portions of the hypolimnion and can promote the dissolution and release of sediment-bound phosphorus. However, the mere presence of thermal stratification does not indicate that significant internal loading will occur. Thermal stratification without anoxia produces no more phosphorus release from sediments than an unstratified lake. Thermal stratification with anoxia present over a portion of the bottom, may result in some phosphorus release from the sediments into the hypolimnion, but not in quantities sufficient to reach the epilimnion and promote algal blooms.

4. Further, water quality measurements within Coffeen Lake indicate that internal phosphorus loading is not currently contributing appreciable amounts of total phosphorus to the epilimnion in Coffeen Lake. Oxygenated hypolimnetic and epilimnetic waters were determined to always be present over the deeper anoxic waters, significantly limiting internal phosphorus

loading. Thus, no observable effect from internal phosphorus loading was observed at Coffeen Lake.

5. MACTEC also reviewed the results of Illinois Environmental Protection Agency's ("Agency") 2007 BATHTUB model used to develop the total maximum daily load ("TMDL") for phosphorus for Coffeen Lake. The Agency's model concluded that internal phosphorus loading dominates Coffeen Lake. We believe that significant modeling errors and misapplications produced a model run that did not match known lake phosphorus concentrations Thus, the Agency's model increased the amount of internal phosphorus loading in Coffeen Lake than is otherwise supported by available monitoring data.

6. An increase in thermal limits in May and October is unlikely to result in additional phosphorus loads from sediment release. MACTEC analyzed the potential impacts on phosphorus loading with the increase in thermal limits in May and October in accordance with Ameren's proposed modification. Results of the analysis indicate that the anticipated additional phosphorus load from the proposed modification is much lower than predicted from the BATHTUB modeling completed by the Agency for the TMDL. Our analysis shows that any potential sediment phosphorus release is not mixing into the epilimnion where it would be available for algal production which could potentially degrade water quality within Coffeen Lake. Our evaluation concludes that sediment phosphorus release is not a significant component of total phosphorus concentrations in Coffeen Lake surface water. Rather other phosphorus loading factors, specifically external phosphorus loading from the surrounding watershed, are more important factors in water quality within Coffeen Lake.

Impact on Mercury

7. MACTEC also evaluated whether mercury methylation is likely to increase in Coffeen Lake as a result of thermal stratification from Ameren's proposed modification to its thermal limits. Methylmercury is more readily absorbed into the tissue of aquatic organisms and tends to bioaccumulate in aquatic systems. Mercury methylation is affected by multiple parameters and is not based solely on thermal stratification.

8. The current fish consumption advisory for Coffeen Lake is based on two largemouth bass fish samples with mercury concentrations exceeding the Agency's designated level of concern. Mercury concentrations in largemouth bass in Coffeen Lake are lower than the average largemouth bass tissue concentration in Montgomery County and nearly half the level of the Illinois Counties average.

9. Our review of available data indicated that mercury concentrations appear generally low in Coffeen Lake. In addition, conditions do not appear favorable for the methylation of mercury. Ameren's proposed modification in May and October will not change lake conditions, apart from potentially lengthening the period of thermal stratification for a few days on average, annually. The minor lengthening of the period of thermal stratification will not significantly increase hypolimnetic mercury methylation rates, and will not result in increased mercury in the biota.

10. In addition, Illinois regulations controlling the release of atmospheric mercury from electric generating facilities is expected to reduce the amount of mercury deposited in Illinois water bodies. It is anticipated that fish tissue concentrations will measurably decline as a result of the reduction in mercury loading into Illinois water bodies from reductions in atmospheric mercury deposition.

Attachment 1

Ann B. Shortelle, PhD

Limnologist

Years of Experience: 24

Education:

- PhD, Limnology, 1985, University of Notre Dame
- BS, Biology, 1975, Mercer University

Dr. Shortelle has 24 years of professional experience in limnology, lake and reservoir management, surface water modeling, (WASP, Bathtub, SWMM) and environmental assessments. She has managed numerous lake and reservoir, riverine, estuarine, and wetland assessments related to eutrophication, acid deposition, toxic effluents, biomonitoring, siting and licensing, mitigation planning, and natural resource damage assessment. She has managed and conducted field and laboratory bioaccumulation studies and bioassays, and has developed and verified bioaccumulation models for contaminants in riverine systems. Dr. Shortelle is an experienced leader in surface water quality monitoring and analysis and has served as an expert witness. She has experience working with both MFLs and TMDLs.

Dr. Shortelle is currently serving on the North American Lake Management Society Board of Directors and served on the policy advisory committee to FDEP for designated use and classification refinement for surface waters.

Representative Experience

Feasibility Study and Implementation of Restoration of Taum Sauk Reservoir and Associated Black River and Tributaries, Project Principal – Initiated field and benchscale studies following an upper reservoir dam break to determine feasible methods for reservoir and downstream restoration based upon hydraulic calculations and field/ laboratory results. The resulting application allows for the immediate drawdown of the reservoir under continuously monitored conditions to prevent further environmental damage and allow for the initiation of restoration projects.

Taum Sauk Alum Injection Systems, AmerenUE, Project Principal – As part of the restoration of the Taum Sauk Reservoir, oversaw the selection of a water quality treatment, design, installation and operation of a system to remove turbidity in the Black River. Due to the regulatory requirements of no environmental impacts, liquid alum was chosen to treat the water. System parameters included creating a system with a backup to maintain river flow downstream while the flocculated fines were cleaned from the holding area. The system included design of a pumping system for regulated injection and line cleansing, ease of access for monitoring and system adjustments and dual detention areas with access for cleaning.

City of Maitland Stormwater / Lakes Management Plan, FL, Project Manager – MACTEC updated this central Florida City's plan to enhance water quality in the City's 22 named lakes, including Impaired Waters requiring TMDLs. MACTEC estimated loadings from nine urban land uses to more than 250 sub basins and outfalls contributing runoff to these lakes, incorporating the effects of in place BMPs, and evaluated potential nutrient loading reductions achievable with alternative additional BMPs. MACTEC characterized the status and trends of water quality in all the lakes, and estimated the water quality benefits and costs associated with more than 500 potential BMPs.

Wekiva River and Floridan Aquifer Nitrate Sourcing Study, St. Johns River Water Management District (SJRWMD), Principal Scientist – The Wekiva is a spring-fed river with seven 2nd magnitude springs that have elevated levels of nitrate. Its basin has relatively low population density including large natural areas and encroaching development. SJRWMD has been tasked by FDEP to develop an estimate of the sources of nitrate to ground and surface waters in the Wekiva basin, and develop preliminary load reduction strategies. MACTEC is responsible for the development of basin-wide nitrate loading estimates to groundwater and surface water. Source types that will be evaluated include municipal and industrial wastewater (point sources), septic tanks, stormwater runoff, fertilizer use (agricultural, residential, golf courses), and atmospheric deposition. Nitrate loads will be partitioned by source types and by land use. Responsibilities include nitrate loading modeling and budgets.

City of Lakeland, Southwestern Basin of Lake Parker: BMP Alternatives Analysis, FL, Project Manager – This project's objective is to provide engineering services to determine Lake Parker Water Quality Improvement Project Best Management Practice (BMP) Identification, Selection, and Ranking for the Southwestern Basin of Lake Parker, an impaired waterbody. Tasks include water quality and hydraulic modeling, nutrient loading estimates, and estimates of BMP nutrient reductions, prioritization of BMPs, conceptual design, and recommendations. Phase II includes design, permitting, and construction management.

Hydraulic and Wetlands Restoration Projects, Pithlachascotee River Wetland Restoration Project, SWFWMD, Project Manager – MACTEC is developing the wetland restoration and FDOT mitigation plans for three areas of the Pithlachascotee River. This effort will restore hydraulic functions, wetland functional values, wildlife habitat restoration, as well as provide mitigation acreage and UMAM is being used to provide "lift" documentation. Dr. Shortelle is responsible for the engineering and environmental monitoring analyses, design, permitting and construction services to accomplish the objectives for the sites.

Hydraulic and Wetlands Restoration Projects, Serenova Preserve Pond and Associated Wetland Restoration Project, SWFWMD, Project Manager – MACTEC is developing the wetland restoration and FDOT mitigation plans for a pond with associated wetland strands and sloughs at the Serenova Preserve. Historic modifications of the pond and drainage of the wetlands have altered site hydrology, and severely impacted the wetlands. This effort will restore hydraulic functions, wetland functional values, wildlife habitat restoration, as well as provide mitigation acreage and UWMAM is being used to provide "lift" documentation. Dr. Shortelle is responsible for the engineering and environmental monitoring analyses, design, permitting and construction services to accomplish the objectives for the sites.

Assessment of Nutrient Management Alternatives, SN Knight North, SJRWMD, FL, Project Manager – Managing the completion of the data evaluation and review tasks for a series of lab and field experiments to evaluate the efficacy of various compounds for possible wide-scale use is a nutrient management program, to include benthic invertebrate sampling and processing. Field work includes collection of water quality data, in situ water quality monitoring and collection of water sample.

Upper Shingle Creek Basin and Western Boggy Creek Basin Water Quality Assessment, Modeling and Planning, Orange County, FL, Project Manager – MACTEC is developing a nutrient loading and reduction evaluation for the management and protection of the Upper Shingle and Western Boggy Creek Basins. Responsibilities include monitoring and analysis of significant pollutant inputs in to the surface and groundwater; revision of watershed and basin delineations; development of hydrologic and nutrient budgets; development of nutrient limitation water quality models; development of alternatives for water quality improvements.

Seminole Reservation Non-point Source Management Plan, Chief Scientist – MACTEC is revising the Seminole Reservation Non-point Source Management Plan. This plan includes identifying data gaps, preparation of water quality models and comparison to the Tribes Water Quality Code and the Water Quality Guidelines. Watershed basins and land use were obtained and field verified for use in the modeling of the seven reservations. The water quality models were prepared for each watershed within the reservation to identify areas of concern. Recommendations for filling the data gaps within the existing sampling plan were outlined and new sample points were identified. The list of recommended BMP's focused on potential water quality per land use type was revised. The revised Plan focuses specifically on each area to provide straight forward and cost effective BMP recommendations. Recommendations in the Plan also contain ranking BMP projects for implementation, which include cost opinions, schedules, and community education associated with the BMP.

Seminole Reservation Numeric Nutrient Criteria Development Plan Central and South Florida, Project Manager – MACTEC is revising the Seminole Reservation Numeric Nutrient Criteria Development Plan. Duties include assisting the Tribe with task by analyzing existing and newly collected data for trends; utilizing statistical analysis between parameters such as total phosphorus, total nitrogen, chlorophyll a, total Suspended Solids, and trophic state index. Criteria will be developed to support each of the waterbodies' designated use classifications within the respective reservations. Recommendations will be made to the Tribe in order to meet the EPA requirements.

Lake Conine Watershed Restoration and Stormwater Treatment Project, Principal – Modeled and designed and permit the South Lake Conine Watershed Restoration Project on a city-owned, 34 acre, vacant, lakefront parcel. This project includes design of a regional stormwater pond, and stormwater treatment train to finish with a polishing wetland before cleaner water is discharged to Lake Conine, an impaired waterbody with a nutrient TMDL. The design also specifically optimizes nutrient load reductions to improve water quality in the lake, and satisfy TMDL load reduction targets. MACTEC will also provide the City with bidding services, construction services and post construction water quality monitoring.

Limnological / Nutrient Investigations, Neponset Reservoir. Technical Expert – Field monitoring and statistical analyses to evaluate whether or not phosphorus in the reservoir sediments are above background. Additionally, analyses were conducted to evaluate the effects of metals and other constituents present in the sediments on ecological receptors. Analyses included bulk sediment and pore water sampling, SEM/AVS evaluations, sediment toxicity testing, ecological risk assessment, comparisons to other waterbodies, and nutrient loading modeling.

SFWMD Biscayne Bay Coastal Wetlands / Basin Restoration, FL, Project Director – Multiple site project involving site assessments of thousands of acres in southeast Florida that are part of the Comprehensive Everglades Restoration Project land acquisition program. Assessments have been performed on over 45 sites where recognized environmental concerns were noted. Dr. Shortelle is currently directing basin wide ecological risk assessments on several parcels formerly used for agricultural purposes in order to determine potential impacts of pesticides and metals to aquatic organisms and birds after the lands are re-flooded. These assessments include consultations with USFWS and SFWMD personnel to ensure compliance with ESA and NEPA. Remedial recommendations and remedial costs are provided to the SFWMD to assist in the acquisition negotiations and planning.

North Shore Restoration Area Feasibility Study SJRWMD, Lake Apopka, FL, Principal Scientist – Responsible for technical quality and completeness of the feasibility study evaluating alternatives to restore the NSRA of Lake Apopka to functioning wetlands. This project focuses on technologies that may used to mitigate the adverse impacts associated with organochlorine pesticide residues in surficial muck soils necessary to accomplish the restoration of these wetlands.

Water Quality, Hydraulics, and Aquatic Biology; Pee Dee River Electrical Generating Station, Santee Cooper, Project Principal – MACTEC was retained by Santee Cooper to review and research a number of environmental topics that were needed to update an environmental assessment for a proposed power plant located on the tidally influenced Pee Dee River. Responsibilities included surface water assessment, which specifically dealt with establishing a baseline for surface water and sediment quality, hydraulic and hydrologic conditions, and aquatic biota conditions. Modeling included the potential for a dissolved oxygen sag, salinity gradient and new plant influence on the baseline salinity regime, and mercury fate and transport.

Ocklawaha River Basin and Emeralda Marsh Nutrient Control Studies, SJRWMD, Eureka, Ocala Areas, FL, Project Manager – Nutrient control and floc distribution studies (including alternative treatments for restoration of wetlands) within Ocklawaha River Basin near Sunnyhill Farms and Ocklawaha Prairie (wetlands), and in Emeralda Marsh Conservation Area. Responsible as Contract Manager and Supervising Limnologist for evaluations of restoration alternatives, such as restoring natural wetland hydrology to sites including Ocklawaha Prairie, Sunnyhill Long Farm, Eustis Muck Farm and in Emeralda Marsh Conservation Area. Sampling and analyses conducted to evaluate potential impacts to Trustee species from restoration implementation.

Assessment of Nutrient Management Alternatives, SN Knight North, SJRWMD, FL, Project Manager – Managing the completion of the data evaluation and review tasks for a series of lab and field experiments to evaluate the efficacy of various compounds for possible wide-scale use is a nutrient management program, to include benthic invertebrate sampling and processing. Field work includes collection of water quality data, in situ water quality monitoring and collection of water sample.

North Shore Restoration Area Feasibility Study SJRWMD, Lake Apopka, FL, Principal Scientist – Responsible for technical quality and completeness of the feasibility study evaluating alternatives to restore the NSRA of Lake Apopka to functioning wetlands. This project focused on technologies that may used to mitigate the adverse impacts associated with pesticide residues in surficial muck soils necessary to accomplish the restoration of these wetlands.

Expert Witness, Effects of Construction and Dewatering on Protected Wetland Species – Records review and depositions to support litigation against a remediation contractor and PRP group for avoidable impacts to protected wetland species in forested riparian wetland setting. Analysis included identification of alternative mitigation strategies, and resulted in settlement favorable to the client.

SJRWMD, Ecological Risk Assessments, Land Acquisition and Restorations, Project Manager – Sampling and analyses to evaluate the potential effects of flooding, water impoundment, and other water regime manipulations associated with proposed restorations at Eustis Muck Farm, Ocklawaha Prairie, Sunnyhill. Evaluations included potential effects to aquatic receptors such as aquatic macrophytes, fish, and invertebrates, and effects on protected species.

Lake Tahoe Master Plan for Erosion Control and Storm Water Management, Lake Tahoe Basin, Nevada, Senior Technical Review – The Nevada Department of Transportation (NDOT) is proceeding with the preparation of storm drainage and erosion control master planning and final design documents for roadways within the Lake Tahoe Basin that are owned and maintained by NDOT. The goal of the project is to identify regional and local erosion control and water conveyance and quality management measures that will reduce discharge of sediments and pollutants into Lake Tahoe. Approximately 38 miles of NDOT right-of-way within the Lake Tahoe Basin are included in the effort.

Best Management Practices for Residential Canals, Southwest Florida Water Management District, Project Manager – Conducted an evaluation of hydrological, limnological and engineering parameters associated with freshwater and estuarine canals to develop BMPs and design alternatives to enhance water quality and natural wetland systems.

Watershed Fate and Effects of BTEX in Hall's Brook Pond and Wetlands, Woburn, MA, Project Manager – Performed biodegradation tests on site sediments to determine the extent of natural processes mitigating the transport and fate of BTEX from groundwater to surface water in this flow way. Site investigations included water budget, flow pathway determinations and potential fate of benzene and toluene in this drainage system.

Duck Lake and Tributaries Diagnostic Analysis and Remediation of Sewer Line, Robbins AFB, Georgia, Supervising Limnologist – Designed and implemented studies to isolate the source and location of high levels of fecal coliforms detected in Duck Lake. A sewer line brake was determined to be discharging into an upstream tributary. Surface flow was diverted around the source until it could be restored. Monitoring of the impoundment and tributary were conducted until a recommendation could be made to reopen the lake.

Impacts of MGP Residues on Aquatic Resources in the Nashua River, NH, Task Manager – Conducted riverine investigations into the fate and effects of PAHs and metals on aquatic receptors, including benthic invertebrates, macrophytes, and fish, in the river. Investigations included hydrologic discharges of groundwater through sediments into the surface waters, determination of porewater chemistries, and population studies.

Watershed Mercury Investigation, PPG Industries, Inc., Lake Charles, LA, Task Manager – Conducted field sampling of surface water, sediments, and biological samples to evaluate the occurrence of mercury in these media and identify approved trends or patterns thorough statistical comparisons.

Ecological and Wetlands Assessment in Big Cypress Swamp, Confidential Client, Task Manager – Managed and evaluated the potential for adverse effects due to chloride exposure to terrestrial and aquatic receptors via multipathway exposure. Activities included determinations of wetland hydroperiods, and monitoring to determine the extent of impacts to wetland species.

Marathon Battery NPL Site, Wetlands Assessment, Vincent, Elkins, and Gould – Evaluated the selected feasible alternative for the tidal marsh including identification of expert witnesses, potential for adverse environmental effects associated with dredging, and the efficiency of the proposed marsh revegetation in restoring wetland functional values.

Bench Scale Determination of Chemical Dosages for Eustis Muck Farm Nutrient Removal, Project Manager, SJRWMD – Conducted laboratory experiments with site water to determine the appropriate dosage and chemical ratio of alum to sodium aluminate (for aluminum and buffering capacity) to accomplish optimum nutrient removal without undue stress to the ecosystem. Testing included dosing experiments, toxicity testing, and laboratory analyses.

UOP, Inc., NPL Site Wetlands/Ecological Assessment, East Rutherford, New Jersey, Task Manager – Conducted an environmental risk assessment at a site involving significant exposure pathways, including potentially contaminated sediments and biota, in the Hackensack estuary and wetlands. This work included jurisdictional boundary determinations, field studies of floral and faunal impacts, and ecological modeling of affected both terrestrial and aquatic estuarine species.

Charles George Landfill Wetlands Assessment, EPA – Conducted field investigation of the fourteen wetlands at this Superfund site to determine wetland boundaries, extent of contamination, evaluate potential adverse effects due to proposed remedial alternatives, and design mitigative measures for the chosen alternative. Studies included flora, benthic invertebrate, and fish investigations.

Clean Lakes Diagnostic and Feasibility Studies, Various Sites, MA, Project Manager and Limnologist – Developed workplans, and executed diagnostic/feasibility studies for nutrient impaired lakes and reservoirs. Determined water budgets and sources and sinks of nutrients, and developed feasible alternatives for reductions in nutrient loadings and/or surface water restoration projects.

