PHASE I CLEAN LAKES PROJECT

DIAGNOSTIC AND FEASIBILITY STUDY OF

THE GAINES CREEK ARM OF LAKE EUFAULA

Kevin Wagner
Technical Writer
Oklahoma Conservation Commission
Water Quality Division

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EXECUTIVE SUMMARY

Lake Eufaula, the fifteenth largest reservoir in the United States, is located in McIntosh and Pittsburg Counties of southeast Oklahoma. It was created in 1964 by impounding the Canadian River (tributary to the Arkansas River) roughly 15 miles downstream of the North Canadian River confluence with the South Canadian River and approximately 20 miles downstream of the Gaines Creek confluence with the Canadian River. Lake Eufaula has the largest surface area (105,500 acres) and the second largest capacity (2,314,600 acre-feet) of any impoundment in Oklahoma. This study focused on the southern-most portion of the Gaines Creek Arm of Lake Eufaula due to the interest associated with acid mine drainage (AMD) in the Gaines Creek watershed.

The study area consists of approximately 4,350 acres of the 31,775 acres Gaines Creek Arm. This area represents the riverine zone of the lake and is comprised of flooded bottom land hardwood forest and the sinuous thalweg of Gaines Creek. The study area is fed by Gaines Creek, Brushy Creek, Peaceable Creek, and Mud Creek. Peaceable Creek joins Brushy Creek near its confluence with the Gaines Creek Arm. All of these streams are perennial.

According to the Oklahoma Water Quality Standards, the beneficial uses of Lake Eufaula include public and private water supply, warm water aquatic community, Class I agricultural irrigation, hydropower, industrial and municipal process and cooling water, primary body contact recreation, navigation, and aesthetics. The Pittsburg County Water Authority, which draws water from the portion of the Gaines Creek Arm studied, provides water for approximately 9,000 people. The Pittsburg County Water Authority sells water wholesale to the Adamson Water Company and the cities of Hartshorne and Haileyville. The Gaines Creek Arm is also a primary recreational attraction for inhabitants of Pittsburg and Latimer Counties. The predominant recreational activities are hunting and fishing (catfish and crappie).

Six sanitary waste treatment facilities discharge in the watershed, two in the Mud Creek watershed and four in the Brushy Creek watershed. Two industrial facilities also discharge into the watershed. Land use in the watershed (405,541 acres) is primarily pasture (37%) and forest (44%). Total rangeland makes up approximately 11% of the watershed. Other notable land uses in the watershed are military/government land (2%) and urban land (3%).

The Gaines Creek watershed also has a history of coal mining activity dating back to 1872 when these mines supplied fuel coal to railroads. Acidic water containing high concentrations of metals (acid mine drainage) is now discharged from the mines from old shaft entrances, air vents, and contaminated springs. Due to this, the Gaines Creek Arm of Lake Eufaula and its watershed have been the subjects of intensive study.

This study monitored water quality in Lake Eufaula's Gaines Creek Arm and its tributaries from July 1991 through September 1992. The primary goals of the diagnostic study were to locate major sources of AMD and to evaluate the impacts of AMD on the lake. The study indicated that the Stafford-Hall Mine, Gowen Strip Pits, and the Adamson seep were contributing the largest amounts of AMD pollutants.

Despite the AMD, the lake water and sediments do not contain quantities of metals which are toxic to human health or aquatic organisms, although Pit Creek and parts of Gaines Creek have been shown to contain toxic levels of metals. Anoxic conditions during summer thermal stratification are responsible for the poor benthic macroinvertebrate and fish communities in the Gaines Creek Arm of Lake Eufaula. The anoxic conditions are caused by the consumption of oxygen by decomposing organic material and reduced forms of metals during lake thermal stratification. Elevated algal productivity caused by excessive levels of nutrients may also be contributing to the development of anoxic conditions.

The Mud Creek and Brushy/Peaceable Creek watersheds are contributing elevated levels of nutrients to the Gaines Creek Arm. The source of the elevated nutrient levels in Mud Creek likely originate primarily from municipal waste treatment facilities, while the elevated nutrient levels in Brushy Creek likely originate from nonpoint source pollution. However, the elevated levels of nutrients have not seriously impacted the Gaines Creek Arm, because algal productivity is severely limited by the extremely high turbidity. Therefore, because productivity is limited by turbidity, the trophic state of the Gaines Creek Arm was classified as argillotrophic.

In conclusion, data suggest that water quality problems in the Gaines Creek Arm of Lake Eufaula are tied primarily to turbidity and the development of an extensive anaerobic hypolimnion due to oxygen demand from decomposing organic matter and reduced metals. Data also demonstrate that the Gaines Creek Arm is receiving elevated nutrient loads. However, these nutrients are not severely impacting the Gaines Creek Arm.