Bioaccumulation Modeling and Site Assessment, Rocky Spring Lakes, Chambersburg, PA Limnologist – Responsible for conducting a study of mercury cycling in aquatic plants, fish, water fowl and abiotic media to identify and quantify the source of episodic mercury exposure to aquatic receptors. This evaluation included sampling and analysis of spring flows and discharges into the Rocky Spring watershed surface waters, and subsequent fate to the surface water impoundment.

Ripogenus Dam Relicensing Hearings, Bowater/Great Northern Paper Company, Millinocket, ME, Expert Witness – Testified at the ME Land Use Regulation Commission hearings in favor of the Ripogenus Dam Relicensing plan regarding the mercury cycling issues related to plant operations of the impoundment and potential for adverse effects to fish and wildlife. Federal procedures for relicensing, and additional investigations regarding mercury biogeochemical cycling in impoundments were also conducted.

Yaworski NPL Site on Quinebaug River, PRP Committee, Senior Scientist – Responsible for preparing endangerment assessment review comments. Designed and conducted field investigation of the site associated wetlands and Quinebaug River to evaluate the potential for adverse environmental effects and bioaccumulation of metals and organic compounds in fish.

TCDD/TCDF Risk Assessment Manual, National Council for Air and Stream Improvement (NCASI) – Managed effort to realistically model dioxin bioaccumulation in fish exposed to contaminated effluent. The model includes fate and transport of dioxin in rivers, dynamics of bioaccumulation and fish physiological and behavioral parameters, and estimation of risk based on fish consumption. The model was designed for use by the pulp and paper industry.

Estuarine and Riverine Fate and Transport of HCB and HCBD, PPG, Inc., Task Manager – Conducting field investigations and modeling to determine the fates of HCB and HCBD in the Calcaseieu estuary. Responsible for conducting the evaluation of contaminant body burdens in a wide variety of organisms to determine bioaccumulation factors and the evaluation of the potential risks to human and nonhuman receptors.

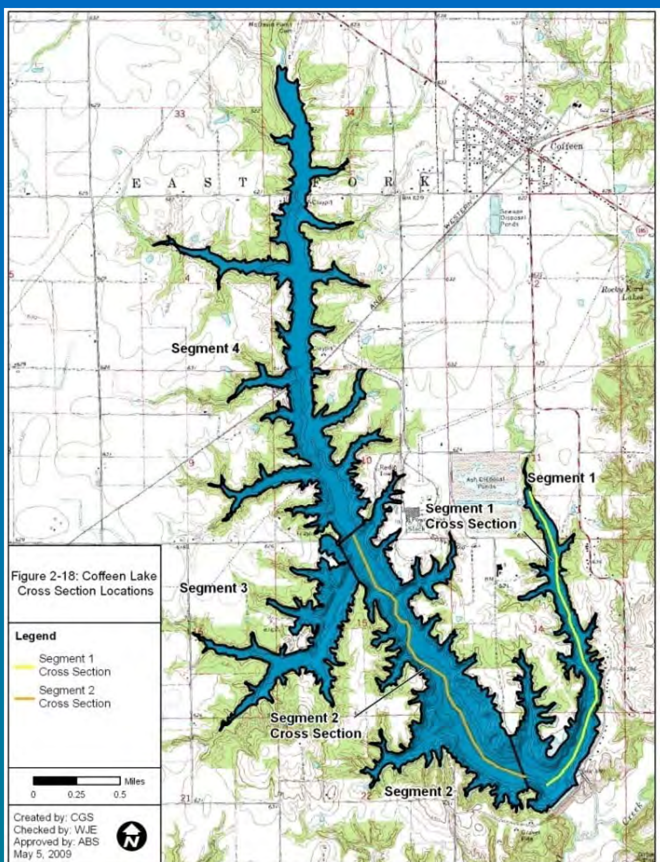
Expert Technical Comparison of NOAA Documents Relevant to Shortnose Sturgeon, Confidential Client, Philadelphia, PA, Technical Expert – Reviewed both an ecological risk assessment and the shortnose sturgeon recovery plan for consistency, and technical relevance to existing shortnose sturgeon resources and potential exposure to PCBs, metals, and other chemicals in sediments from an NPL site in the Delaware River. Evaluated watershed sources of PCBs and probable uptake scenarios for tissue residues.

Floreffe Oil Spill Assessment, Kirkpatrick and Lockhart (Representing Ashland Oil Company), Task Manager – Conducted field investigation and ongoing analyses of the Ohio and Monongahela Rivers according to Natural Resource Damage Assessment procedures to determine environmental and human health effects due to the spilling of No. 2 diesel fuel. Responsible for directing laboratory and field investigations, including chemical fate and transport and bioaccumulation analysis, to evaluate the potential for adverse health effects associated with consumption of fish possibly contaminated with inorganic and organic substances.

Representative Publications and Presentations Available upon Request.

Attachment 2

Evaluation of Effects of Revised Thermal Standards on Phosphorus and Mercury Cycling in Coffeen Lake



Prepared for:
Ameren
St. Louis, Missouri

Prepared by:
MACTEC Engineering and Consulting, Inc.
3199 Riverport Tech Center Drive
Maryland Heights, Missouri

May 2009

Evaluation of Effects of Revised Thermal Standards on Phosphorus and Mercury Cycling in Coffeen Lake

Prepared for:

Ameren

St. Louis, Missouri

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MACTEC

May 11, 2009

Ann B. Shortelle, PhD
Chief Scientist

William Elzinga
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Executive Summary

MACTEC Engineering and Consulting, Inc., (MACTEC) evaluated potential for impacts on phosphorus and mercury cycling from proposed modifications to current site-specific thermal standards in Coffeen Lake in support that raising the thermal limits for the months of May and October will not result in significant increases in phosphorus loading or mercury methylation over current lake conditions.

Illinois EPA claimed that Ameren failed to address the impact of the proposed thermal limits on total phosphorus and mercury levels in Coffeen Lake, in addition to failing to address the impact on Lake Habitat. Illinois EPA stated a concern that higher temperatures of Coffeen Lake in May and October may result in prolonged stratification which can increase phosphorus levels and methylmercury levels.

Phosphorus is a limiting nutrient in Coffeen Lake and is therefore an important component of its long-term water quality. Internal phosphorus release from sediments can serve as an additional source of phosphorus loading to the lake, yet is ultimately dependent on a number of chemical and physical factors which occur at the sediment-water interface. The mere presence of thermal stratification does not indicate that significant internal loading will occur as a result. Despite the potential for seasonal sediment phosphorus release from the sediments, water quality measurements within Coffeen Lake indicate that internal phosphorus recycling is currently not contributing appreciable amounts of total phosphorus to epilimnetic surface water. Oxygenated hypolimnetic water and epilimnetic waters (DO> 1 mg/L) were always present overlying these deeper anoxic layers as shown by cross section for May and October. The data and this analysis clearly show that there is no “dead zone” within the lake.

TMDL assessments for Coffeen Lake attribute elevated phosphorus concentrations to external watershed loading, primarily due to expansive agriculture surrounding the lake. External loading as a driver of water quality is also apparent in high phosphorus concentrations measured in the shallow northern portions of the lake. Additionally, seasonal water quality comparisons do not show elevated phosphorus or chlorophyll-a concentrations during summer stratification of the water column, indicating that phosphorus is either not being released in large volumes from the sediment or is not being mixed into the epilimnion where it may be available for algae production.

Review of the original TMDL BATHTUB (2007) model revealed significant modeling errors and misapplications which led to the erroneous conclusion that internal phosphorus loading dominates Coffeen Lake. These errors produced a model run which did not match known lake phosphorus concentrations. To compensate for this “under-prediction of observed phosphorus concentrations”, the modelers introduced an additional internal phosphorus load (the BATHTUB model already incorporates internal loading) to force the model to calibrate. The conclusions and load reduction requirements of the original TMDL were not revised, despite these errors and discrepancies. However, available monitoring data do not confirm this estimated level of internal loading (see Section 2.1.1).

An evaluation of potential impacts associated with modified thermal discharge during the months of May and October was also performed to quantify the potential for additional phosphorus release and

anticipated impacts to surface water quality. Results of this analysis indicate that the additional phosphorus load which may be anticipated from the proposed modification ranges from 329.1 kg P/year to 658.1 kg P/yr under existing permit conditions, which is much lower than predicted from the BATHTUB modeling completed for the TMDL. Additionally, any phosphorus released from the sediment is not expected to reach the epilimnion, and is therefore unavailable for biological production within Coffeen Lake. Based on seasonal water quality comparisons sediment phosphorus release does not appear to be an important component of surface water phosphorus loading within Coffeen Lake. Future modifications to thermal discharge limits from the Ameren Power Generating Plant are unlikely to present additional phosphorus loads from sediment release in the future, and therefore are not a threat to the existing water quality of Coffeen Lake.

Mercury readily bioaccumulates in living tissues, and thus, fish consumption advisories are common nationwide. Coffeen Lake is currently included in the Illinois fish consumption advisories based on two fish tissue samples with mercury concentrations exceeding the Illinois EPA level of concern of 0.06 mg/kg. These samples consist of two composite (5 fish per composite) samples of largemouth bass filet with concentrations of 0.08 and 0.09 mg/kg of mercury. Because largemouth bass are a top aquatic predator in the lake, although the sample size is small, the results are conservative for the lake. Illinois EPA’s concern for Coffeen Lake is that mercury methylation is likely based on thermal stratification throughout the summer months.

Methylation is affected by multiple parameters and cannot be based solely on thermal stratification. There are multiple indicator parameters that may predict whether the methylation of mercury is favorable under certain conditions. While general trends may be observed as these indicator parameters increase or decrease, the suite of parameters should be evaluated as a whole to predict the potential for methylation of mercury.

Based on the available Coffeen Lake data, mercury concentrations appear to be generally low and conditions do not appear to be favorable for methylation. Current sources of methylation may be within the lake or occurring in the watershed, but appear low. The proposed change in the thermal standard affecting May and October conditions does not substantially change lake conditions, although thermal stratification may persist for more days on average, annually. This change is minor, and does not represent a change that could or would significantly increase hypolimnetic mercury methylation rates. It is anticipated that the change, if any, would be so small, that it would not result in increased mercury in the biota. Fish tissue concentrations are anticipated to measurably decline, however, as a result of regional mercury load reductions.

1.0 Introduction

1.1 Purpose

This report provides an evaluation of the potential for impacts on phosphorus and mercury cycling from proposed modifications to current site-specific thermal standards in Coffeen Lake. Coffeen Lake is a 384 hectare reservoir constructed as the source for steam condenser cooling water for the 945-MW Coffeen Power Station (Coffeen or the "Station"), located in Montgomery County in central Illinois, approximately 1 mile south of the city of Coffeen, Illinois and 50 miles northeast of St. Louis, Missouri (Figure 1-1).

Current thermal standards for Coffeen Lake specify that the months of May and October fall within an 8-month "winter" period extending from October through May. During this 8-month period, thermal discharges from Coffeen Power Station may not result in water temperatures that exceed:

- 89°F as a monthly average, or
- 94°F as a maximum for greater than 2 percent of the hours during that period, as measured at the boundary of a 26-acre mixing zone.

Abnormally warm temperatures and low precipitation in recent years have resulted in instances, particularly during late May and early October, when Coffeen Power Station has had to reduce electric generation (derate) in order to comply with the above thermal standards. The existing limits of 89°F and 94°F were not established on the basis of definitive thermal requirements for the aquatic community and fish populations of Coffeen Lake during these two months. Rather, they were set as assurance that thermal limits set for the "summer" months of June through September (105°F mean or 112°F maximum for greater than 3 percent of the hours) were not applied year-round.

The petitioner, Ameren Energy Generating Company (Ameren), proposed relief in the form of the following revised standards for the months of May and October:

- 96°F as a monthly average, and
- 102°F as a maximum for more than 2 percent of the hours during that period.

The Illinois Environmental Protection Agency (EPA) denied the proposed revised standards in April 2009. Specifically, the Illinois EPA claimed that Ameren failed to address the impact of the proposed thermal limits on total phosphorus and mercury levels in Coffeen Lake, in addition to failing to address the impact on Lake Habitat. The Illinois EPA stated a concern that higher temperatures of Coffeen Lake in May and October may result in prolonged stratification which can increase phosphorus levels and methylmercury levels.

This report presents an evaluation of the conditions in Coffeen Lake with regard to phosphorus and mercury supporting the conclusion that raising the thermal limits for the months of May and October will not result in significant increases in phosphorus loading or mercury methylation over current lake conditions.


Christian
Nokomis
Shelby
Montgomery
Litchfield
Hillsboro
Coffeen
Lake
Fayette
Vandalia
Bond
Greenville
Figure 1-1: Site Location Map - Coffen Lake, Montgomery County, Illinois
Legend
Miles
0
2.5
5
Created by: CGS
Checked by: WJE
Approved by: ABS
May 5, 2009
Illinois
Area of Interest

1.2 Report Organization

In this report, the effects of phosphorus and mercury cycling of Coffeen Lake are evaluated. MACTEC evaluated temperature and lake chemistry data collected during the SIUC and Illinois EPA studies to evaluate the thermal environment of Coffeen Lake, specifically examining the stratification and anoxic conditions of the lake. A general description of the thermal environment in the lake is explained in Section 2.

MACTEC evaluated the phosphorus loading of the lake and the potential impacts of revised thermal standards on phosphorus cycling as further explained in Section 2. Phosphorus is a limiting nutrient in Coffeen Lake and has been evaluated by the Illinois EPA to ensure the lake meets its designated use under the Total Maximum Daily Load (TMDL) determination (Illinois EPA, 2007; Illinois EPA, 2009a). MACTEC evaluated the potential for increased internal loading of phosphorus as a result of increasing water temperatures.

In Section 3, MACTEC evaluated methylmercury loading of the lake and the potential impacts of the revised thermal standards on mercury cycling. Increased internal loading of mercury could result from anoxic conditions. MACTEC evaluated the potential for increased internal loading of mercury as a result of increasing water temperatures resulting in anoxic conditions.

Finally, Section 4 summarizes and integrates the multiple lines of investigation presented in the previous sections in order to characterize the actual risk for adverse impact occurring from revisions to the thermal standards for May and October.

2.0 Internal Phosphorus Loading

Coffeen Lake was determined to be impaired due to excessive algal growth caused by excess phosphorus. It has been evaluated by the Illinois EPA to ensure the lake meets its designated use by development of a Total Maximum Daily Load (TMDL) (Illinois EPA, 2007; Illinois EPA, 2009a). To protect water quality and provide the designated "aesthetic quality" established for the lake, the Illinois EPA has set a water quality standard of 0.05 mg P/L as the TMDL endpoint. Concerns regarding degradation of water quality and trophic status which may result from modification to the existing thermal limits are largely based on internal cycling processes of phosphorus within Coffeen Lake. The Illinois EPA contends that increasing water temperatures within the lake will result in enhanced phosphorus release from the sediments into the water column, thereby providing an additional phosphorus load within the Lake.

2.1 Relationship Between Elevated Temperature and Surface Water Phosphorus in Coffeen Lake

Seasonal temperature differences in productive (eutrophic) freshwater lakes and reservoirs often lead to seasonal thermal stratification within the water column, resulting in the development of an epilimnion (surface water) and hypolimnion (bottom water) which are separated by temperate and density gradients which prevent mixing within the water column. The mere presence of thermal stratification does not indicate that significant internal loading will occur as a result. Thermal stratification without anoxia produces no more phosphorus release from sediments than an unstratified lake. Seasonal stratification can also result in anoxic conditions in the lower portions of the hypolimnion, a condition which is generally recognized as promoting dissolution and subsequent release of sediment-bound phosphorus, where sediment phosphorus is loosely bound. Thermal stratification with anoxia present over a portion of the bottom, may result in some phosphorus release from the sediments into the hypolimnion, but in insufficient quantities to actually reach the epilimnion and fuel algal blooms. Although anoxia within the hypolimnion has the potential to release sediment phosphorus to the water column, water quality measurements within Coffeen Lake indicate that internal phosphorus recycling is currently not contributing appreciable amounts of total phosphorus to epilimnetic surface water. The following analysis also shows that the incremental difference in phosphorus that may result from the revised thermal standard for May and October will not result in measureable adverse impact to the lake.

2.1.1 Seasonal Changes in Phosphorus and Chlorophyll-*a*

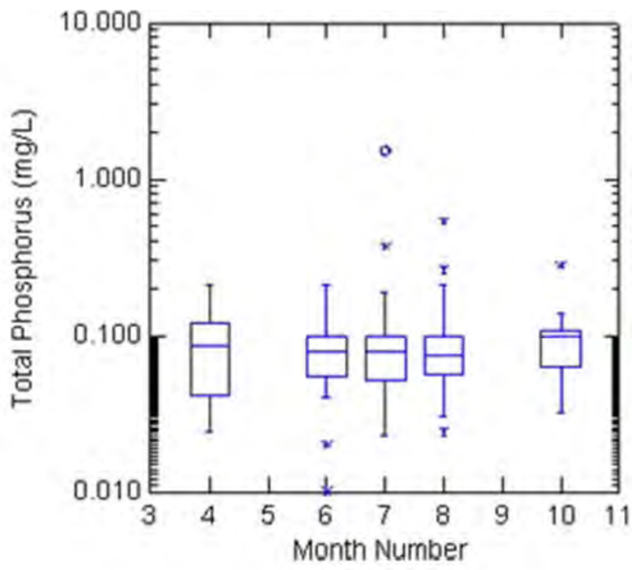
Surface water temperature measurements in Coffeen Lake reveal that different segments of the lake display seasonal stratification for a period of days to months during the months between May and October (see Section 2.2.1). In its April 2009 Recommendation, the Illinois EPA states that "the amount of phosphorus released from the sediments is directly related to the period of anoxia during stratification." Although seasonal changes in oxygen concentrations can alter the short-term uptake and release of phosphorus from the sediments, oxygen availability at the sediment-water interface cannot control the long-term P retention of lake sediments (Hupfer and Lewandowski, 2008), or determine the net effect of any release on the lake. Numerous physical and chemical processes within the sediment and overlying water column will determine the exchange capacity of phosphorus from the sediment to surface waters such that the relationship between anoxia and sediment phosphorus release cannot be universally applied to all lakes under varying conditions. In Coffeen Lake, phosphorus release from the sediment is modest, and does not affect the epilimnion (see discussion below).

An evaluation of seasonal phosphorus concentrations during the warmest portion of the year (April-October) was performed using data from the 2009 Coffeen Lake TMDL Addendum (Illinois EPA, 2009a) as well as data used in the 2007 TMDL (Illinois EPA, 2007), which was obtained from the United States Environmental Protection Agency (USEPA) STORET database (Illinois EPA, 2009b). No statistically significant trends were observed for water column phosphorus concentrations within Coffeen Lake during summer months (Figure 2-1). Additionally, chlorophyll-*a* may be used as a surrogate or response analysis for increased phosphorus loading due to increased biological production that would result from excess sediment phosphorus release if this phosphorus reached the epilimnion during destratification at fall turnover. A similar comparison of chlorophyll-*a* concentrations between 1989-2002 (Figure 2-2) show no significant increase in chlorophyll-*a* concentrations during and following turnover. The lack of a seasonal component to phosphorus concentrations in Coffeen Lake, and the absence of a chlorophyll-*a* spike or algal blooms at fall turnover are both strong evidence that internal phosphorus recycling is not currently a significant contribution of the total lake phosphorus budget. Fluctuations in either phosphorus or chlorophyll-*a* concentrations during fall turnover at Coffeen Lake would indicate that internal sediment phosphorus release is a controlling process in seasonal nutrient concentrations within lake surface waters. However, neither total phosphorus or chlorophyll-*a* reveal correlated trends with warmer surface water temperatures within the lake. The lack of correlating water quality responses following seasonal stratification and hypolimnion anoxia suggests that other phosphorus loading factors, including external phosphorus loading from the surrounding watershed (Section 2.1.3), are more important factors in water quality within Coffeen Lake.