Due to the nature and extent of the problems, remediation of this portion of the lake is not feasible. However, preventing or treating AMD should result in noticeable improvements in receiving streams. Implementation of BMPs which reduce nutrient loading will not result in significant improvements to the Gaines Creek Arm; however, receiving waters should benefit from these measures.

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I. DIAGNOSTIC STUDY OF THE GAINES CREEK ARM OF LAKE EUFAULA

I.1 Lake Identification and Description

Lake Eufaula, the fifteenth largest reservoir in the United States, is located in McIntosh and Pittsburg Counties of southeast Oklahoma. It was created in 1964 by impounding the Canadian River (tributary to the Arkansas River) roughly 24 km downstream of the North Canadian-South Canadian confluence and approximately 32 km downstream of the Gaines Creek confluence. Lake Eufaula has the largest surface area (42,696 ha) and the second largest capacity (2.86×10^9 m^3) at normal pool elevation (178 m above mean sea level) of any reservoir in Oklahoma. The top elevation of the flood pool is 182 m above mean sea level which expands the surface area to 57,872 ha (OWRB 1990). The U.S. Army Corps of Engineers (COE) is responsible for operation of the lake, while the Oklahoma Department of Wildlife Conservation (ODWC) is responsible for managing the fish and wildlife resources of the lake. Lake Eufaula consists of 5 major areas: the central pool near the hydrostructure on the Canadian River, the Deep Fork Arm, the North Canadian River Arm, the South Canadian River Arm, and the Gaines Creek Arm. This study focused only on the southern-most portion of the Gaines Creek Arm due to the interest associated with acid mine drainage (AMD) in the Gaines Creek watershed. The study area encompassed approximately 1,760 ha (4350 acres) of the 12,859 ha Gaines Creek Arm and its 164,122 ha (405,541 acres) watershed (Figure 1). Major tributaries to the southern-most portion of the Gaines Creek Arm, which is located entirely in Pittsburg County, include Gaines Creek, Brushy Creek, Peaceable Creek, and Mud Creek.

I.2 Geological Description of Drainage Basin

The elevation in the Gaines Creek Arm watershed ranges from approximately 180 m at the lake to 460 m at the highest point in the watershed. The Gaines Creek Arm watershed (164,122 ha) encompasses portions of three ecoregions: the Arkansas Valley, Ouachita Mountains, and Central Oklahoma-Texas Plains. Gaines Creek flows through the Arkansas Valley and Ouachita Mountain ecoregions. The Arkansas Valley ecoregion is generally composed of varied forest types (oak, hickory, pine, and bottomland hardwood forest) on plains and hills. The landuse in this ecoregion is predominately cropland with areas of pasture, woodland, and forest. The soils are primarily alfisols and sandstone/shale soils. The Ouachita Mountains ecoregion is generally composed of oak/hickory/pine forests on open high hills to open low mountains. The landuse in this ecoregion is primarily forest or grazed woodland. The soils are primarily moist ultisols. Brushy Creek and Mud Creek flow through the Central Oklahoma-Texas Plains ecoregion, which is composed primarily of cross timbers (mosaic of bluestem prairie and oak/hickory forests). Landuse in this ecoregion is primarily cropland with pasture, woodland, and forested areas. The soils are primarily alfisols (Omernik 1987).

The mean annual temperature is 16.8^{o}C with monthly means ranging from 4.8^{o}C in January to 28.3^{o}C in July and August. Temperatures greater than 32.2^{o}C occur, on average, 85 days a year while temperatures below freezing occur, on average, 66 days a year. South-southeasterly winds, averaging 18 km per hour, prevail except during January and February when the prevailing winds are northerly (SCS 1971; SCS 1981).

The soil types found in the watershed of Lake Eufaula's Gaines Creek Arm are listed in Appendix A. Over a quarter of the watershed contains soils of the Enders-Hector complex. The remaining area is comprised of an assortment of 73 soils each of which make up less than 5% of the watershed area. Soils considered highly erodible by the *Highly Erodible Lands Report* (SCS 1993) are present on 69% of the watershed. Another 10% of the watershed contains soils considered potentially erodible. Only 20% of the watershed contains soils are considered non-erodible.

I.3 Lake Uses

Lake Eufaula was constructed to provide flood control, water supply, hydroelectric power, and sediment control for navigation (OWRB 1990). According to the Oklahoma Water Quality Standards (OWQS), the beneficial uses of Lake Eufaula include public and private water supply, warm water aquatic community, Class I agricultural irrigation, hydropower, industrial and municipal process and cooling water, primary body contact recreation, navigation, and aesthetics (OWRB 1995).