By comparison, Greenville Lake, which was also evaluated under the 2007 TMDL (Illinois EPA, 2007), shows distinct differences in seasonal phosphorus (Figure 2-3) and chlorophyll-*a* (Figure 2-4) concentrations resulting from sediment phosphorus release to the water column during fall turnover. Phosphorus in Greenville Lake shows peak concentrations occurring in the fall, with increasing phosphorus loads entering surface waters towards the end of the summer. Chlorophyll-*a* concentrations in Greenville Lake show a similar pattern of increasing concentrations in the late fall, and this seasonal pattern is typical for a lake or reservoir where internal phosphorus loading is a significant portion of the loading. Neither phosphorus or chlorophyll-*a* in Coffeen Lake show similar patterns of increasing concentrations in late summer into fall, indicating that any potential sediment phosphorus release is not mixing into the epilimnion where it would be available for algae production.

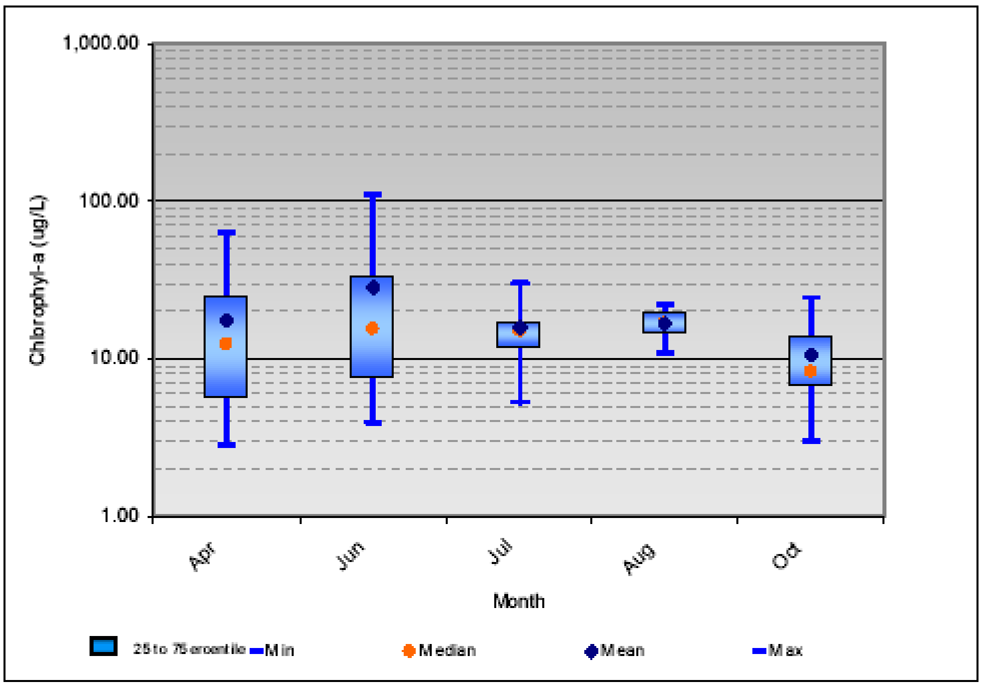
While thermal stratification and some deep water anoxia in the hypolimnion does appear to occur on a seasonal basis within Coffeen Lake (Section 2.2.1), the lack of phosphorus and chlorophyll-*a* pulse during fall overturn suggest that that a majority of the sediment phosphorus remains bound in sediments or that whatever phosphorus is released in not reaching the epilimnion in sufficient quantities to degrade water quality (see further discussion in Section 2.1.4).

Figure 2-1. Coffeen Lake Phosphorus Comparison Between 1989 and 2008



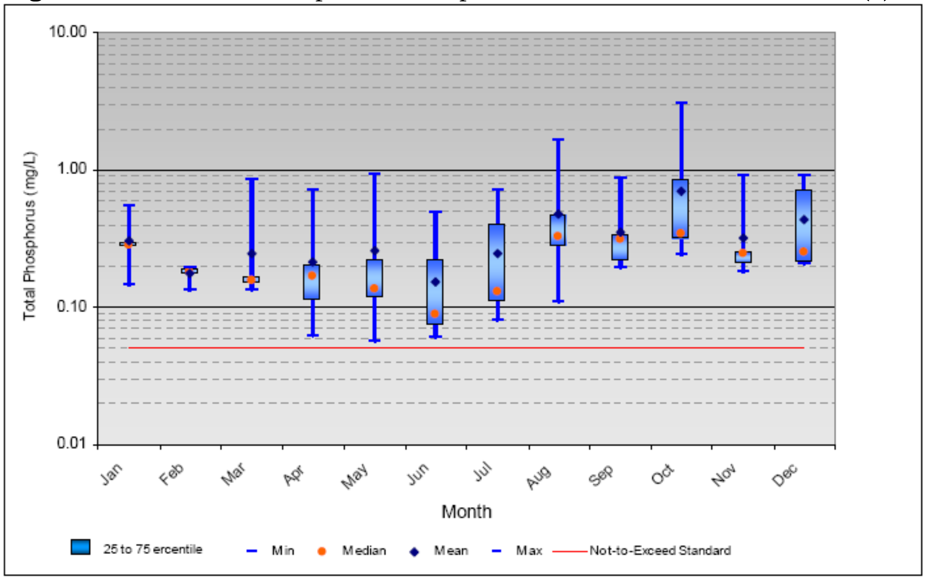
(Data Source: Illinois EPA, 2009a; Illinois EPA, 2009b).
Created by: DRD Checked by: BMJ 5/5/2009

Figure 2-2. Coffeen Lake Seasonal Chlorophyll-*a* Concentrations Between 1989-2002

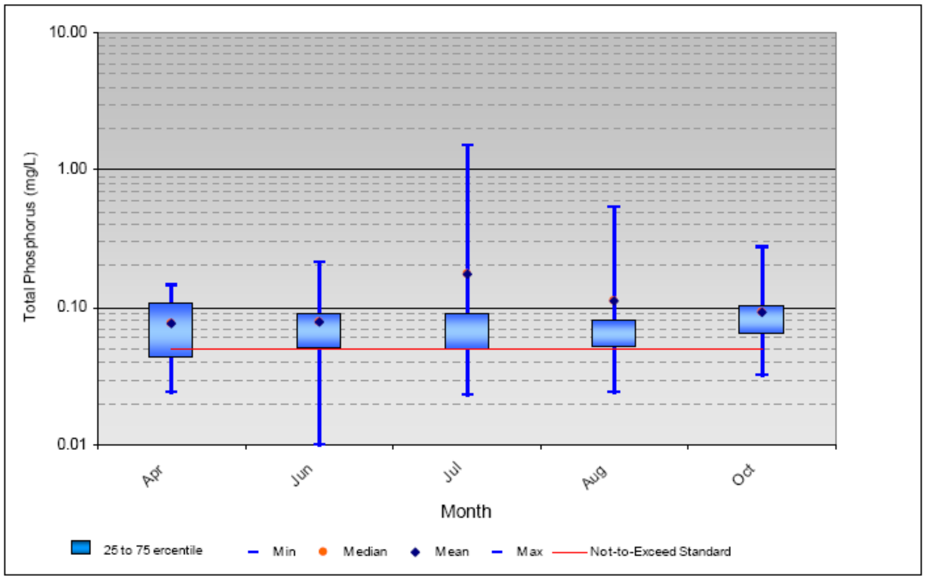


(Source: Illinois EPA, 2007)

Figure 2-3. Seasonal Phosphorus Comparison Between Greenville Lake (a) and Coffeen Lake (b)



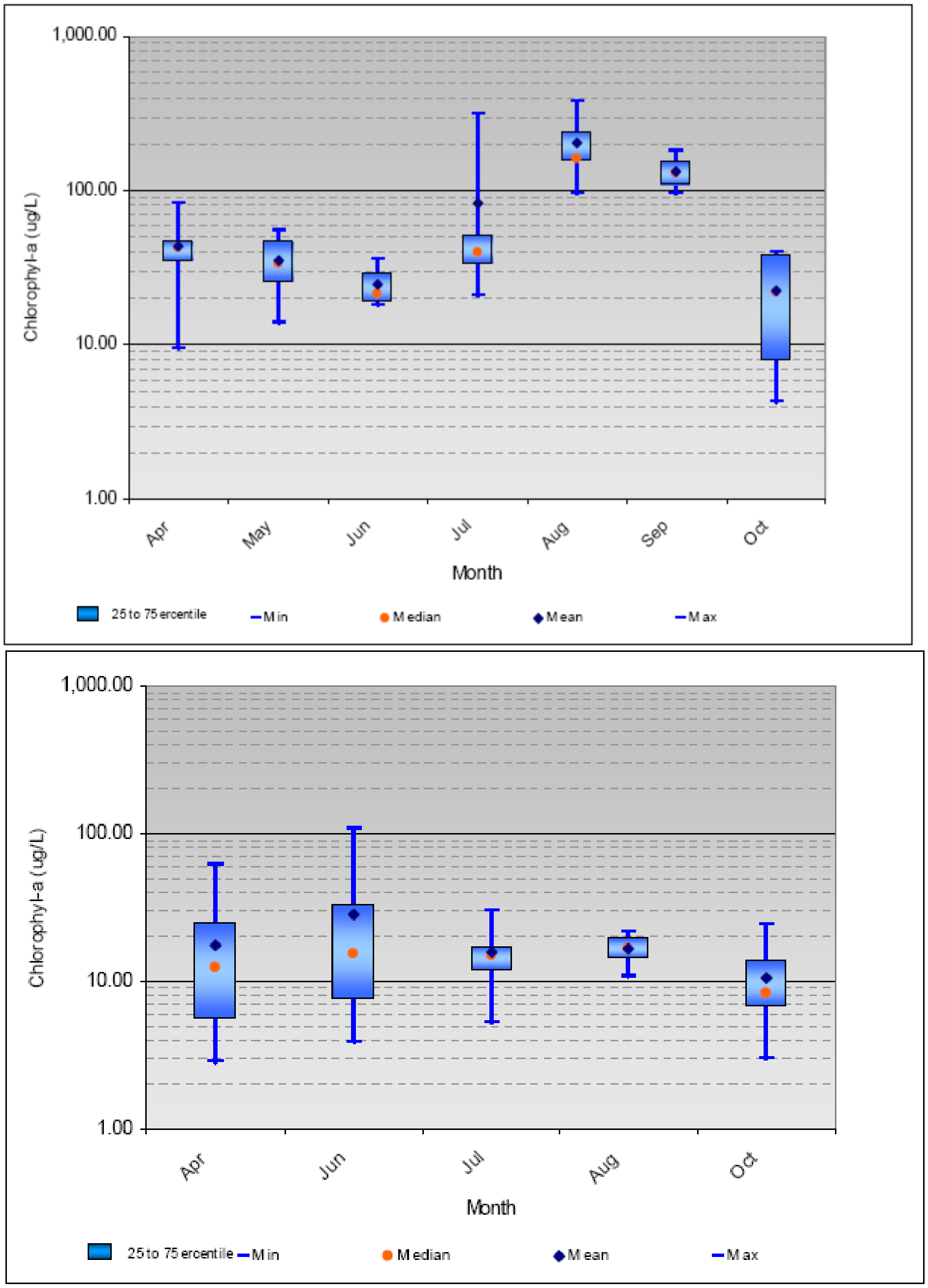
a - Greenville Lake



b - Coffeen Lake

(Source: Illinois EPA, 2007)

Figure 2-4. Seasonal Chlorophyll-*a* Comparison Between Greenville Lake (a) and Coffeen Lake (b)



a - Greenville Lake

b - Coffeen Lake

(Source: Illinois EPA, 2007)

2.1.2 Sediment Phosphorus Adsorption

Inorganic phosphorus is highly particle reactive and will vary in its sorption and exchange capacities with different physical and chemical sediment characteristics, including iron, aluminum, and organic matter content (Detenbeck and Brezonik, 1991). Speciation of phosphorus into saloid-bound (NH_4Cl-P_i), iron-bound (NaOH-P_i), and aluminum-bound (NH_4F-P_i) phosphorus (Chang and Jackson, 1957) is often characterized to evaluate the proportion of phosphorus which may be released into the water column under changing environmental conditions at the sediment-water interface. Saloid-bound phosphorus represents the portion of phosphorus which is highly soluble and is therefore considered readily available for release from the sediments into the water column. Iron-bound phosphorus, however, is generally considered stable under oxidizing conditions in the sediment, but becomes unstable under anoxic (reducing) conditions, allowing the iron-bound phosphorus to separate from the sediment for release into the water column. Phosphorus bound by aluminum in the sediments is considered inert under both oxidizing and reducing conditions, and is therefore considered unavailable for release back into the water column.

An analysis of total phosphorus concentrations in Coffeen Lake sediments indicate large variations between sampling locations and annual sampling events, with an overall mean concentration of 769 mg/kg and a standard deviation of 268 mg/kg (Table 2-1). While no phosphorus speciation data exists for Coffeen Lake sediments, available iron concentrations (Table 2-1) were determined to have no correlation to total phosphorus sediment concentrations within the eight individual samples (R^2=0.328). Although a portion of available phosphorus within the sediments is likely iron-bound, the lack of increased surface water phosphorus concentrations suggest that other phosphorus species may remain permanently bound to sediments despite enhanced redox potential associated with bottom water anoxia.

Table 2-1. Sediment Phosphorus Concentrations Between 1989-2002

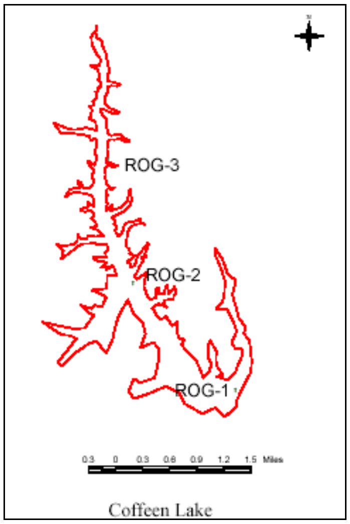
Monitoring Location	Date Sampled	Iron (mg/kg)	Phosphorus (mg/kg)
ROG-1	4/27/1989	26,500	297
ROG-1	7/8/1993	40,000	1,034
ROG-1	7/1/1997	30,000	1,156
ROG-1	7/22/2002	24,000	814
ROG-3	4/27/1989	23,500	648
ROG-3	7/8/1993	30,000	842
ROG-3	7/1/1997	24,000	780
ROG-3	7/22/2002	17,000	577
Mean Concentration (mg/kg)		**26,875**	**769**

(Data Source: Illinois EPA, 2009b).
Created by: BMJ Checked by: KAR 5/5/2009

2.1.3 Impact of External Phosphorus Loading Seasonal Changes in Phosphorus and Chlorophyll-*a*

Segmentation of Coffeen Lake for sampling and analysis in the 2007 TMDL (Illinois EPA, 2007) provided a comparative assessment of deep and shallow portions of the lake, as well as a comparison of regional watershed characteristics which contribute to the total phosphorus load within the Lake. Sample locations ROG-1 and ROG-2 (Figure 2-5) were taken closest to the Coffeen Power Generating Station, and are representative of the deeper locations within the Coffeen reservoir. Sample location ROG-3 is the northernmost sampling location, and represents the shallowest portion of Coffeen Lake monitored during both the 2007 (Illinois EPA, 2007) and 2009 (Illinois EPA, 2009a) TMDL evaluations.

Figure 2-5. Illinois EPA Sampling Locations at Coffeen Lake

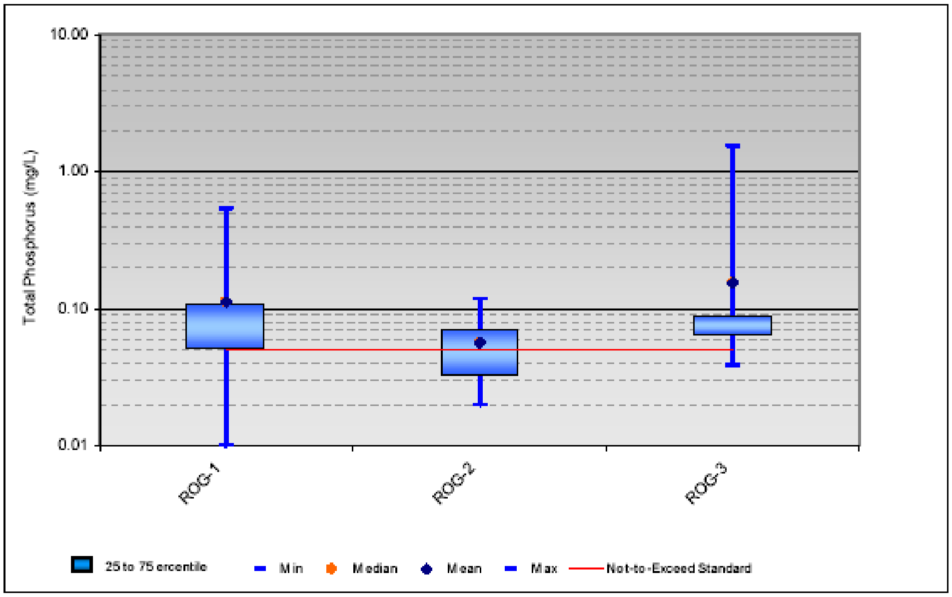


(Source: Illinois EPA, 2007)

Phosphorus concentrations by sampling location (Figure 2-6) were taken from the Illinois EPA TMDL assessment for Coffeen Lake (Illinois EPA, 2007). Mean phosphorus concentrations at ROG-3 are elevated compared to ROG-1 and ROG-2, with a greater maximum range of phosphorus concentrations sampled. Similarly, Chlorophyll-*a* results (Figure 2-7) show greater mean concentrations at ROG-3 than the other sampling locations. These data confirm that external loading (from the tributary and watershed) rather than internal loading are dominant in this reservoir. Further, the shallow depth of this upper region of the reservoir has been caused by sedimentation, another indicator of the extent to which the watershed is contributing to the eutrophication and impairment of the lake. Elevated phosphorus and chlorophyll-*a* concentrations at shallow portions of the lake indicate that external loading is the dominant factor in Coffeen Lake phosphorus concentrations. The Coffeen Lake watershed is largely dominated by agricultural land use, which accounts for 66.5% of the total watershed area (Illinois EPA, 2007). The 2007 TMDL report (Illinois EPA, 2007) recognizes row crop agriculture as a common source of sediment and nutrient loads which are prevalent within the Coffeen Lake watershed. Water quality modeling used in the 2009 Coffeen Lake TMDL addendum (Illinois EPA, 2009a) also attributes elevated phosphorus concentrations to the dominant agricultural land use found in the watershed. Fertilizers commonly used within the watershed include anhydrous ammonia, ammonium phosphate, and potash, which are frequently applied in the fall and spring (Illinois EPA, 2007).