The Pittsburg County Water Authority, which withdraws roughly 1,000 acre-feet of water annually from the portion of the Gaines Creek Arm studied (SW 1/4 of Section 6, Township 5 North, Range 17 East), provides water for approximately 9,000 people. The Pittsburg County

Water Authority sells water wholesale to the Adamson Water Company and the cities of Hartshorne (pop. of 2,120) and Haileyville (pop. of 918).

The Gaines Creek Arm is also a primary recreational attraction for inhabitants of Pittsburg and Latimer Counties. The predominant recreational activities are hunting and fishing (catfish and crappie). Because the Gaines Creek Arm is relatively shallow and turbid, there is little skiing or swimming.

I.4 Lake User Population Impacted by Lake Degradation

Water quality degradation in the Gaines Creek Arm would impact those that depend on it for drinking water (Hartshorne, Haileyville, Adamson Water Company) the greatest.

I.5 Size and Economic Structure of Population Using Lake

The Gaines Creek Arm is not as developed as other areas of Lake Eufaula and is used primarily by people residing in McAlester, Hartshorne, and Wilburton, and the rural areas of Pittsburg and Latimer Counties. According to the 1990 U.S. Census, the populations of Pittsburg and Latimer Counties are 40,581 and 10,333, respectively. The median age in Pittsburg County is 37.5 years, while the median age in Latimer County is 33.8 years. Table 1 summarizes the economic structure of Pittsburg County and Latimer County (1990 Census).

Table 1. Economic Structure of Pittsburg and Latimer Counties, OK.

Category	Pittsburg County	Latimer County
Total Persons	40,581	10,333
Total Families	11,536	2,832
Total Households	15,908	3,740
Per Capita Income	$9,832	$9,427
Median Family Income	$23,292	$19,937
Median Household Income	$18,906	$17,477
Persons Below Poverty	7,624	2,257
% Persons Below Poverty	19.6	23.34
Families Below Poverty	1,821	510
% Families Below Poverty	15.79	18.01
Households Below Poverty	3,255	909
% Households Below Poverty	20.46	24.30

I.6 Public Access to Lake

The Gaines Creek Arm is easily accessible from any direction (Figure 2). It may be accessed from State Highway 31 northeast from McAlester or southwest from Quinton. Access may be attained from U.S. Highway 69 south from Muskogee or north from McAlester. Access can also be obtained via U.S. Highway 270 east from McAlester and west from Wilburton. U.S. Highway 69 can be accessed from such arterial highways as U.S. Interstate 40 and the Indian Nation Turnpike, making it very accessible to vacationers from the major metropolitan areas (i.e. Oklahoma City and Tulsa). U.S. Highway 270 and State Highway 31 are both accessible via the Indian Nation Turnpike. The lake is also accessible from numerous county roads from the highways discussed above. Ten recreation areas are located on the Gaines Creek Arm; however, only the Highway 31 Landing and Hickory Point are located in the study area.

In addition to the parks, seven public boat ramps are located along the Gaines Creek Arm. An extensive Army Corps of Engineers buffer zone area also exists in the lower end of the Gaines Creek Arm, with most of this operated through the Oklahoma Department of Wildlife Conservation as the Gaines Creek Unit of the Eufaula Wildlife Management Area. The Gaines Creek Unit encompasses about 1,600 ha.

I.7 Comparison of Lake Use to Other Lakes within 80 km Radius

Twenty-three lakes with known public access are located within an 80 km (50 mile) radius of the study area (Table 2). For comparative purposes, only the lakes constructed by the U.S. Army Corps of Engineers (Eufaula, Robert S. Kerr, Sardis, Webbers Falls, and Wister) will be examined in the following narrative. According to the 1994 ϶305(b) Water Quality Assessment Report for Oklahoma, the overall use support statuses of the five U.S. Army Corps of Engineers lakes are partially supporting (ODEQ 1994).

Lake Eufaula was constructed to provide flood control, water supply, hydroelectric power, and sediment control (to prevent sediment from entering the navigation system on the Arkansas River). Twenty-two recreational areas are located on its shores, of which two are located in the study area (OWRB 1990). It was estimated that in 1995 there were 2,647,146 recreational visits to Lake Eufaula where an estimated 36,982,331 visitor hours were spent (COE 1995). In the OWQS, the following beneficial uses are listed for Lake Eufaula: public and private water supply, warm water aquatic community, Class I agriculture irrigation, hydropower, industrial and municipal process and cooling water, primary body contact recreation, navigation, and aesthetics (OWRB 1995).

Lake	Owner	Legal Location	Year Built	Surface Area (Ac)	Storage (Ac-ft)
Atoka	Oklahoma City	30-T1S-R12E	1964	5,700	125,000
Carl Albert	Talihina	35-T4N-R21E	1964	183	2,739
Carlton	State of Oklahoma	24-T6N-R18E	1938	46	552
Clayton	State of Oklahoma	21-T2N-R19E	1935	66	953
Coalgate	Coalgate	11-T1N-R10E	1965	352	3,437
Dripping Springs	Okmulgee	26-T13N-R11E	1976	1,150	16,200
Eufaula	Corps of Engineers	25-T10N-R18E	1964	105,500	2,314,600
Henryetta	Henryetta	22-T11N-R13E	1928	450	6,660
Holdenville	Holdenville	4-T6N-R9E	1931	550	11,000
John Wells	Stigler	29-T9N-R21E	1936	194	1,352
Lloyd Church	Wilburton	30-T5N-R19E	1964	160	3,060
McAlester	McAlester	2-T6N-R14E	1930	1,521	13,398
McGee Creek	Bureau of Reclamation	7-T3S-R14E	1988	3,810	113,930
Nanih Waiya	State of Oklahoma	22-T2N-R19E	1958	131	1,064
Okmulgee	Okmulgee	8-T13N-R12E	1928	668	14,170
Robert S. Kerr	Corps of Engineers	8-T10N-R24E	1970	43,800	525,700
Sardis	Corps of Engineers	19-T2N-R19E	1983	13,610	274,330
Talawanda No. 1	McAlester	23-T6N-R14E	1902	91	1,200
Talawanda No. 2	McAlester	14-T6N-R14E	1924	195	2,750
Wayne Wallace	State of Oklahoma	13-T6N-R18E	1969	94	1,746
Webbers Falls	Corps of Engineers	34-T13N-R20E	1970	11,600	170,100
Weleetka	Weleetka	17-T10N-R11E	1923	59	385
Wetumka	Wetumka	3-T9N-R10E	1939	169	1,839
Wister	Corps of Engineers	1-T5N-R24E	1949	7,333	62,360

The Robert S. Kerr Reservoir Lock and Dam were constructed to provide navigation, hydro-electric power, and recreation. The lock allows large barges to navigate the Arkansas River. Eleven recreational areas are located on the lake (OWRB 1990). It was estimated that in 1995 there were 608,778 recreational visits to Robert S. Kerr Reservoir where an estimated 1,936,779 visitor hours were spent (COE 1995). In the OWQS, the following beneficial uses are listed for Robert S. Kerr Reservoir: public and private water supply, warm water aquatic community, Class I agriculture irrigation, hydropower, industrial and municipal process and cooling water, primary body contact recreation, navigation, and aesthetics (OWRB 1995).

Lake Sardis was constructed to provide flood control, water supply, recreation, and fish and wildlife habitat. Six recreational areas are located at Lake Sardis (OWRB 1990). It was estimated that in 1995 there were 326,786 recreational visits to Lake Sardis where an estimated 2,454,473 visitor hours were spent (COE 1995). In the OWQS, the following beneficial uses are listed for Lake Sardis: sensitive public and private water supply, warm water aquatic community, agriculture, primary body contact recreation, and aesthetics (OWRB 1995).

The Webbers Falls Reservoir Lock and Dam were constructed to provide navigation and hydroelectric power. Webbers Falls Reservoir is located upstream of Robert S. Kerr Reservoir on the Arkansas River. Therefore, the lock on the dam allows barges to continue their trek up the Arkansas River. Seven recreational areas are located on the lake (OWRB 1990). It was estimated that in 1995 there were 469,139 recreational visits to Webbers Falls Reservoir where an estimated 5,986,522 visitor hours were spent (COE 1995). In the OWQS, the following beneficial uses are listed for Webbers Falls Reservoir: emergency water supply, warm water aquatic community, agriculture, hydropower, industrial and municipal process and cooling water, primary body contact recreation, navigation, and aesthetics (OWRB 1995).

Lake Wister was constructed to provide flood control, water supply, low flow augmentation (for the navigation system on the Arkansas River), water conservation, and sedimentation (to prevent sediment from entering the navigation system). Six recreational areas are located at Lake Wister (OWRB 1990). It was estimated that in 1995 there were 333,929 recreational visits to Lake Wister where an estimated 3,148,983 visitor hours were spent (COE 1995). In the OWQS, the following beneficial uses are listed for Lake Wister: public and private water supply, warm water aquatic community, Class I agriculture irrigation, industrial and municipal process and cooling water, primary body contact recreation, and aesthetics (OWRB 1995).