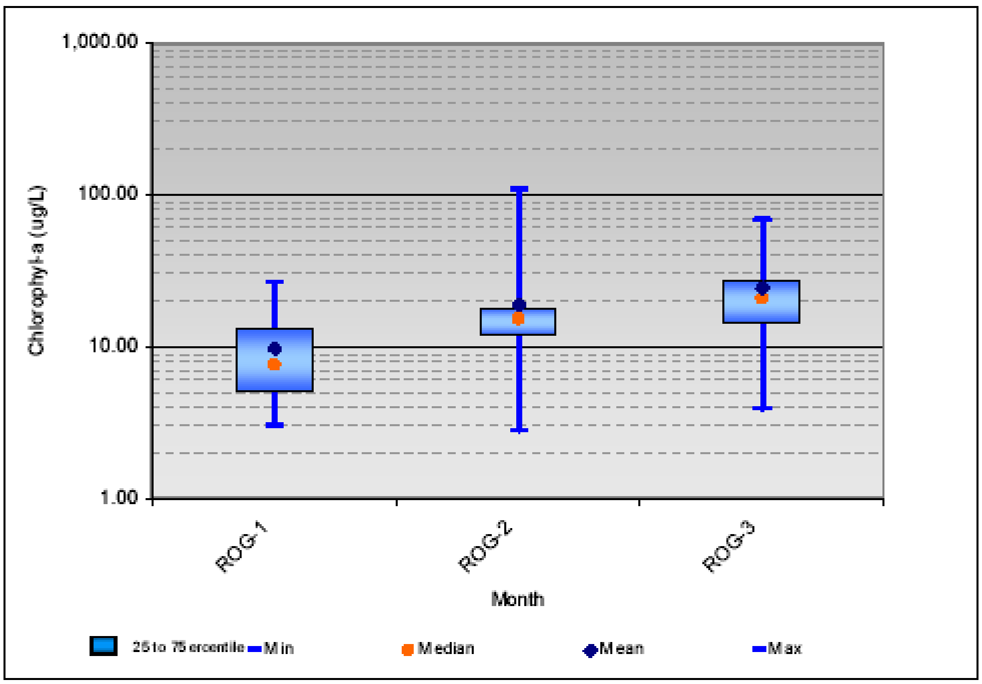
ROG-3 is located in the northernmost portion of Coffeen Lake, where a majority of runoff from agricultural operations to the north enter the lake (Figure 2-8). The high range of phosphorus concentrations recorded at this site (Figure 2-6) suggest that period runoff entering the lake, particularly in the shallower northern portions, is controlling the total available phosphorus load for algae production in surface waters. Sediment phosphorus release is unlikely to contribute to the total phosphorus load at ROG-3 due to infrequent occurrences of anoxia in shallow bottom waters (Section 2.2.1), leaving external phosphorus loads as the primary mechanism for phosphorus loading and water quality within Coffeen Lake.

Figure 2-6. Total Phosphorus Concentrations at Coffeen Lake by Sampling Site



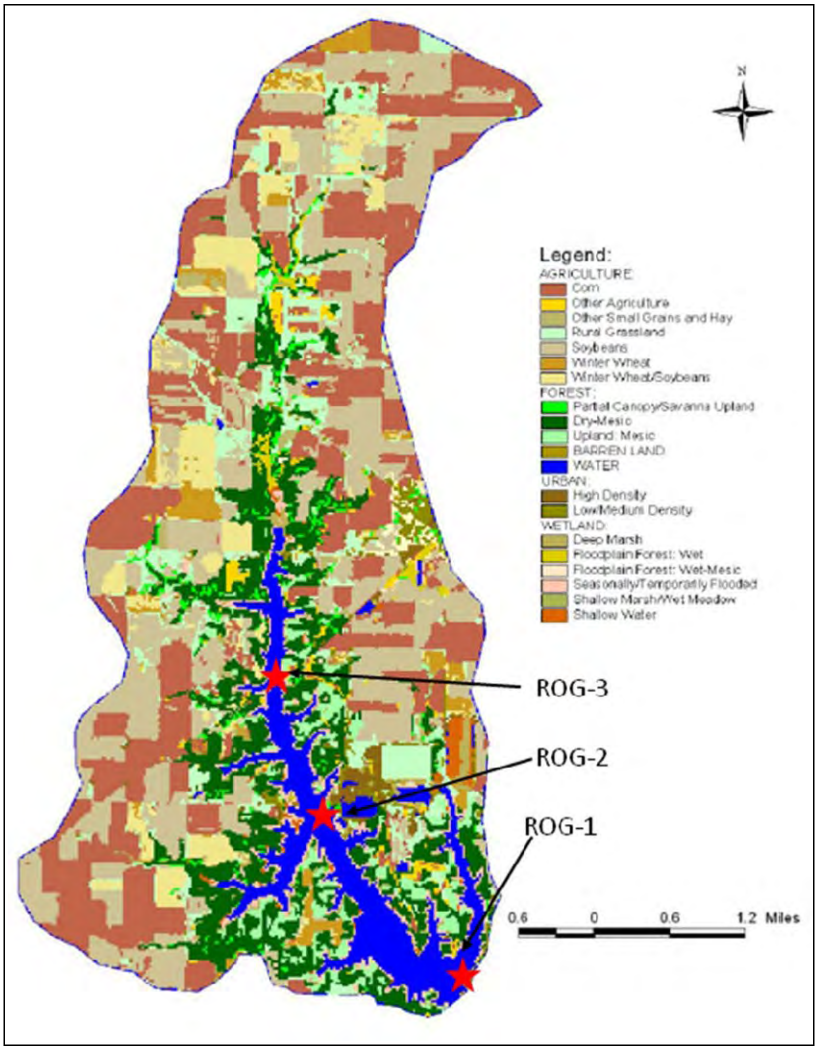
(Source: Illinois EPA, 2007)

Figure 2-7. Chlorophyll-*a* Concentrations at Coffeen Lake by Sampling Site



(Source: Illinois EPA, 2007)

Figure 2-8. Coffeen Lake Watershed Land Use and Surface Water Sampling Locations



(Source: Illinois EPA, 2007)

2.1.4 Internal Loading Assumptions from the TMDL BATHTUB Model

The available phosphorus and chlorophyll-*a* data for Coffeen Lake are indicative of a eutrophic waterbody with high external (watershed) phosphorus loading. There is no observable effect from internal phosphorus loading. This contradicts the TMDL BATHTUB model results (Illinois EPA, 2007, Illinois EPA, 2009a). Review of the original (2007) model revealed significant modeling errors and misapplications which led to the erroneous conclusion that internal phosphorus loading dominates Coffeen Lake. A non-exhaustive list of errors includes (but is not limited to):

- Use of the approximate maximum depth instead of the mean depth, resulting in a gross overestimate of the lake volume and phosphorus mass,
- Approximately a four fold increase in hydraulic retention time over either the Stage 1 or TMDL addendum assumptions,
- Underestimate of tributary (watershed) phosphorus concentrations.

These errors produced a model run which did not match known lake phosphorus concentrations. To compensate for this "under-prediction of observed phosphorus concentrations", the modelers introduced an additional internal phosphorus load (the BATHTUB model already incorporates internal loading) to force the model to calibrate.

The BATHTUB model was produced by the United States Army Corp of Engineers. The guidance for this model explicitly states (USACE, 2004):

> Internal Loading Rates reflect nutrient recycling from bottom sediments. Rates are normally set to 0, since the pre-calibrated nutrient retention models already account for nutrient recycling that would normally occur (at least in the collection of reservoirs used for model calibration).
>
> Nonzero values should be specified with caution and only if independent estimates or measurements are available.
>
> In some studies, internal loading rates have been estimated from measured phosphorus accumulation in the hypolimnion during the stratified period. This procedure should not be followed unless there is evidence the accumulated phosphorus is transported to the mixed layer during the growing season.
>
> Specification of a fixed internal loading rate may be unrealistic for evaluating response to changes in external load. Because they reflect recycling of phosphorus that originally entered the reservoir from the watershed, internal loading rates would be expected to vary with external load.
>
> This option is included at the request of model users but is not endorsed by the author. In situations where monitoring data indicate relatively high internal recycling rates to the mixed layer during the growing season, a preferred approach would generally be to calibrate the phosphorus sedimentation rate (specify calibration factors< 1). There is some risk that apparent internal loads actually reflect under-estimation of external loads (USACE, 2004).

The forcing of this model through the use of an internal loading factor, as noted above, is not recommended or endorsed by the model developers, and may lead to erroneous conclusions about the phosphorus sources in the waterbody. In this case, the model produced the following estimate of phosphorus mass sources for Coffeen Lake:

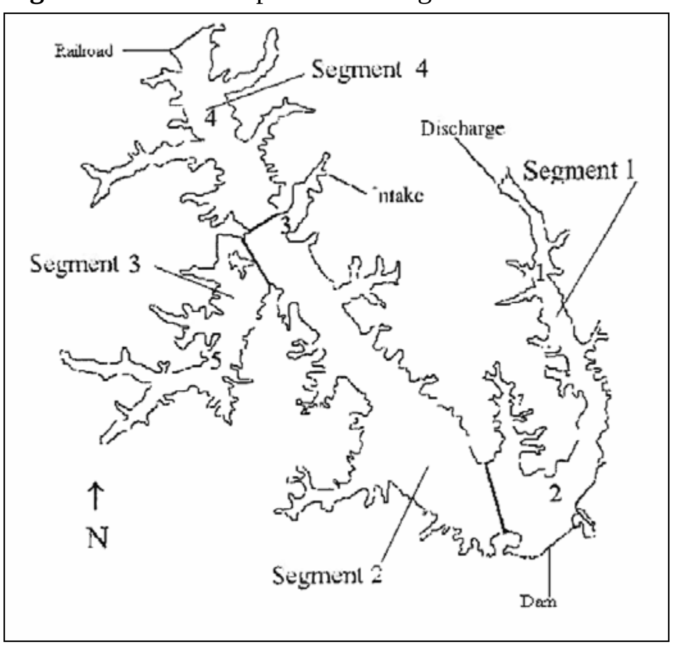
External sources of phosphorus (watershed, precipitation, point sources) (kg/yr):	329.7
Internal phosphorus load (kg/yr):	3,495.8
Total phosphorus load (kg/yr):	3,825.2

Many of the above errors were eliminated in the BATHTUB modeling conducted for the TMDL addendum, however, this model was assembled in a simpler framework. Based upon discussion with the modelers, the updated model was kept consistent with the original modeling where possible, except for the correction of significant errors. The update did include additional data for watershed loading and water budget information that led to model improvements, but lake morphometry was not updated. Sediment transport to the lake from the watershed has reduced the effective lake volume, and this factor, for example, was not addressed in the modeling. Reduction in lake volume would have resulted in better agreement between predicted and observed values of phosphorus concentration in the lake without the use of a "correction factor". The baseline case for the TMDL addendum modeling estimated 9054.8 kg P/yr total phosphorus loading, with the majority of this attributable to McDavid Branch (an inflowing tributary from the watershed). However, an internal loading factor was still applied, and resulted in an estimate of approximately 39% internal loading. The conclusions and load reduction requirements of the original TMDL were not revised, despite these errors and discrepancies. However, available monitoring data do not confirm this estimated level of internal loading (see Section 2.1.1).

2.1.5 Evaluation of the Spatial Extent of Anoxic Sediment and Water

Historic surface water depth profiles of temperature and dissolved oxygen were evaluated from the Southern Illinois University at Carbondale (SIUC) annual monitoring reports (SIUC, 2006 ; SIUC, 2007, etc.). Depth profiles used in this analysis were collected between 2001 and 2006; however no data were available from 2002. Four segments were identified by SIUC for Coffeen Lake Depth profiles (Figure 2-9). Nearly all depth profiles collected at segments one and two, which represent the deepest portions of the lake, displayed thermal stratification between the months of May-September. Thermal stratification of surface water at segments three and four were less consistent during the warm summer months, showing less frequent stratification and periodic mixing in shallower portions of the lake. Although stratification is frequently present, the presence of a thermocline and hypolimnion does not indicate anoxia (DO < 1mg/L) at the surface of the sediments or in the deeper hypolimnetic waters. Anoxic conditions, if and when they form, develop more slowly, over time, compared to thermal stratification.

Figure 2-9. SIUC Depth Profile Segments for Coffeen Lake



(Source: SIUC, 2007)

In order to determine the depth within each segment of Coffee Lake which experiences seasonal stratification and anoxia, all vertical profiles provided by SIUC (2007, and others) between 2001 and 2006 were visually analyzed to record the total depth to bottom, depth to the thermocline, if present, and the depth to anoxic conditions (defined as a dissolved oxygen concentration <1 mg/L). The total depth in which anoxic conditions were present was calculated by subtracting the depth to anoxia from the depth to bottom of the lake. Each segment was then separated by month and year to determine an average depth below which anoxic conditions were observed within the recorded depth profiles. Once an average depth had been determined by segment for each month and year, a final average of the depth to anoxic conditions was calculated for each segment between 2001 and 2006 (Table 2-2).

Table 2-2. Average Depth (m) Below Which DO Less Than 1 mg/L (Anoxia) by Month

	MAY	JUN	JUL	AUG	SEP	OCT
Segment 1	8.19	4.97	5.72	5.73	6.33	7.00
Segment 2	9.07	8.31	7.36	7.69	8.07	10.50
Segment 3	7.17	6.58	5.67	5.92	7.25	--
Segment 4	--	6.67	6.33	6.17	7.75	--

-- No anoxia observed within the segment between 2001 and 2006
(Data Source: SIUC, 2007)
Created by: KAR Checked by: BMJ 5/5/2009

The presence and extent of seasonal anoxia within Coffeen Lake due to stratification of the water column during summer months was also evaluated. Similar to the procedure used to determine the mean depth of anoxic conditions (Table 2-2), the total number of days during which anoxic conditions were observed was also determined for each segment and month between 2001 and 2006. The date at which vertical depth profiles were measured by SIUC (2007, and others) was compared to the dissolved oxygen profiles to determine the total length of time within each month that anoxic conditions at the sediment water interface, and the depth of oxygen depleted hypolimnetic waters, were observed. A conservative estimate of the total length of time anoxia was observed was made between sample events. Each segment was then separated by month and year to determine an average number of days per month for which anoxic conditions were observed. Once an average number of days had been determined by segment for each month and year, a final average of the number of days anoxic conditions were observed was calculated for each segment between 2001 and 2006 (Table 2-3).

Similar to monthly patterns of thermal stratification, anoxic bottom waters are most frequently observed during July and August in segments one and two, with decreasing frequency resulting from increased mixing during the months of May, June, and September (Table 2-3). Less frequent hypolimnion anoxia was observed in segments three and four, which frequently mix and rarely remain stratified for all summer months.

Table 2-3. Summary of Average Monthly Anoxic Days (Percentage of the Month)

	MAY	JUN	JUL	AUG	SEP	OCT
Segment 1	18 (58%)	23 (77%)	31 (100%)	31 (100%)	26 (84%)	1 (3%)
Segment 2	17 (55%)	25 (83%)	31 (100%)	31 (100%)	21 (68%)	1 (3%)
Segment 3	9 (29%)	4 (13%)	5 (16%)	4 (13%)	1 (3%)	0 (0%)
Segment 4	0 (0%)	8 (27%)	4 (13%)	4 (13%)	1 (3%)	0 (0%)

(Data Source: SIUC, 2007, and others)

Created by: BMJ Checked by: KR5/6/2009

The depth to anoxic water (Table 2-2) was used to estimate the area of potential internal phosphorus loading. Depths in each segment were analyzed spatially (GIS) by applying the depth intervals to existing bathymetry for the lake (Illinois DNR, 2006). Figures 2-10 through 2-15 depict the areas of anoxic sediment and deep hypolimnetic waters for existing conditions (May through October). Oxygenated hypolimnetic water and epilimnetic waters (DO> 1 mg/L) were always present overlying these deeper anoxic layers as shown by cross section for May and October (Figures 2-16 and 2-17). The data and this analysis clearly show that there is no “dead zone” within the lake. Anoxic conditions were not present in other areas, as estimated from the available data. Existing conditions within Coffeen Lake show that the greatest spatial area exposed to anoxic conditions is found in the deepest portions of the lake at segments 1 and 2 (Table 2-4). The spatial extent of seasonal anoxia is greatest during the months of July and August when temperatures are warmest, the same period of time in which segments one and two exhibit continual stratification and anoxia (Table 2-3).

Table 2-4. Area of Substrate Surface Exposed To Seasonal Anoxia (Hectares) under Existing Conditions

	MAY	JUN	JUL	AUG	SEP	OCT
Segment 1	25.3	41.8	38.2	38.2	29.7	28.1
Segment 2	72.7	77.2	83.4	81.0	78.6	52.3
Segment 3	6.4	6.8	9.6	8.9	6.3	0.0
Segment 4	0.0	13.3	14.0	14.3	11.3	0.0

(Data Source: SIUC, 2007, and others)

Created by: CGS Checked by: BMJ 5/7/2009

Using these areas and representative flux rates (Haggard *et al*, 2005; Illinois EPA, 2009a) estimates of phosphorus flux into the hypolimnion were made. This estimate ranges from 329.1 kg P/year to 658.1 kg P/yr under existing permit conditions. This estimate is much lower than predicted from the BATHTUB modeling completed for the TMDL, but is consistent with available site data.