I.8 Inventory of Point Source Pollutant Discharges

There are a number of permitted point source discharges into the Gaines Creek Arm watershed. Sanitary waste treatment facilities which discharge in the watershed are as follows:

Facility	Location of Discharge	Watershed
City of McAlester (East Plant)	SE NE NW 32-6-15	Mud Creek
Krebs Utilities Authority	E1/2 SE SE 3-5-15	Mud Creek
Savanna Public Works Authority	NE NE SE 17-4-14	Brushy Creek
Pittsburg Public Works Authority	NW NW SW 21-3-14	Brushy Creek
City of Haileyville	SE SW SE 35-5-16	Brushy Creek
City of Hartshorne	SE NE NE 12-4-16	Brushy Creek

Estimated phosphorous loadings from the sanitary waste treatment facilities (above) are discussed in Section I.10.L. Current records (8/95-8/96) indicate that the McAlester (East Plant) and Pittsburg Public Works Authority are in compliance with their respective permits. However, enforcement actions have been taken against Krebs Utilities Authority for permit violations related to by-passing problems and Savanna Public Works Authority, City of Haileyville, and City of Hartshorne for violating their permitted levels of TSS and B.O.D.

Two industrial facilities also have permitted discharges in the watershed. The Dolese Company of Hartshorne discharges rock wash water and stormwater to the Gaines Creek watershed. The U.S. Army Ammunition Depot (SE NW SE 8-4-14) discharges to the headwaters of the Peaceable Creek system in the Brushy Creek watershed. Current records indicate that both Dolese Company of Hartshorne and the U.S. Army Ammunition Depot are in compliance with their respective permits. In addition, until recently the P & K Coal Company was permitted to discharge mine water into Pit Creek. However, the facility has closed down, mining has ceased, and their permit has now expired. The Pittsburg County Water Authority also discharges its backwash water into the Gaines Creek Arm.

I.9 Watershed Landuse

The landuse was determined from a Geographical Information System (GIS) using GRASS (Geographic Resources Analysis Support System). Landuse data was obtained from 1985-89 using aerial photography interpretation and local knowledge of the area by the Soil Conservation Service (now the NRCS). The landuse in Lake Eufaula's Gaines Creek Arm watershed (Table 3) is primarily pasture (37%) and forest (44%). Post Oak and Blackjack Oak forest is the predominant forest type in the watershed with areas of shortleaf pine intermixed. Total rangeland makes up approximately 11% of the watershed.

Other notable land uses in the watershed are military/government land (2%) and urban land (3%). Many rural communities are scattered throughout the watershed. The remaining 3% of the watershed is comprised primarily of water, urban ranchettes, and highways.

The Gaines Creek watershed also has a history of coal mining activity dating back to 1872 when these mines were worked for the purpose of supplying fuel coal to railroads. Some mining still exists in this area; however, it mainly consists of small scale strip pit operations. Most of the coal from these mines is high in sulphur. Water in the mines reacts with the sulphur producing sulfuric acid. The sulfuric acidic then leaches metal ions from the coal and surrounding strata. Eventually, this acidic, metal laden water, is discharged into streams as acid mine drainage (AMD) from old shaft entrances, air vents, and contaminated seeps. The amount of discharge from any one of these seeps is dependent upon local rainfall and ground water parameters. Nineteen seeps from were found to be discharging AMD at some time during the course of this study. The most visible areas of AMD impact are in the upper reaches of the Pit Creek watershed near Gowen, Oklahoma. This area supported a plethora of surface and subterranean coal mines from which AMD is now discharged.

Landuse	Acres	% Area
Forest Land	178,041	44%
Pastureland	150,238	37%
Rangeland	44,971	11%
Urban Land	12,790	3%
Military / Government Land	8,055	2%
Water	4,982	1%
Urban Ranchettes	2,195	1%
Highways	2,194	1%
Other	2,076	<1%
TOTAL	**405,541**	**100%**

I.10 Lake Limnology

A. Historical Data

The Gaines Creek Arm and its watershed have been the subjects of intensive study. A brief summary of the findings of studies conducted follows. It should be noted that summaries of findings concerning the fishery in the Gaines Creek Arm can be found in Section I.10.G(5a).

In 1977, the U.S. Army Corps of Engineers (COE) conducted a study on the AMD from Union Coal Company No. 1 near Adamson, Oklahoma. The seep was found to discharge 35,000-36,000 gallons per day. Metals most commonly found in the seep were sodium, iron, calcium, magnesium, manganese, and aluminum. In the seep, most of the iron and manganese was dissolved. AMD has created water treatment problems for the Adamson Rural Water District. The COE recommended that water be prevented from entering the mine and AMD flow from the mine be stopped. To halt the inflow of water, it was suggested that subsidence areas be filled and sealed with bentonite or a PVC cover. To stop AMD flow from the mine, it was recommended that the mine be injected with fly ash and mine gob (COE 1977).

In 1981, the Oklahoma Water Resources Board (OWRB) investigated a complaint on Brushy Creek because elevated levels of arsenic, cadmium, chromium, copper, and lead were detected below the Haileyville and Hartshorne sewage treatment plants. The Hartshorne treatment plant, which discharges to Blue Creek (a tributary to Brushy Creek), receives industrial discharge from a plating material industry. The OWRB only detected arsenic, downstream from coal mines and the Hartshorne treatment plant (OWRB 1981).

Conductivity in the Gaines Creek Arm was the lowest of the 5 major lake areas. The mean lakewide Secchi (1979-82) was 58.9 cm (23.2"). Fish habitat in the Gaines Creek Arm is primarily mud substrate with submerged woody vegetation. Bankwitz (1982) attributed most lake turbidity to sediment from the tributaries instead of shoreline erosion. However, large areas of the Gaines Creek Arm are very shallow and susceptible to resuspension of bottom sediment which certainly contributes to the lake turbidity. Soils on 14.2 % of the Gaines Creek Arm shoreline have low erosion potential, 77.0% have moderate erosion potential, 6.1% have high erosion potential, and 2.7% of the shoreline is rip-rap. During the study, stabilization of mud flats using wheat was tried; however, poor germination was observed in the Gaines Creek Arm (Bankwitz 1982). Poor redox conditions and a harsh chemical environment likely resulted in poor germination on the Gaines Creek Arm mud flats.

In 1983, J.F. Heitman of the OWRB investigated possible subsurface migration of oil and gas drilling waste from an abandoned strip pit near Gowen, Oklahoma. Results showed that oil and gas drilling wastes had been deposited into what is known as the Fluid Haulers Pit which is hydrologically connected to underground mines thus threatening local groundwater. However, petroleum contaminants were likely diluted by the large volume of water in the underground mines. Results also showed that Pit Creek was contaminated by AMD (Heitman 1983).

The *Oklahoma Surface Water Quality Report for Water Years 1978-83* reported that dissolved oxygen, temperature, pH, chlorine, sulfate, turbidity, and chromium criteria were violated in Brushy Creek (OSDH 1984).

Due to complaints of low pH and high metal content discharges from P & K strip mines, W.S. Cooter of the OCC conducted a bioassay experiment (using indigenous fish) in Pit Creek near Gowen, Oklahoma in 1986. The study found that acutely toxic conditions existed throughout the length of Pit Creek during base flow. Below the P & K strip mine, fish mortality was extremely high. The deaths were attributed to acidity. Bluegill sunfish mortality rates ranged from 25-62% after only a three hour exposure. Thus, the study concluded that AMD creates acutely toxic conditions for indigenous fish in Pit Creek (Cooter 1986).

The 1986 *Surface Water Quality Assessment for Oklahoma* revealed that Brushy Creek violated the OWQS for dissolved oxygen and pH to protect fish and wildlife propagation (ODPC 1986).

In 1987, Bill Reynolds conducted an abandoned mine land (AML) inventory in the Gaines Creek watershed. The study reported that early miners had problems with acid water. Fish kills in Gaines Creek date back to 1949. In 1949, mine water from the Gowen area killed fish in a 20 mile stretch of Gaines Creek from Highway 270 east of Gowen to Highway 31 at Elm Point east of McAlester. The study reported that Gowen underground and strip mines discharged approximately 25,000 gallons per day to Pit Creek. The study also reported that the Stafford Hall Mine discharges approximately 60,000 gallons per day to Brushy Creek only two miles south (upstream) of the Pittsburg County Water Authority intake (Reynolds 1987).

In 1988, the ODWC conducted a fish survey of Pit Creek. Two tributaries of Pit Creek had live aquatic vegetation and fish; however, the tributary to Pit Creek receiving P & K Mine drainage was devoid of aquatic life, as was Pit Creek, from the P & K Mine to its mouth. Gaines Creek upstream of the Pit Creek inflow had 3.5 times more fish than down stream of the inflow. The study concluded that AMD, including that from the P & K Mine, have seriously impaired the beneficial use of fish and wildlife propagation in Pit Creek, and partially impaired it in Gaines Creek (ODWC 1988).

In 1988, J. Adams of the OWRB conducted a water quality assessment on Pit Creek. This study found that Pit Creek, from the P & K Mine to its mouth, violated the OWQS for pH, TDS, sulfate, and zinc (Adams 1988).