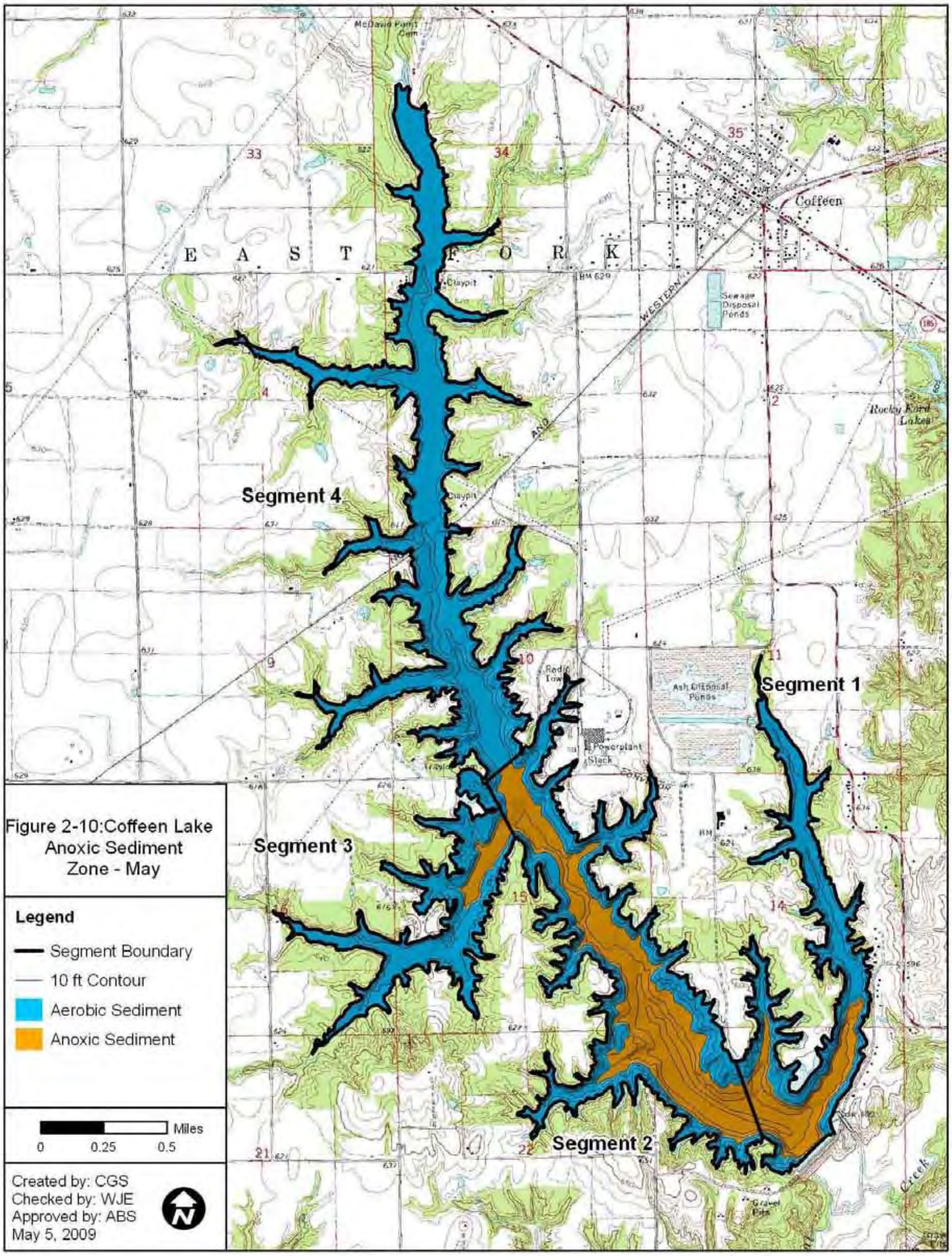
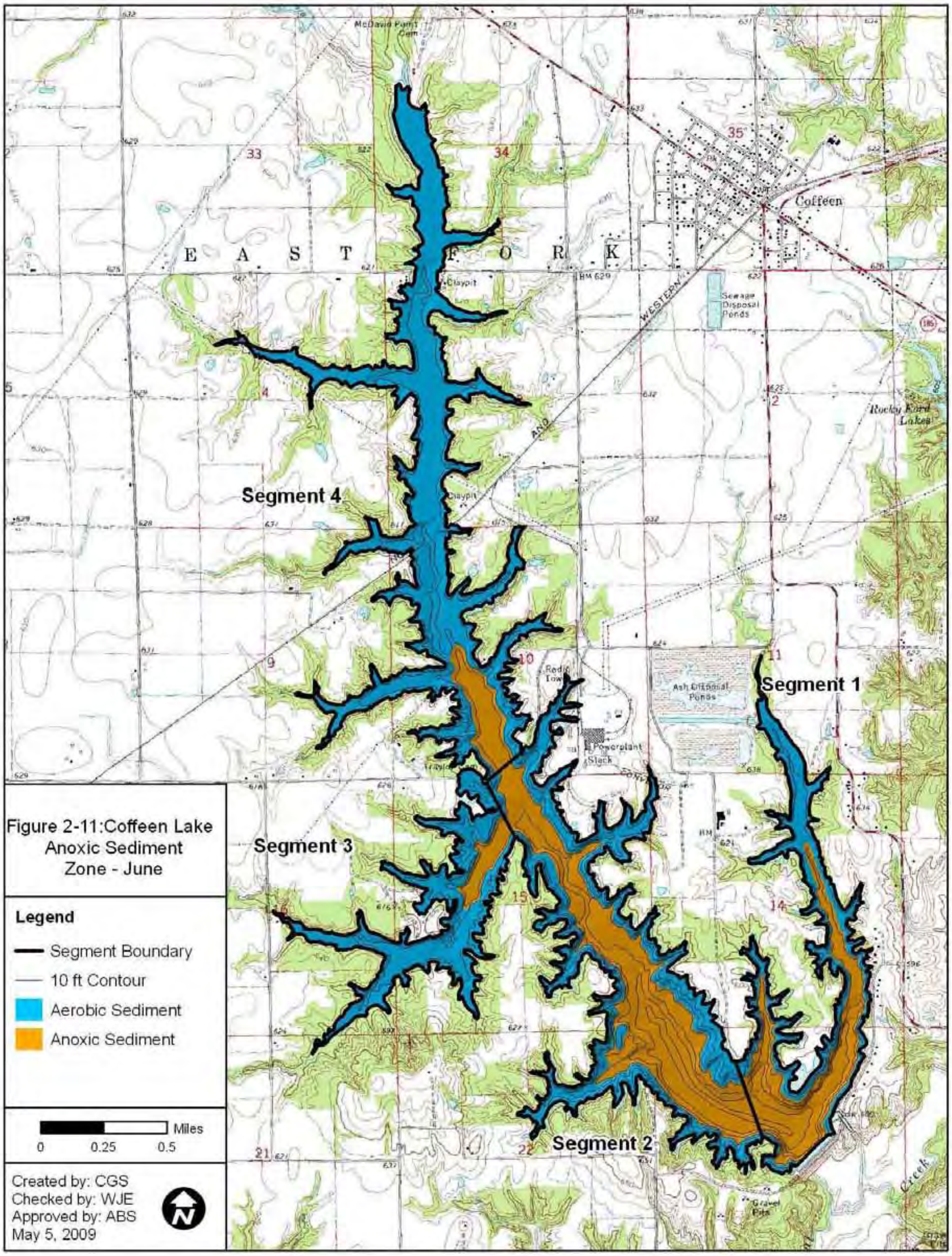


Figure 2-10:Coffeen Lake Anoxic Sediment Zone - May


Segment 1
Segment 2
Segment 3
Segment 4
Coffeen
Rocky Ford Lakes
Sewage Disposal Ponds
Ash Disposal Ponds
Powerplant Stack
Gravel Pits
Creek
E A S T F O R K
Figure 2-11:Coffeen Lake Anoxic Sediment Zone - June
Legend
Segment Boundary
10 ft Contour
Aerobic Sediment
Anoxic Sediment
Miles
0 0.25 0.5
Created by: CGS
Checked by: WJE
Approved by: ABS
May 5, 2009

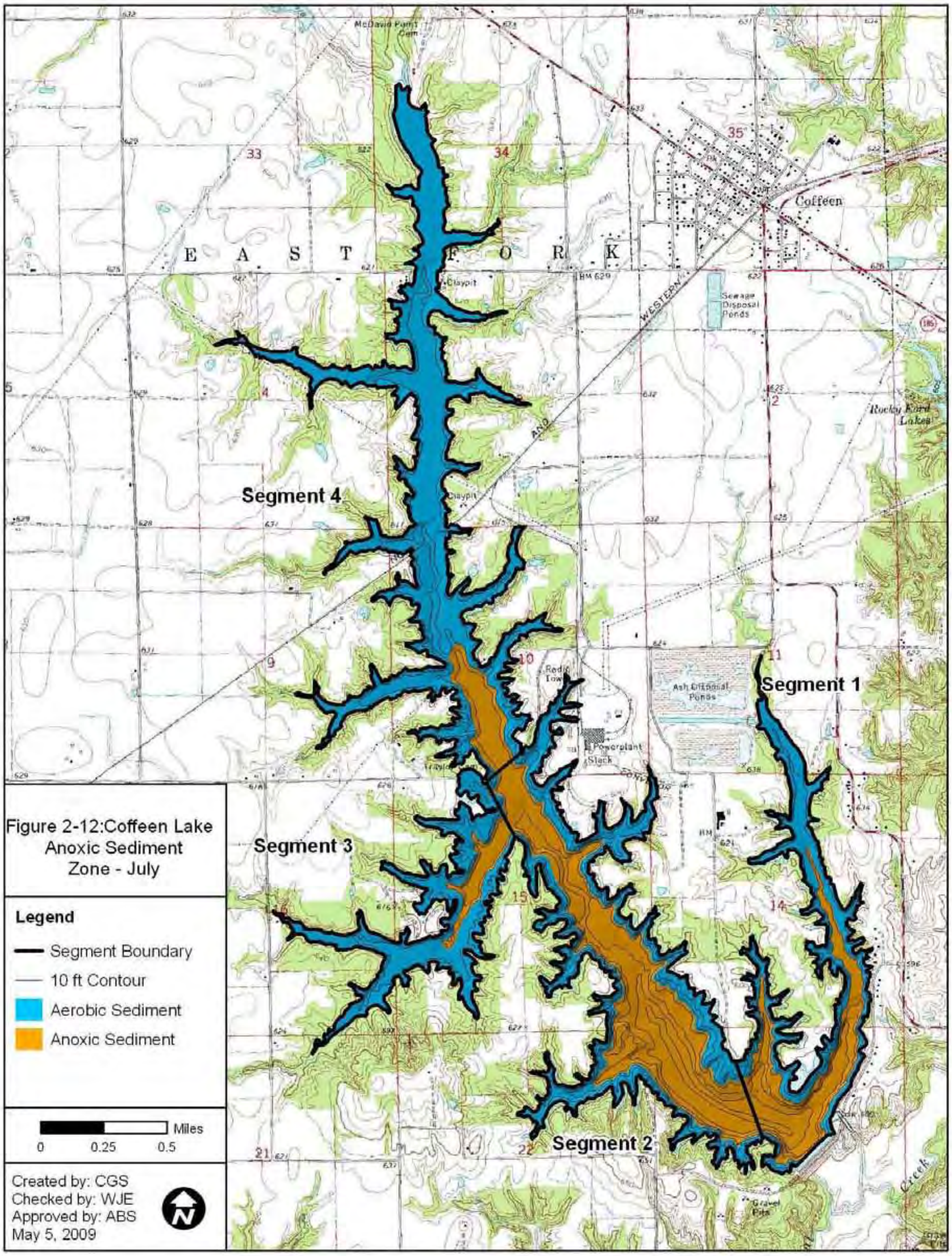


Figure 2-12:Coffeen Lake Anoxic Sediment Zone - July

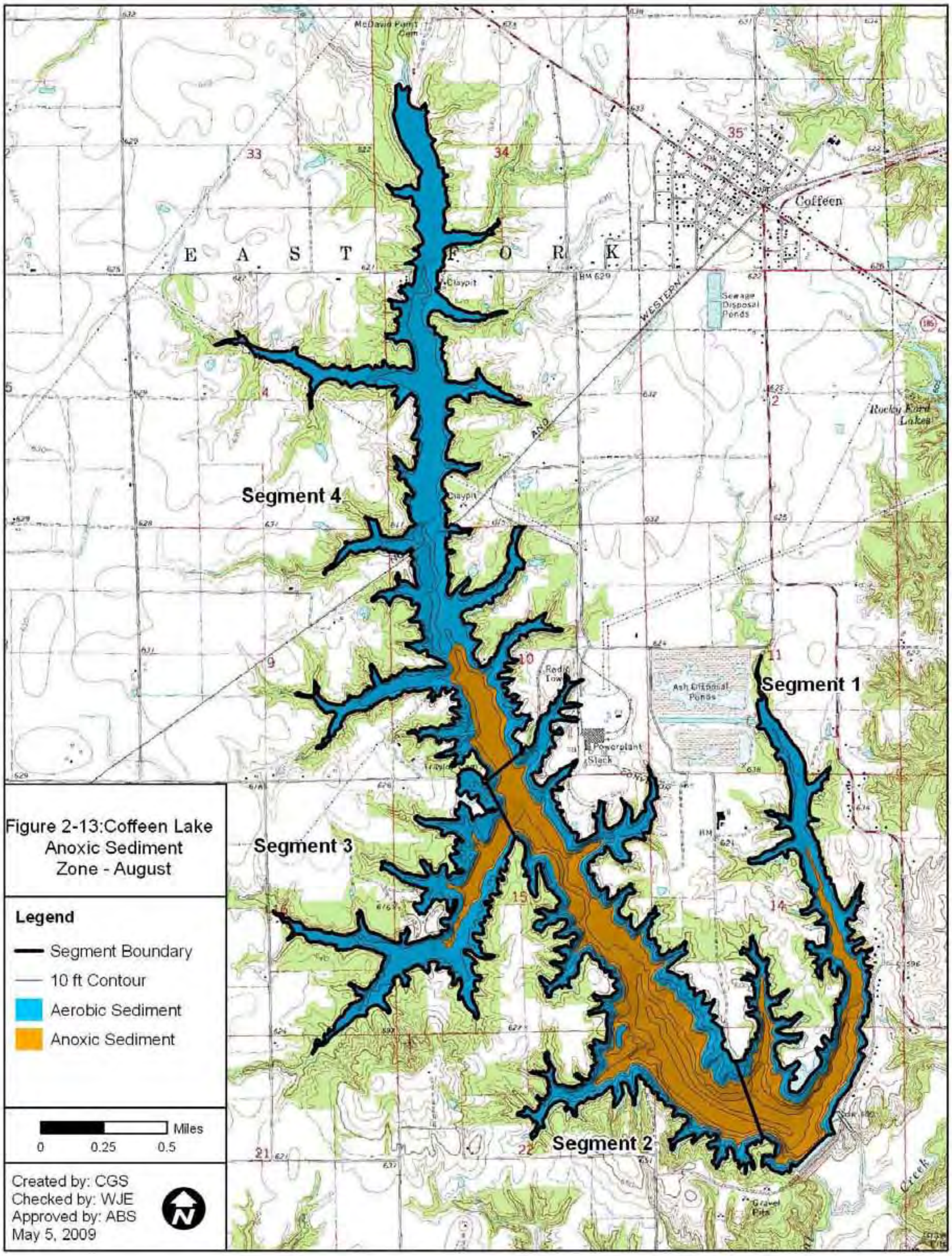


Figure 2-13:Coffeen Lake Anoxic Sediment Zone - August

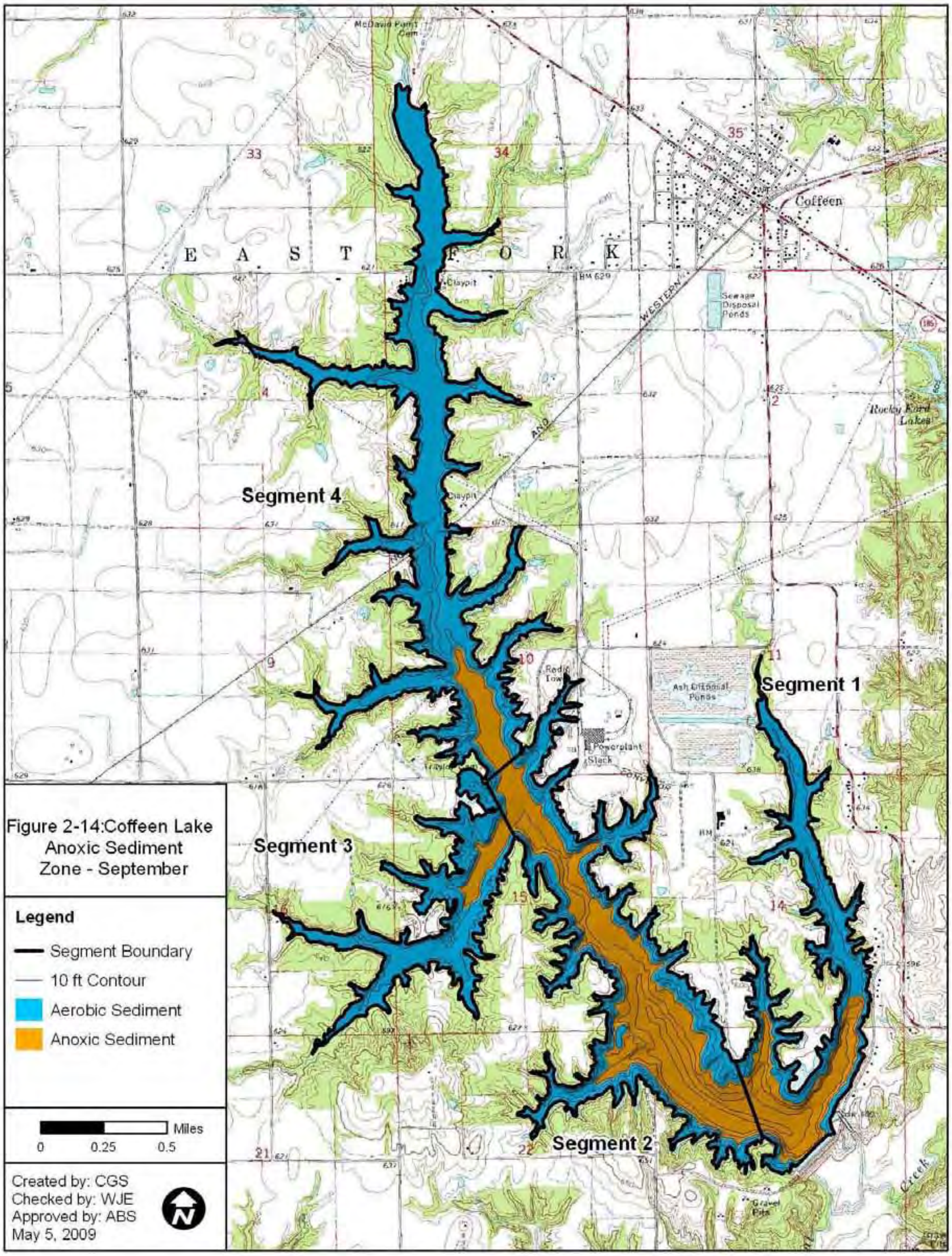


Figure 2-14:Coffeen Lake Anoxic Sediment Zone - September
Legend
Segment Boundary
10 ft Contour
Aerobic Sediment
Anoxic Sediment
Miles
0 0.25 0.5
Created by: CGS
Checked by: WJE
Approved by: ABS
May 5, 2009
Segment 1
Segment 2
Segment 3
Segment 4
E A S T F O R K
Coffeen
Sewage Disposal Ponds
Ash Disposal Ponds
Powerplant Stack
Rocky Ford Lakes
Gravel Pits
Creek

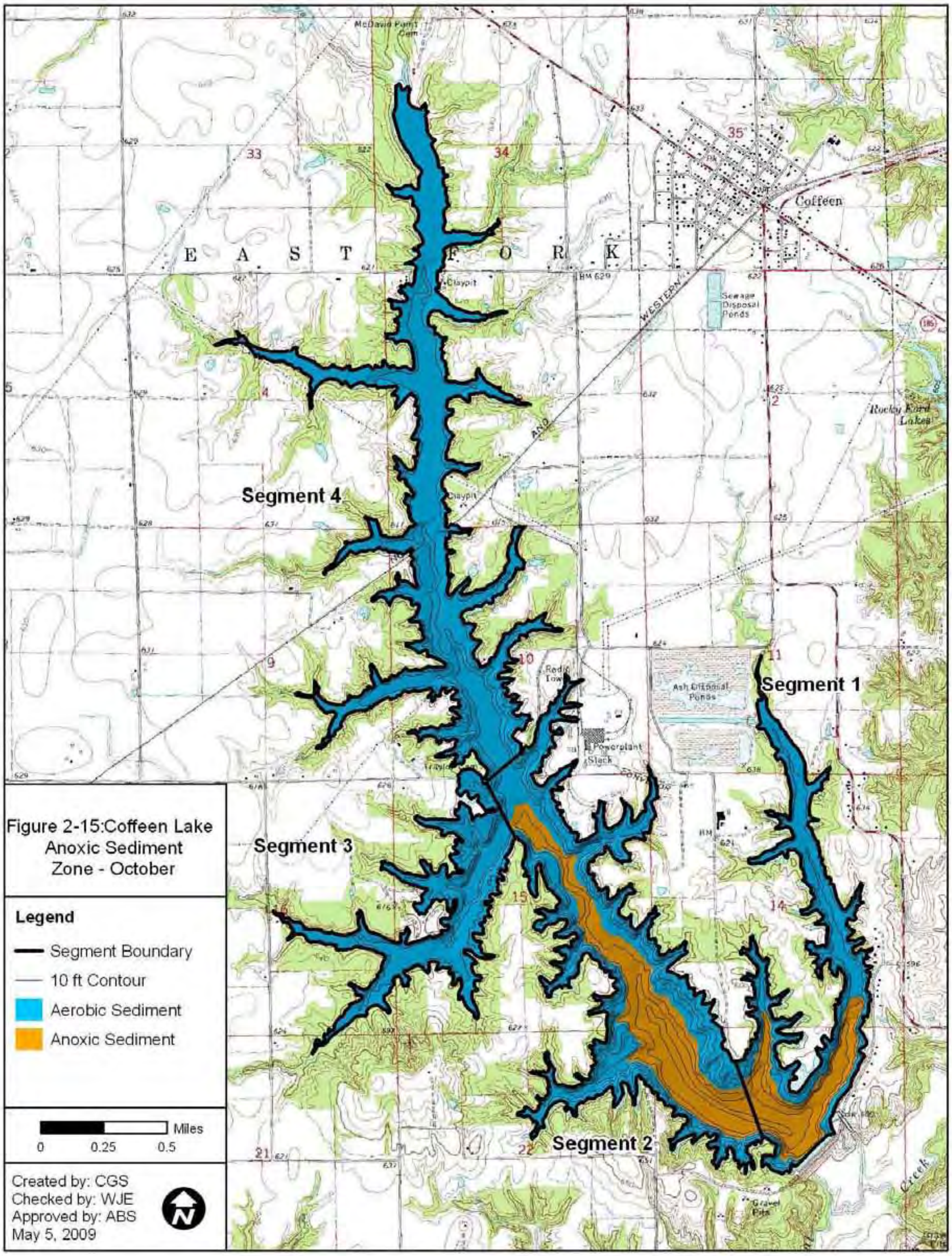


Figure 2-15:Coffeen Lake
Anoxic Sediment
Zone - October
Legend
Segment Boundary
10 ft Contour
Aerobic Sediment
Anoxic Sediment
Miles
0 0.25 0.5
Created by: CGS
Checked by: WJE
Approved by: ABS
May 5, 2009
Segment 1
Segment 2
Segment 3
Segment 4
E A S T F O R K
Coffeen
Sewage Disposal Ponds
Ash Disposal Ponds
Powerplant Stack
Rocky Ford Lakes
Gravel Pits
Creek

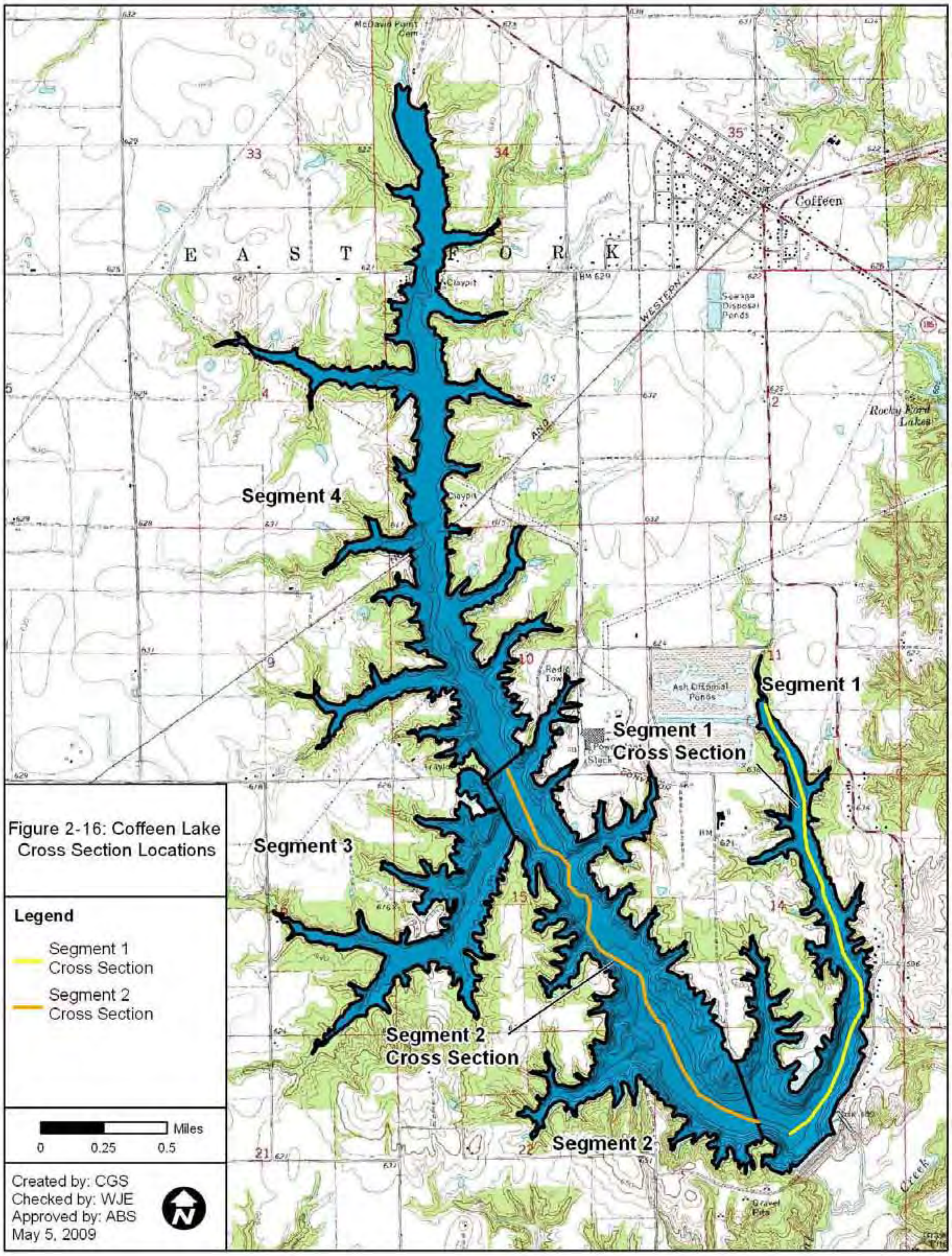


Figure 2-16: Coffeen Lake Cross Section Locations

Figure 2-17. Cross-Section of Lake Bottom, Average Anoxic Water Depth, and Oxygenated Surface Water Depth for Segments 1 and 2, May and October

Note: Percentages indicate the percent water volume per segment which is oxygenated and anoxic

2.2 Potential Impacts of Increased Thermal Standard for May and October on Internal Phosphorus Loading

Although internal phosphorus cycling does not appear to be a primary driver of surface water quality in Coffeeen Lake, potential impacts to lake water quality following modification of the existing thermal standard were evaluated. Changes to seasonal temperature and oxygen stratification were estimated for May and October to evaluate the potential for incremental effect on internal phosphorus loading resulting from changes to seasonal anoxia in Coffeen Lake bottom waters.

2.2.1 Spatial Impacts to Lake Stratification

The proposed change in the thermal discharge during May and October could potentially result in a small increase in lake substrate surface area that will experience seasonal anoxia as a result of increased discharge temperatures. Existing data were reviewed and evaluated to estimate potential changes during May and October (Table 2-5). These estimates reflect May conditions that are expected to resemble current June conditions once ambient temperatures sustain stratification, and October conditions that resemble late September. In October, the plant will be able to operate more frequently, but ambient conditions will be cooling, and aerated waters from Segments 3 and 4 are likely to contribute to general contraction of the anoxic areas, although stratification may remain stable through at least a portion of October.

Table 2-5. Current and Predicted Days with Anoxic Sediment Conditions

	Existing MAY	Proposed MAY	Existing OCT	Proposed Oct
Segment 1	18	23	1	13
Segment 2	17	25	1	11
Segment 3	9	9	0	0
Segment 4	0	0	0	0

Based on Coffeen Lake bathymetry, and existing May and October data, only Segments 1 and 2 will have additional sediment surface area exposed to potential anoxic conditions during May (Figure 2-18) and October (Figure 2-19). The resultant increase in exposed surface area for the entire lake is 21.1 hectares in May and 11.1 hectares in October, resulting in an 8% increase in sediment surface exposed to anoxia during that time period within Coffeen Lake (Table 2-6). Although increased thermal discharge may expose additional sediment surface area to seasonal periods of anoxia, the frequency and duration of stratification and anaerobic activity within the hypolimnion during the months of May and October is significantly lower than the rest of the summer months, and will likely not expose the additional surface area to prolonged anaerobic activity such that a measurable increase in surface water phosphorus concentrations will be observed.

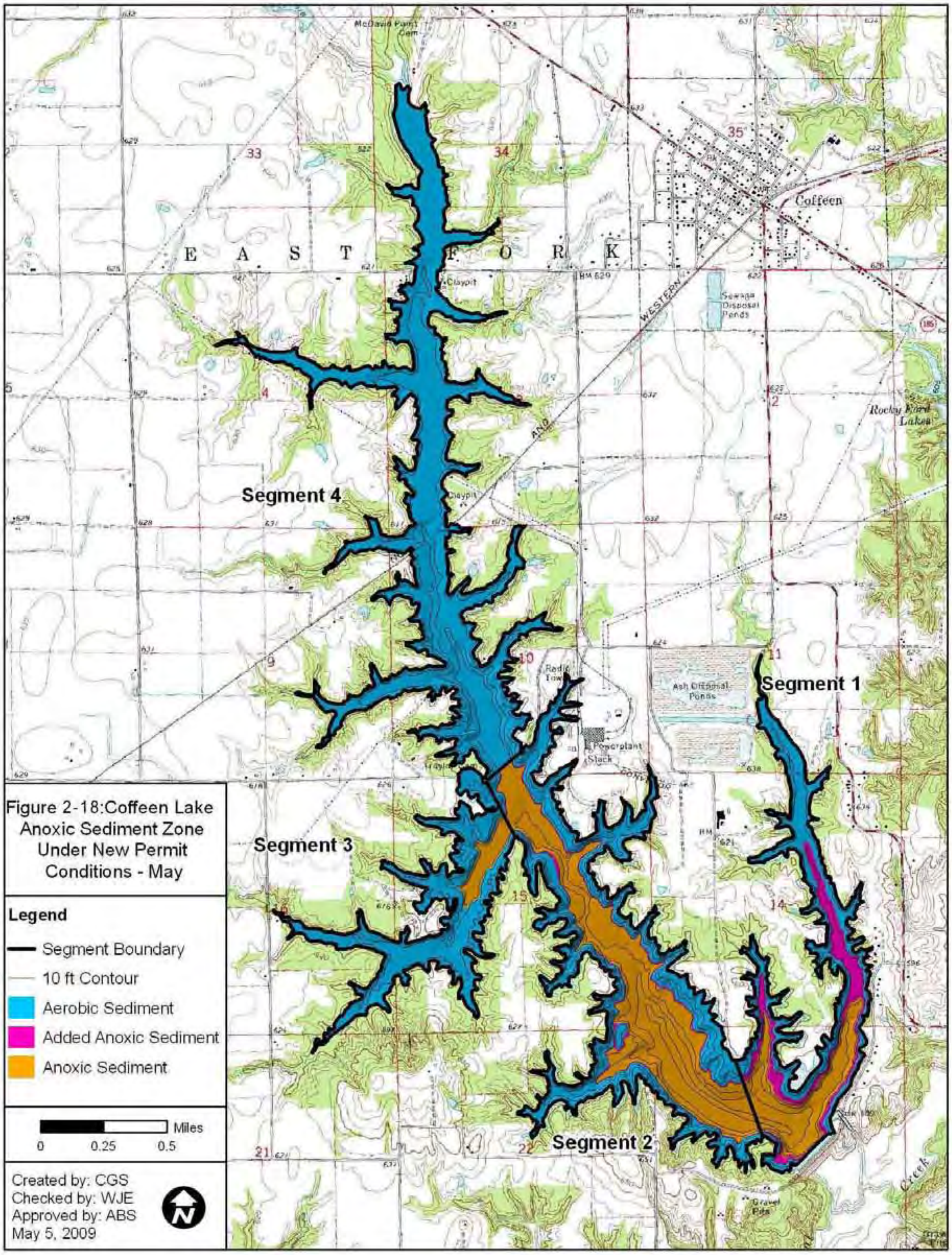


Figure 2-18:Coffeen Lake Anoxic Sediment Zone Under New Permit Conditions - May

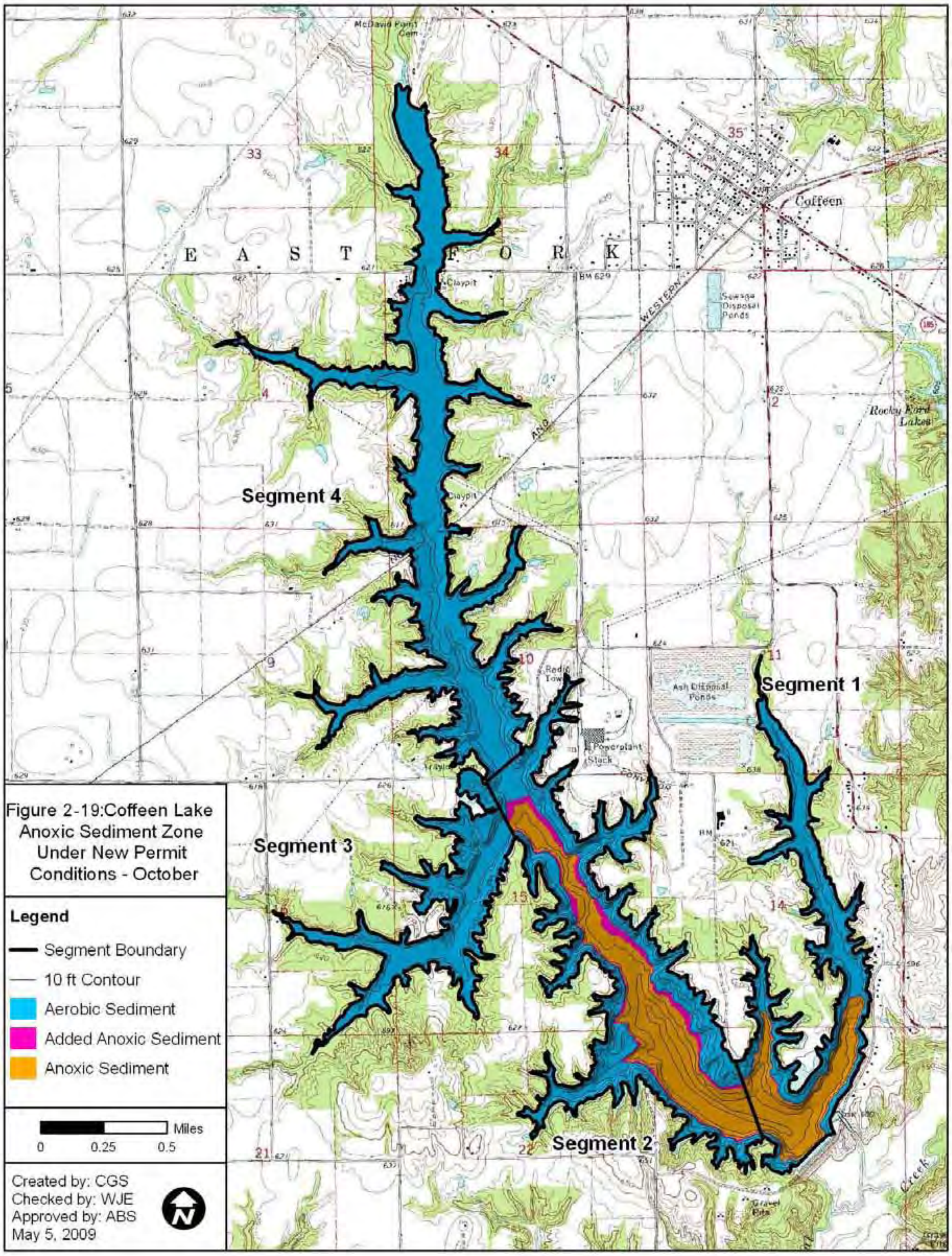


Figure 2-19:Coffeen Lake Anoxic Sediment Zone Under New Permit Conditions - October

Table 2-6. Potential Increase in Lake Substrate Surface Area Exposed To Seasonal Anoxia (Hectares)

	May	October
Segment 1	16.5	0.8
Segment 2	4.5	10.3
Total:	**21.1**	**11.1**

(O_2 Profile Data Source: SIUC, 2007)
Created by: BMJ Checked by: ABS 5/7/2009

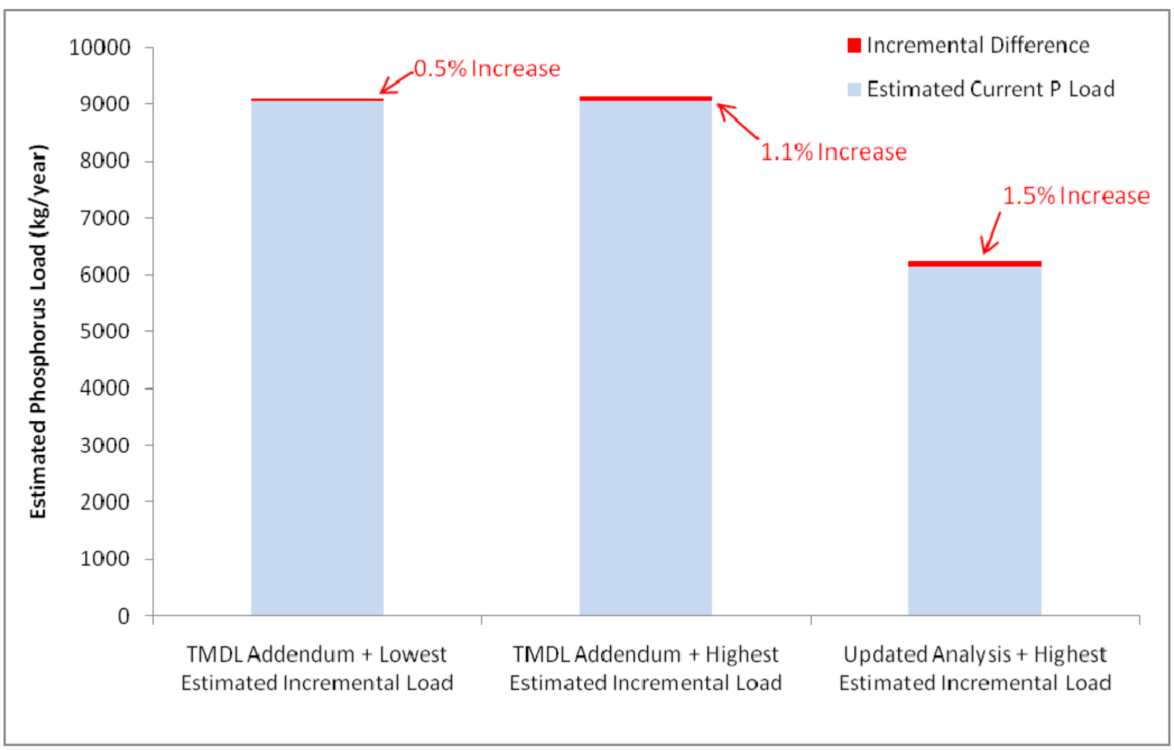
2.2.2 Potential Increase in Phosphorus Loading

Using these areas and representative flux rates (Haggard *et al*, 2005; Illinois EPA, 2009a), estimates of the incremental difference in phosphorus flux into the hypolimnion were made. This estimate ranges from 48.08 kg P/year to 96.17 kg P/yr under the new permit conditions.

2.2.3 Limitation of Impacts to Epilimnion Water Quality

The incremental difference in phosphorus loading is a 0.5% to 1.1 % increase of the TMDL addendum predicted internal loading (Illinois EPA, 2009a), and a 1.5% predicted increase if the internal loading estimate in this analysis (see Section 2.2.1) is accurate (Figure 2-20). In any case, the incremental increase is *de minimus*, and poses no harm to the lake, as this phosphorus is not expected to reach the epilimnion or change current in-lake conditions with respect to phosphorus.