In 1990, J.K. Kurklin of the USGS analyzed water quality data collected between May 1978 and May 1980 from Gaines Creek and the Gaines Creek Arm. The pH in the Gaines Creek Arm of Lake Eufaula ranged from 6.0 to 9.2. Sulfate ranged from 3.1 to 41.0 mg/l. Chloride concentrations ranged from 2.8 to 31.0 mg/l. Concentrations of arsenic, chromium, copper, mercury, selenium, and zinc were within drinking water standard limits. However, cadmium, iron, lead, and manganese exceeded drinking water standards. The phytoplankton community indicated that the lake was acidic, with significant levels of nutrients and organic matter, and little conductivity and dissolved solids. In addition, levels of fecal coliform bacteria were within recommended limits. Even though several metals exceeded drinking water standards, the study concluded that Gaines Creek and the Gaines Creek Arm provide suitable sources for drinking water (Kurklin 1990).

In 1992, the OWRB conducted another watershed investigation of Pit Creek. The Pit Creek watershed encompasses approximately 12 square miles. The study found that 6.7 (nearly all of the Pit Creek mainstem) of the approximately 21 stream miles in the Pit Creek watershed are directly affected by AMD. Pit Creek□s tributaries are indirectly impacted because they are cut off from areas of aquatic life repopulation. The study found that Pit Creek contains excessive levels of metals due to AMD. Zinc exceeded the OWQS acute and chronic criteria at all sites. Cadmium, chromium, and copper exceeded the OWQS chronic criteria at two sites. Iron exceeded EPA criteria at all sites. The mean pH was 4.0 S.U. which also violated the OWQS. Aquatic life had been severely affected by toxic metals and low pH. Macroinvertebrates were impoverished and fish were essentially non-existent at all sites. The AMD from the P & K site was found to be significant as it contributes approximately half of the zinc loading to Pit Creek (3.84 kg/day), even though it contributes only an estimated 5% of the volume. However, zinc levels would be acute in Pit Creek even if the P & K mine discharge was eliminated due to other sources of AMD (OWRB 1992).

B. Investigative Approach of 1991-92 Clean Lakes Study

The study focused on the upper reaches of Lake Eufaula's Gaines Creek Arm and its watershed. The primary goals of the study were to: 1) evaluate the impact of AMD on the lake, 2) locate sources of AMD, 3) and determine the feasibility of implementation measures to bring about a substantial reduction in documented pollution problems.

C. Experimental Procedures

1. Location and Description of Sampling Sites

Five representative sampling sites were established in the Gaines Creek Arm to assess the lake water quality (Figure 2). Lake sample sites were located at Mungle Point, Highway 31 Landing, Hickory Point, Adamson Road, and Adamson-Hartshorne Road. Additional sampling sites (Figure 3) were established on the major tributaries (Mud Creek, Brushy Creek, and Gaines Creek), as well as Pit Creek (a tributary to Gaines Creek which receives AMD). Several acid mine seeps were also sampled during the course of the study (Figure 3). Sample sites and their respective locations and waterbody I.D. numbers are listed in Appendix B.

The furthest upstream lake site (site T) is located at the Adamson-Hartshorne Road bridge just north of Adamson Ridge. This is about 1/4 mile downstream of the Bull Creek-Gaines Creek confluence. This site is basically a swollen, back watered stream about 5 m deep. The water is extremely turbid. Site T is near the Adamson Seep.

Site R, which is located at the Adamson Road bridge, is geographically close and very similar to site T, except for the obvious increase of discharge during prolonged rain events. Site R is downstream of the confluence of Gaines Creek, Brushy Creek, Blue Creek, and Peaceable Creek. During high flow, this site is covered with woody debris, deposited from flooded bottomlands in the watershed. The depth is about 7 m. The Pittsburg County Water Authority intake is adjacent to this site.

Site P, which is located north of Hickory Point, is a long, relatively narrow part of the lake where the deep cut bank of Gaines Creek and its associated bottomland and riparian zone are now completely inundated. At this location, the thalweg is about 8 m deep, steep and narrow, while the historical floodplain is broad and relatively shallow.

Site N, which is located east of State Highway 31 crossing, is a large, yet shallow pool of only 1 to 3 m deep. This site is near the historical confluence of Gaines and Mud Creeks.

The furthest downstream site (site K) is located at Mungle Point, a narrow constriction of about 70 m wide connecting two large pools. The depth at this site is about 12 m deep.

2. Lake and Tributary Sampling

The lake and its tributaries were sampled at least monthly throughout the project. From May through September the lake and tributaries were sampled semi-monthly. Water temperature, dissolved oxygen, conductivity, and pH profiles were measured *in situ* at all lake sites using a Hydrolab Surveyor III - H2O instrument. Water transparency was measured with a 20 cm Secchi disk. Water temperature, dissolved oxygen, pH, and conductivity were measured *in situ* in the creeks.