Figure 2-20. Incremental Loading Differences to Estimated Current Phosphorus Loads



(Data Source: Illinois EPA, 2009a).
Created by: BMJ Checked by: KAR 5/11/2009

3.0 Mercury Cycling

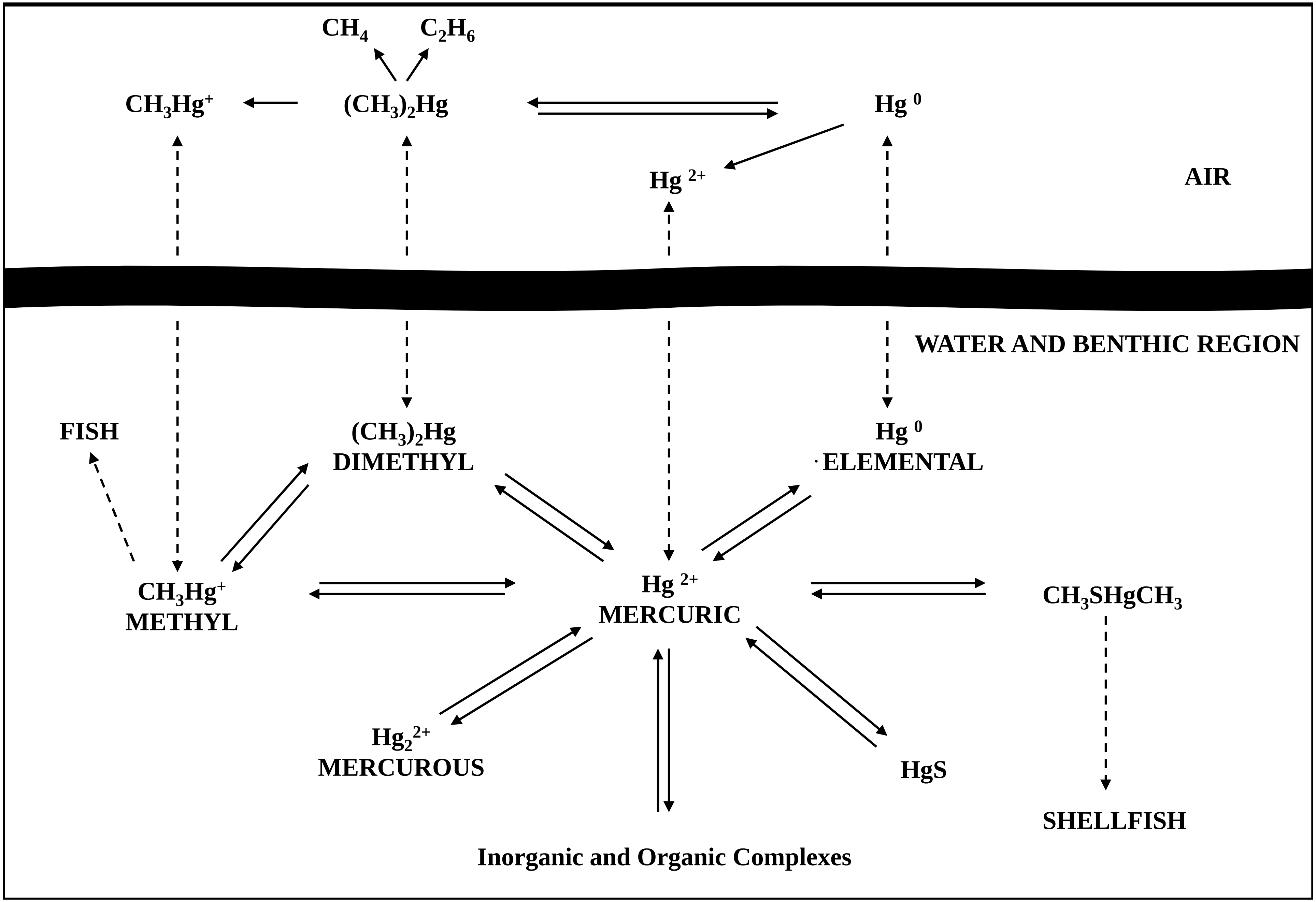
Coffeen Lake is currently listed on the Illinois EPA 303(d) list of impaired water for mercury. Illinois EPA states their concerns as follows: “During periods of stratification and low dissolved oxygen, more methylmercury is produced. Methylmercury bioaccumulates and is typically found in predatory fish. If the temperature of the Lake is higher in May and October, and the period of stratification is lengthened, the levels of mercury in the fish may also increase.” This chapter discusses the complexity of mercury methylation, the current understanding of mercury and mercury dynamics in Coffeen Lake, and the incremental effect of the change in the thermal standard for May and October on mercury cycling in the lake.

Current Illinois fish consumption advisories include waters containing at least one fish tissue where the mercury level 0.06 mg/kg (Illinois EPA, 2008). Mercury readily bioaccumulates in living tissues, and thus, fish consumption advisories are common nationwide. Coffeen Lake is included in this advisory based on fish tissue samples from collections in 2002. These samples consist of two composite (5 fish per composite) samples of largemouth bass filet. Because largemouth bass are a top aquatic predator in the lake, although the sample size is small, the results are conservative for the lake. Illinois EPA’s concern for Coffeen Lake is that mercury methylation is likely based on thermal stratification throughout the summer months. Methylation is affected by multiple parameters and cannot be based solely thermal stratification.

Mercury in the environment is constantly cycled through a biogeochemical cycle, and its presence is the result of natural (e.g., geothermal activity) and anthropogenic activities. Two main types of reactions in the mercury cycle convert mercury through its various forms: oxidation-reduction and methylation-demethylation. In oxidation-reduction reactions, mercury is either oxidized to a higher valence state (e.g., Hg^0 to Hg^{2+}) or reduced to a lower valence state. In methylation-demethylation reactions, mercury is transformed into methylmercury when the oxidized mercury (i.e., Hg^{2+}, or mercuric species) gains a methyl group (CH_3) (Environment Canada, 2007). Chemical speciation is an important variable in determining mercury toxicity (Eisler, 2006). Mercury compounds in aqueous systems are complex, and, depending on various physical and chemical parameters, a variety of chemical species may be formed (Figure 3-1) (Eisler, 2006). Methylmercury is the biologically active form of mercury and bioaccumulates up the food chain.

Mercury may be methylated through biological processes, chemical processes, or both in aquatic systems. Mercury methylation in ecosystems depends on mercury loadings, nutrient content, pH, oxidation-reduction conditions, bacterial activity, and other variables (Eisler, 2006). Changes in biological or chemical parameters can result in increased or decreased methylation and demethylation rates in aquatic systems (Eisler, 2006), however external mercury loading is a dominant variable in fish tissue mercury concentrations. This section summarizes available research on the factors that affect methylation of mercury and how it relates to Coffeen Lake. The parameters discussed in the following subsections are indicator parameters that may indicate whether the methylation of mercury is favorable or unfavorable under certain conditions. While general trends may be observed as individual indicator parameters

Figure 3-1 Major transformations of mercury in the environment. (Eisler, 2006)



increase or decrease, the suite of parameters should be evaluated as a whole to indicate the potential for methylation of mercury.

Mercury may be methylated in a variety of areas and under various conditions throughout the Coffeen Lake watershed. Within the Coffeen Lake watershed, various land use activities are present, totaling 12,278.4 acres surrounding Coffeen Lake (Illinois EPA, 2007). Certain types of land use may attribute to methylation of mercury in and around Coffeen Lake and other nearby waterbodies. According to Illinois EPA (2007) 8,170.70 acres in the Coffeen Lake watershed are used for various forms of agricultural farming, such as soybeans, corn, grasslands and other small grains and hay. During times of harvest and planting runoff from various types of agricultural fields can lead to deposition of sediments, suspended solids and sources of organic carbon into Coffeen Lake and nearby waterbodies. Along with sediment deposition suspended solids and sources of organic carbon as well as various other contaminants may also enter the water systems due to runoff. Contaminants may include pesticides, herbicides, large sediment loads and animal and plant waste materials (as a source of organic carbon). Over 600 acres of the lake's watershed are wetlands. Wetlands are another land use type where mercury methylation is commonly favored. Wetland areas may also be an area of high rates of methylation. This is true because the highest rates of mercury methylation are often observed in surface sediments where microbial activity is relatively high due to input of fresh organic matter. As a result, systems with high organic matter production (e.g., wetlands, reservoirs) may exhibit extremely high rates of methylmercury production (Benoit *et al.*, 2003). Mercury methylation may be occurring in a variety of areas throughout the watershed, depending upon site-specific conditions. East Fork Shoal Creek Gate Structure project proposes to pump water from East Fork Shoal Creek in order to provide additional water to Coffeen Lake. The creation of new floodplain and wetland areas may provide additional areas for potential methylation of mercury to Coffeen Lake due to inundation of areas not previously covered with water. This environment may encourage certain bacteria to anaerobically metabolize available mercury, resulting in methylmercury as a byproduct. However, the annual flooding frequency for the area will not increase, and thus, methylation rates may not be affected by this action.

Methylation can occur in a variety of situations, most notably in surficial sediments at the oxic-anoxic interface (Park and Bartha, 1998), however it may also occur in surrounding areas inundated with water for various amounts of time, forcing bacteria to switch from aerobic respiration to anaerobic respiration. Runoff from agricultural land use may attribute to the amount of sediment deposition, organic carbon, and chemical depositions occurring in Coffeen Lake and in surrounding waterbodies. Methylation rates may increase as sediment loads increase, organic carbon enters a waterbody or dissolved oxygen becomes depleted as a result of nutrient loading. Along with sediment, organic carbon and DO depletion, pH may also play a role in changing methylation rates of mercury. As low pH (acidic conditions) may not favor methylation, higher pHs may favor methylation. Some types of nutrient runoff from agricultural areas may contain chemicals which can raise or lower pH values.

3,464.2 acres of the Coffeen Lake watershed are forested, wetland areas or urbanized and not used for agricultural land use activities. Of the 3,464.2 acres not used for agriculture, 343.2 acres are urbanized.

Due to impervious surface, urbanized areas may also contribute runoff and various forms of potential pollutants to Coffeen Lake and surrounding waterbodies.

3.1 Mercury Load and Bioavailability

The presence of mercury in environmental media, the availability of that mercury for methylation, and the bioavailability of methylmercury, are important for understanding potential risks to receptors. The relationship between mercury load (i.e., mercury concentration) and mercury methylation is logarithmic so that the rates of mercury load and methylation are proportional at relatively low mercury levels. Methylation rates become asymptotic at relatively high levels (Krabbenhoft *et al*., 1999). The greatest potential for mercury methylation occurs in surficial sediment (Korthals and Winfrey, 1987) at the oxic-anoxic interface in sediments (Pak and Bartha, 1998).

3.1.1 Surface Water Data

In 2007, the USEPA conducted mercury sampling in Illinois lakes as part of the National Lakes Survey. Survey locations were chosen based on waterbody acreage and included a subset of lakes included in the 1972 USEPA National Lake Eutrophication Study. Approximately 50 Illinois lakes were sampled, the average total mercury concentration was 2.24 ng/L, and the average methylmercury concentration was 0.07 ng/L (Krabbenhoft, *et al*., 2008).

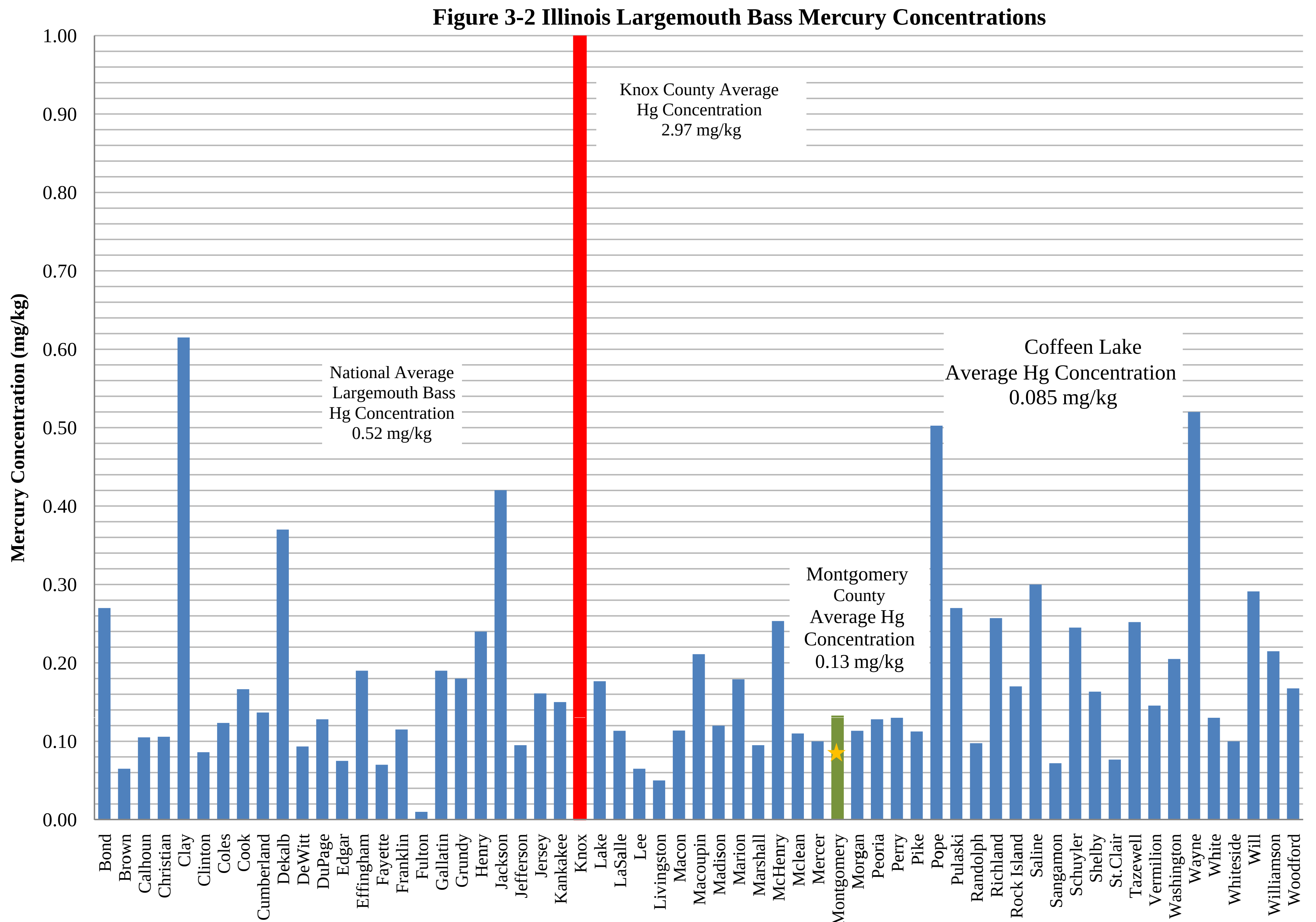
Based on readily available Illinois EPA data, Coffeen Lake surface water was not analyzed for mercury.

3.1.2 Sediment Data

Mercury concentrations from Segments 1 and 3 in Coffeen Lake (Figure 3.-2) sediments collected in 2002 were below the Illinois EPA detection limit. Sediment mercury concentrations from samples collected between 1989 and 1997 ranged from 0.03 to 0.51 mg/kg (average 0.21 mg/kg) in Segment 1 and ranged from 0.0005 to 0.10 mg/kg (average 0.07 mg/kg) in Segment 3 (Illinois EPA, 2009b).

3.1.3 Fish Tissue Data

Coffeen Lake is located in Montgomery County, southwestern Illinois. The Illinois Contaminant Monitoring Program sampling (1985-2004) and USEPA Lake Fish Tissue Study sampling (1999-2003) included composite fish tissue analysis for Montgomery County and surrounding counties of Bond, Christian, Fayette, Macoupin, Madison, Sangamon, and Shelby Counties. A total of 54 fish were sampled from Montgomery County, including largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), and white crappie (*Pomoxis annularis*). The average mercury concentration in Montgomery County was 0.13 mg/kg with concentrations ranging from 0.08 to 0.22 mg/kg. Fish species collected from surrounding counties included, largemouth bass, bluegill, carp (*Cyprinus carpio*), channel catfish (*Ictalurus punctatus*), smallmouth buffalo (*Ictiobus bubalus*), walleye (*Sander vitreus*), black crappie (*P. nigromaculatus*), and spotted bass (*M. punctulatus*). The average mercury concentration in fish tissues from the surrounding counties was 0.14 mg/kg, with a sample range from 0.01 mg/kg to



Sources: Illinois Fish Contaminant Monitoring Program Database 1985-2004
USEPA National Survey of Cioncentrations in Fish Database 1999-2003

Prepared by/Date: AES 5/7/09
Checked by/Date: MBR 5/7/09

0.51 mg/kg. Average mercury concentrations from fish collected in Montgomery and surrounding counties is presented in Table 3-1.

Jenkins (2007) assessed the Illinois Fish Mercury Monitoring Program, which included samples collected between 1974 and 1998. Sample locations were divided by watersheds. Montgomery County is in the Kaskaskia watershed, which comprised 77% of Jenkins' dataset. Other nearby counties in this watershed are Bond, Fayette, Madison, and Shelby Counties. The median tissue mercury concentration from Jenkins' entire fish dataset (>2300 samples, 18 species, 149 lakes) was 0.10 mg/kg.

3.1.3.1 Largemouth Bass

The largemouth bass is the top predatory fish species in Coffeen Lake. Available fish tissue mercury data for Coffeen Lake is limited to two largemouth bass samples, comprised of 5 composited filets each, collected October 22, 1990 and October 21, 1991 (Illinois EPA, 2009c; ; USEPA, 2009). Mercury concentrations of these samples were 0.08 and 0.09 mg/kg, respectively. Using the maximum observed mercury concentration (0.09 mg/kg) in Coffeen Lake largemouth bass, a 33% reduction in mercury loading would be necessary to reach 0.06 mg/kg. Over time, this reduction in fish tissue concentration can be expected to be achieved by regional mercury load reductions. Montgomery County average largemouth bass tissue concentration (0.13 mg/kg) was nearly half than the Illinois Counties average (0.22 mg/kg) (Illinois EPA, 2009c). Figure 3-2 presents the average Illinois largemouth bass mercury concentrations as compared to the national average concentration of 0.52 mg/kg (USEPA, 2001).

3.1.3.2 Wildlife

Some animals, such as bald eagles and wading birds, within the watershed may prey on fish from Coffeen Lake. Mercury levels in fish of concern to wildlife are higher than the benchmark of 0.06 mg mercury/kg adopted by Illinois EPA for protection of human health. Given the current and anticipated low levels of mercury in fish (with the largemouth bass samples representing the upper end of mercury concentrations in fish), wildlife are not at risk from mercury in fish from Coffeen Lake.

3.2 Additional Parameters Related to Methylation

In addition to the mercury load, acid volatile sulfide (AVS)/simultaneously extracted metals (SEM) ratios, changes in water levels, dissolved oxygen (DO), hardness and alkalinity, metals, molybdate, organic carbon, oxidation-reduction potential (ORP), pH, salinity, seasonality and temperature, sulfate and sulfide, water levels, and the microbial community structure are factors that affect methylation. Readily available Coffeen Lake analyte data are not available for each of these parameters; however, data are available for DO, alkalinity, iron, manganese, pH, organic carbon, and temperature. A summary of these parameters and their expected influence on mercury methylation are listed below. The parameters with Coffeen Lake data are discussed further in the following sections.

Table 3-1. Average Fish Tissue Mercury Data from Montgomery and Surrounding Counties

County	Waterbody	No. of Samples	No. of Fish Sampled	Species	Ave Hg Conc (mg/kg)
Bond	Greenville New Lake	1	5	LMB	0.100
Bond	Patriots Park Lake	2	10	LMB	0.360
Christian	Sangchris Lake	5	22	LMB	0.118
Christian	Taylorville Lake	3	14	LMB	0.090
Fayette	Kaskaskia river	4	17	C, CC, LMB, SMB, WE	0.125
Fayette	Vandalia Lake	1	5	LMB	0.070
Macoupin	Beaver Dam Lake	1	5	LMB	0.140
Macoupin	Bunn Lake	2	10	BG, LMB	0.140
Macoupin	Mt. Olive New Lake	2	10	LMB	0.215
Macoupin	Mt. Olive Old Lake	1	5	LMB	0.260
Macoupin	Otter Lake[1]	5	25	C, LMB	0.166
Macoupin	Staunton City Lake	2	10	LMB	0.175
Madison	Highland-Silver Lake	1	5	LMB	0.240
Madison	Horseshoe Lake	3	15	BG, LMB	0.100
Madison	Mississippi River - S. Central	3	12	LMB, WB	0.110
Madison	Pine Lake	4	13	BC, BG, LMB	0.100
Montgomery	Coffeen Lake	2	10	LMB	0.085
Montgomery	Glenn Shoals Lake	2	10	LMB	0.140
Montgomery	Lou Yaeger Lake	8	34	BG, LMB, WC	0.138
Sangamon	Springfield Lake	5	25	LMB	0.072
Shelby	Kaskaskia river	2	6	LMB, WE	0.100
Shelby	Little Wabash River	4	15	C, LMB, SB	0.238
Shelby	Shelbyville Lake	6	30	LMB, WC, WE	0.085

Notes:

Samples comprised of composite filets collected between 1985 and 2004 as part of the Illinois Contaminant Monitoring Program.

[1]Includes four composited filet samples collected in 2001 as part of the US EPA Lake Fish Tissue Study.

Species Codes:

BC = Black Crappie
BG = Bluegill
C = Carp
CC = Channel Catfish
Hg = Mercury
LMB = Largemouth Bass
SB = Spotted Bass
SMB - Smallmouth Buffalo
WB = White Bass
WC = White Crappie
WE = Walleye

Source:

Illinois Fish Contaminent Monitoring Program database (1985-2004);
USEPA National Survey of Concentrations in Fish database (1999-2003).

Prepared by/Date: MBR 5/5/09
Checked by/Date: AES 5/6/09

Table 3-2. Summary of Various Parameters that may Influence Mercury Methylation Rates

Mercury Methylation Parameter	General Effect on Methylation of Mercury
AVS/SEM	AVS/SEM ratios greater than 1 tend to inhibit methylation.
DO/ORP	Oxic and oxidizing environments do not favor methylation.
Hardness/Alkalinity	Increased hardness and alkalinity reduce metal toxicity and reduce uptake of metals.
Iron/Manganese	May favor or inhibit methylation depending on concentration and chemistry.
pH	Acidic conditions in sediment may not favor methylation.
Salinity	As salinity increases, methylation of mercury decreases.
Sulfate	Reduction of sulfate by sulfate reducing bacteria (SRB) may enhance methylation of mercury.
Sulfide	The presence of sulfide may reduce methylation of mercury and bioavailability of methylmercury.
Temperature	Increasing temperature increases methylation of mercury.
Organic Carbon	DOC in the water column may enhance methylation but may also bind methylmercury; TOC in sediment may enhance methylation.

3.2.1 Dissolved Oxygen

DO plays a role in mercury methylation. When oxic conditions exist in the water column and in sediments (i.e., DO >1 milligrams per liter [mg/L]), bacteria respire aerobically, which means that they use oxygen as the terminal electron receptor during metabolism. When anoxic conditions are present in the water column or in sediments, bacteria will respire anaerobically, which means they will use another molecule besides oxygen as the terminal electron receptor during metabolism. The molecule used depends on the types of bacteria present. Mercury can be methylated to produce methylmercury as a byproduct of these metabolic reactions. Several studies have concluded that the formation of methylmercury from mercury in lakes and reservoirs is favored under low DO conditions; the rate of mercury methylation is lower in the presence of oxygen; and methylmercury may be formed primarily in anoxic waters and sediments but is demethylated under aerobic conditions (Ramlal *et al*., 1986; Korthals and Winfrey, 1987; Bloom and Effler, 1990; Oremland *et al*., 1991; Gilmour *et al*., 1992; Watras *et al*., 1995; Herrin *et al*., 1998). Pak and Bartha (1998) discovered that the most important location of methylation is at the oxic-anoxic interface in sediments. However, the mere absence of oxygen does not demonstrate that rates of mercury methylation are high.

Based on Coffeen Lake bottom conditions between 2001 and 2006 (see Section 2), anoxic conditions are present over a portion of the lake bottom and in the hypolimnion (at depth) in waters overlying these sediments during a portion of the six month period from May to October. Mercury (whether methylated or not) is quite low in Coffeen Lake, compared to many other lakes in Illinois, based upon the available largemouth bass data. Changes to the thermal standard for Coffeen Lake during May and October will not increase the overall mass of mercury in the lake. The marginal changes in anoxia in these two months attributable to these changes (see Figures 2-18 and 2-19 in Section 2), compared to the current operating conditions, leads to the conclusion that any effect on mercury methylation rates that may occur would be very minor, and likely not result in measureable changes in fish mercury concentrations.

3.2.2 Alkalinity

Total alkalinity (i.e., carbonate and bicarbonate) can also regulate metal content in surface water by precipitating toxic metals out of solution. Total alkalinity is also an indication of the buffering capacity of the surface water system or the ability of a water body to resist changes in pH. The pH level also plays a role in the methylation of mercury and is discussed in Section 2.10. Buffering capacity of a water body is geologically dependent, but, in general, total alkalinity levels less than or equal to 10 mg/L indicate a poorly buffered system that is susceptible to changes in pH (Wilkes University, 2007). Higher alkalinity levels have also been correlated with reduced bioaccumulation rates (Barkay *et al*., 1997).

Total alkalinity concentrations in Coffeen Lake Segment 1 ranged from 80 to 140 mg/L. Segment 2 concentrations ranged from 50 to 120 mg/L. Segment 3 concentrations ranged from 60 to 110 mg/L. Based on these results, total alkalinity concentrations indicate potentially reduced bioaccumulation rates within Coffeen Lake.

3.2.3 Metals

Substrates other than oxygen act as the terminal electron receptor for bacterial metabolism under anoxic conditions. Depending on the species of bacteria present and the physico-chemical environment, metals such as iron and manganese can be used as terminal electron receptors. The production of methylmercury can be a byproduct of these metabolic reactions. In addition, non-microbial methylation of mercury was documented to be stimulated by the presence of certain metals, such as iron and manganese (Stokes and Wren, 1987). Iron and manganese can also inhibit the methylation of mercury through mineralization. Selenium has been shown to decrease bioaccumulation rates of methylmercury. Research on each metal is presented in the following sections.

3.2.4 Iron

Iron can potentially stimulate or inhibit methylmercury production depending on concentration and speciation. Iron reduction by bacteria may be responsible for some amount of in situ mercury methylation (Kerin *et al*., 2006). Depending on iron speciation, iron can stimulate iron-reducing bacteria to methylate mercury, and these bacteria can do so at a rate equivalent to SRB in some circumstances (Fleming and Nelson, 2006) (see Section 1.14). As a result, the presence of iron, which can be used as a terminal electron receptor in metabolism for certain bacterial populations, can increase methylation rates. Warner *et al*. (2003) found measurable methylation in sediments where iron was the dominant terminal electron acceptor, although methylation rates were lower than those observed in sulfate-reducing or methanogenic sediments. In sediments from Clear Lake, California, where microbial iron reduction was occurring, inhibition of sulfate reduction did not result in complete inhibition of mercury methylation, suggesting that iron reduction may have been responsible for some amount of in situ mercury methylation (Fleming *et al*., 2006). Jackson found that iron-coated clays counter depression of both methylation and demethylation (Jackson, 1989). Ferric oxyhydroxide addition was documented to increase methylation rates in certain lacustrine (lake) sediments (Fleming *et al*., 2006).

While iron may stimulate methylmercury production under certain conditions, it may also inhibit methylmercury production. In a study of estuarine wetland sediment slurries from San Francisco Bay, California, Mehrotra and Sedlak (2005) observed decreases in mercury methylation rates with the addition of 30 millimolar (mM) ferric iron; they believe that this effect was caused by decreases in dissolved mercury and sulfide due to complexation with iron. The addition of ferrous iron may also decrease the net rate of methylmercury production by reducing the concentration of dissolved sulfide. Complexation with iron could also reduce mercury bioavailability.

Coffeen Lake iron concentrations in sediments in Segment 1 ranged from 26,500 to 40,000 mg/kg at Segment 1 and from 17,000 to 30,000 mg/kg at Segment 3. At these concentrations, the mercury may be complexed with iron and not available to iron-reducing bacteria for methylation, as noted in research by Mehrotra and Sedlak above.

3.2.4.1 Manganese

Manganese, like iron, may complex with mercury and reduce bioavailability. The role of clays in reducing methylation was dependent on their surface coatings in research involving clay minerals and oxides on methylation and demethylation of mercury (Jackson, 1989). Manganese oxide coatings sometimes promoted methylation, but larger amounts of manganese oxide suppressed methylation (Jackson, 1989).

Coffeen Lake manganese concentrations in Segment 1 ranged from 712 to 1,600 mg/kg at Segment 1 and from 290 to 521 mg/kg at Segment 3. At these concentrations, the mercury present in Lake sediments may be complexed with manganese and, therefore, may not be bioavailable.

3.2.5 Organic Carbon

Two types of organic carbon, DOC and total organic carbon (TOC), can affect the methylation of mercury. Both mercury and methylmercury will complex strongly with DOC and, as a result, can both decrease and increase bioaccumulation (Brumbaugh *et al.*, 2001). Organic complexation can increase the amount of mercury substrate for methylation in the water column, but the binding of methylmercury by DOC in the water column can result in lower fish bioconcentration factors (Watras *et al.*, 1995). DOC associations may decrease the bioaccumulation of mercury in aquatic food webs by lowering the bioavailability of mercury to methylating organisms (Barkay *et al.*, 1997; Haitzer *et al.*, 2003).

TOC has also been shown to have opposing effects on the methylation of mercury and its bioavailability. TOC can enhance mercury methylation by acting as a food source and thereby increasing the metabolism of heterotrophic microorganisms (Furutani and Rudd, 1980; Stokes and Wren, 1987); however, mercury methylation may also be inhibited through formation of mercury complexes with organic ligands (Robinson and Tuovinen, 1984; Gilmour *et al.*, 1992; Macalady *et al.*, 2000; Han *et al.*, 2007). The highest rates of mercury methylation are often observed in surface sediments where microbial activity is greatest due to the input of fresh organic matter. As a result, systems with high organic matter production (wetlands, reservoirs) may exhibit extremely high rates of methylmercury production (Benoit *et al*., 2003).

Illinois EPA 1997 Coffeen Lake samples had concentrations of 0.58 and 0.82 percent TOC, which may suggest conditions do not appear to favor methylation. Krabbenhoft, *et al.* (2008) correlated DOC levels with total and methyl mercury, stating "proximity to sources and DOC levels are the most significant drivers." Coffeen Lake DOC levels are not available; however, Illinois DOC averaged 7.1 mg/L. As discussed in Section 2.1.1, total mercury average concentration in Illinois was 2.24 ng/L and methyl mercury concentrations averaged 0.07 ng/L.

3.2.6 pH

The level of pH also plays a role in the methylation of mercury. Acidic pH generally favors the methylation of mercury to a point. The pH level may also affect the bioavailability of methylmercury to higher trophic level organisms. Low pH (usually less than 5) is frequently associated with high mercury concentrations in fish tissue (Stokes and Wren, 1987; Watras *et al*., 1995; Barkay *et al*., 1997; Brumbaugh *et al*., 2001). Low pH favors both the direct uptake of methylmercury through the gills of fish and dietary uptake due to increased mercury accumulation by organisms in lower trophic levels (WHO, 1990). In some systems, surface water pH has been identified as the most important factor controlling mercury bioaccumulation in fish (Moore *et al*., 2003).

Coffeen Lake surface waters are neutral or circum-neutral, which does not favor methylation. Data for pH are not available for Coffeen Lake sediment samples, but are also likely to be circum-neutral.

3.2.7 Seasonality and Temperature

Seasonality resulting from temperature changes affects the methylation of mercury. The potential for mercury methylation varies at different times of the year, with the greatest potential generally occurring in the summer from mid-July to September (Korthals and Winfrey, 1987). Lacustrine environments (i.e., lakes and ponds) with a significant depth profile and low water flows may thermally stratify in the summer and in the winter. The stratification generally disappears during the spring and fall during what is known as turnover events. The ratio of methylmercury to mercury in thermally stratified lakes is generally greater in the hypolimnion (bottom layer), especially if the hypolimnion is anoxic, than in the epilimnion (upper layer) (Bloom and Effler, 1990; Mason and Sveinsdottir, 2003; Eckley *et al*., 2005). The increase in methylmercury in the hypolimnion appears to be related to the anaerobic conditions and the inability of DO to penetrate the thermocline (region between the epilimnion and hypolimnion that exhibits a marked temperature gradient equal to or exceeding 1˚C per meter) until a turnover event. Korthals and Winfrey (1987) discovered that the seasonal peak in mercury methylation in profundal (deep, bottom-water area beyond the depth of effective light penetration) surficial sediments coincided with a depletion of DO in the lower hypolimnion, and the decrease in mercury methylation corresponded with the reaeration of the hypolimnion during fall turnover. Several mechanisms have been proposed to explain the seasonal changes of mercury methylation rates in anoxic hypolimnia. These potential mechanisms include the diffusion of methylmercury from sediment to surface water during anoxic conditions, methylation occurring in anoxic water column, and sedimentation of particulate methylmercury (Eckley *et al.,* 2005).

Herrin *et al*. (1998) observed pronounced increases in mercury body burdens of zooplankton and juvenile bass at the time of thermal destratification of a seasonally anoxic reservoir. Methylmercury stored in the anoxic hypolimnion during the summer stratified period became available to lake biota during the fall turnover and remained available for a short time after complete turnover (Herrin *et al*., 1998).

Increasing temperature also promotes methylation (Shanley *et al*., 2005). It also appears that mercury methylation can be stimulated in the late spring by the high supply of fresh organic matter after the spring plankton bloom (Choe *et al.,* 2004). These increases are difficult to isolate, as other parameters, such as input of fresh organic matter, coincide with temperature changes.

Based on Coffeen Lake bottom conditions between 2001 and 2006 (see Section 2), anoxic conditions are present over a portion of the lake bottom and in the hypolimnion (at depth) in waters overlying these sediments during a portion of the six month period from May to October. Mercury (whether methylated or not) is quite low in Coffeen Lake, compared to many other lakes in Illinois, based upon the available largemouth bass data. Changes to the thermal standard for Coffeen Lake during May and October will not increase the overall mass of mercury in the lake. The marginal changes in anoxia in these two months attributable to these changes (see Figures 2-18 and 2-19 in Section 2), compared to the current operating conditions, leads to the conclusion that any effect on mercury methylation rates that may occur would be very minor and likely not result in measureable changes in fish mercury concentrations.

3.3 Summary

Several geochemical factors that may affect the methylation of mercury were discussed in the previous sections. The parameters discussed in the previous subsections are indicator parameters that may generally predict whether the methylation of mercury is favorable under certain conditions. While general trends may be observed as these indicator parameters increase or decrease, the suite of parameters should be evaluated as a whole to predict the potential for methylation of mercury.

Flooding of terrestrial and wetland environments may or may not play a role in the methylation of mercury. Current research on flooding or re-wetting of sediments or soils and methylation rates is contradictory and appears largely dependent on site characteristics. While it may not be possible to manipulate all parameters to reduce mercury methylation or methylmercury bioavailability, it may be possible to manipulate some parameters. The effectiveness of manipulating any particular parameter depends on various site-specific conditions. Recent research indicates that the most important parameter that affects the methylation of mercury may be its mineralization with various other compounds in the environment.

Based on the available Coffeen Lake data, mercury concentrations appear to be generally low and conditions do not appear to be favorable for methylation. Current sources of methylation may be within lake or occurring in the watershed, but appear low. The proposed change in the thermal standard affecting May and October conditions do not substantially change the lake conditions, although thermal stratification may persist for more days on average, annually. This change is minor, and does not represent a change that could or would significantly increase hypolimnetic mercury methylation rates. It is anticipated that the change, if any, would be so small that it would not result in increased mercury in the biota. Fish tissue concentrations are anticipated to measurably decline, however, as a result of regional mercury load reductions

4.0 Summary

4.1 Introduction

MACTEC evaluated potential for impacts on phosphorus and mercury cycling from proposed modifications to current site-specific thermal standards in Coffeen Lake in support that raising the thermal limits for the months of May and October will not result in significant increases in phosphorus loading or mercury methylation over current lake conditions.

Illinois EPA claimed that Ameren failed to address the impact of the proposed thermal limits on total phosphorus and mercury levels in Coffeen Lake, in addition to failing to address the impact on Lake Habitat. Illinois EPA stated a concern that higher temperatures of Coffeen Lake in May and October may result in prolonged stratification which can increase phosphorus levels and methylmercury levels.

4.2 Phosphorus

Phosphorus is a limiting nutrient in Coffeen Lake and is therefore an important component of its long-term water quality. Internal phosphorus release from sediments can serve as an additional source of phosphorus loading to the lake, yet is ultimately dependent on a number of chemical and physical factors which occur at the sediment-water interface. The mere presence of thermal stratification does not indicate that significant internal loading will occur as a result. Despite the potential for seasonal sediment phosphorus release from the sediments, water quality measurements within Coffeen Lake indicate that internal phosphorus recycling is currently not contributing appreciable amounts of total phosphorus to epilimnetic surface water. Oxygenated hypolimnetic water and epilimnetic waters (DO> 1 mg/L) were always present overlying these deeper anoxic layers as shown by cross section for May and October. The data and this analysis clearly show that there is no “dead zone” within the lake.

TMDL assessments for Coffeen Lake attribute elevated phosphorus concentrations to external watershed loading, primarily due to expansive agriculture surrounding the lake. External loading as a driver of water quality is also apparent in high phosphorus concentrations measured in the shallow northern portions of the lake. Additionally, seasonal water quality comparisons do not show elevated phosphorus or chlorophyll-a concentrations during summer stratification of the water column, indicating that phosphorus is either not being released in large volumes from the sediment or is not being mixed into the epilimnion where it may be available for algae production.

Review of the original TMDL BATHTUB (2007) model revealed significant modeling errors and misapplications which led to the erroneous conclusion that internal phosphorus loading dominates Coffeen Lake. These errors produced a model run which did not match known lake phosphorus concentrations. To compensate for this “under-prediction of observed phosphorus concentrations”, the modelers introduced an additional internal phosphorus load (the BATHTUB model already incorporates internal loading) to force the model to calibrate. The conclusions and load reduction requirements of the original TMDL were not revised, despite these errors and discrepancies. However, available monitoring data do not confirm this estimated level of internal loading (see Section 2.1.1).

An evaluation of potential impacts associated with modified thermal discharge during the months of May and October was also performed to quantify the potential for additional phosphorus release and anticipated impacts to surface water quality. Results of this analysis indicate that the additional phosphorus load which may be anticipated from the proposed modification ranges from 329.1 kg P/year to 658.1 kg P/yr under existing permit conditions, which is much lower than predicted from the BATHTUB modeling completed for the TMDL. Additionally, any phosphorus released from the sediment is not expected to reach the epilimnion, and is therefore unavailable for biological production within Coffeen Lake. Based on seasonal water quality comparisons sediment phosphorus release does not appear to be an important component of surface water phosphorus loading within Coffeen Lake. Future modifications to thermal discharge limits from the Ameren Power Generating Plant are unlikely to present additional phosphorus loads from sediment release in the future, and therefore are not a threat to the existing water quality of Coffeen Lake.

4.3 Mercury

Mercury readily bioaccumulates in living tissues, and thus, fish consumption advisories are common nationwide. Coffeen Lake is currently included in the Illinois fish consumption advisories based on two fish tissue samples with mercury concentrations exceeding the Illinois EPA level of concern of 0.06 mg/kg. These samples consist of two composite (5 fish per composite) samples of largemouth bass filet with concentrations of 0.08 and 0.09 mg/kg of mercury. Because largemouth bass are a top aquatic predator in the lake, although the sample size is small, the results are conservative for the lake. Illinois EPA's concern for Coffeen Lake is that mercury methylation is likely based on thermal stratification throughout the summer months.

Methylation is affected by multiple parameters and cannot be based solely on thermal stratification. There are multiple indicator parameters that may predict whether the methylation of mercury is favorable under certain conditions. While general trends may be observed as these indicator parameters increase or decrease, the suite of parameters should be evaluated as a whole to predict the potential for methylation of mercury.

Based on the available Coffeen Lake data, mercury concentrations appear to be generally low and conditions do not appear to be favorable for methylation. Current sources of methylation may be within the lake or occurring in the watershed, but appear low. The proposed change in the thermal standard affecting May and October conditions does not substantially change lake conditions, although thermal stratification may persist for more days on average, annually. This change is minor, and does not represent a change that could or would significantly increase hypolimnetic mercury methylation rates. It is anticipated that the change, if any, would be so small, that it would not result in increased mercury in the biota. Fish tissue concentrations are anticipated to measurably decline, however, as a result of regional mercury load reductions.

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