Water was collected from 0.1 m below the surface in the creeks. At lake sites, water was collected at 0.1 m below the surface, mid-depth, and 0.5 m above the lake bottom, and composited into a single sample. When stratification was evident, discrete samples were taken from 0.1 m below the surface and 0.5 m above the lake bottom. Samples were analyzed for ortho-phosphorous (PO_4), total phosphorous (TP), ammonia-nitrogen (NH_4), nitrite-nitrogen (NO_2), nitrate-nitrogen (NO_3), total Kjeldahl-nitrogen (TKN), sulfate (SO_4), chloride (Cl), total alkalinity, total hardness, total dissolved solids (TDS), and total suspended solids (TSS). Lake samples were analyzed for chlorophyll *a*. Water samples were also analyzed twice for pesticides and metals. Samples were also collected from the tributaries during four runoff events. Runoff samples were analyzed for field parameters, nutrients, metals, and pesticides.

Zooplankton and phytoplankton were analyzed twice at site K. A 500 ml sample was collected for analysis of phytoplankton. A single, bottom to surface vertical tow with a Wisconsin net was used to collect zooplankton. The samples were sent to the USDA-ARS Agricultural Water Quality Research Lab in Durant, OK for taxonomic identification. Benthic macroinvertebrates were collected once during summer sampling, in the lake. Fish flesh was analyzed once for metals and pesticides.

In addition to the routine lake sites, sediment samples were also collected from four deep water locations: between Crowder and Mungle Point (site J); near Crowder, OK (site H); south of the Arrowhead Lodge (site E); and south of the highway 9A bridge (site B). Sediment samples were analyzed once for metals and pesticides.

D. Morphological and Hydrological Characteristics of the Lake

1. Lake Morphology

The area of the portion of the lake studied covers approximately 1760 ha (4350 acres) at normal pool elevation. This area is located in the riverine zone of the Gaines Creek Arm and is primarily comprised of flooded bottom land hardwood forest and the sinuous thalweg of Gaines Creek. A bathymetric map of Lake Eufaula, which was produced by FHS Maps, is included in Appendix L. Lake levels varied 2.7 m from a minimum lake elevation of 177.4 m on August 29, 1991, to a maximum lake elevation of 180.1 m on December 24, 1991.

2. Lake Hydrology

The portion of Lake Eufaula studied is fed primarily by Gaines Creek, Brushy Creek, Peaceable Creek, and Mud Creek. Peaceable Creek joins Brushy Creek near its confluence with the Gaines Creek Arm. All these streams are perennial. The total annual precipitation averages approximately 43 inches per year. The annual distribution of this rainfall is fairly even. Approximately 32% falls in spring, 27% in summer, 22% in fall, and 19% in winter. Lake evaporation averages 53 inches annually of which 71% occurs from May through October (SCS 1971; SCS 1981).

Discharge was not measured during the study; therefore, historic discharge measurements from the USGS gaging station on Gaines Creek near Krebs (34° 59' 00", 95° 37' 00") were obtained for calendar years 1943-62. The Gaines Creek site (USGS station number 07232000) had a drainage area of 588 square miles and an average total annual discharge of 420,932 acre-feet .

From the 20 years of discharge data on Gaines Creek it was determined that annual runoff averages approximately 1.12 acre-feet/acre. This compares closely with USGS estimations of runoff ranging from 0.83-1.25 acre-feet/acre annually for this area (Linsley et al. 1975).

Using the estimated average annual runoff of 1.12 acre-feet/acre, the crude hydrologic budget in Table 4 was computed. Estimates of direct rainfall input to the lake were based on 43 inches of rain per year falling on 4,350 acres. Thus, the total annual hydraulic input into the Gaines Creek Arm is approximately 465,000 acre-feet.

Input	**Acre-feet/year**
Gaines Creek	149,000
Brushy/Peaceable Creek	226,000
Mud Creek	20,000
Unassessed Area	54,000
Rainfall	16,000
Output	
Drinking water	1,000
Evaporation	19,000
Calculated outflow	445,000

Of the total annual input, Gaines Creek contributes roughly 32%, Brushy and Peaceable Creeks contribute 49%, Mud Creek contributes 4%, the unassessed area contributes 12%, and rain contributes 3%.

It was estimated (using discharge data collected from Gaines Creek from 1943-63) that roughly 12.5% of the total discharge resulted from base flow, while 87.5% of the total discharge resulted from runoff. Approximately 1,000 acre-feet of raw water are drawn from the lake annually by the Pittsburg County Water Authority. Estimates of evaporation were based on 53 inches evaporating from 4,350 acres. The true outflow could not be measured, thus it was calculated by subtracting drinking water and evaporation from the total annual input. Because the volume of the study area was not known, the retention time could not be determined.

E. Lake Water Quality

Water quality in Lake Eufaula's Gaines Creek Arm and its tributaries was monitored from July 1991 through September 1992. This involved semi-monthly sampling from May through September, and monthly sampling during the remaining months. The tributaries were also sampled during four storm events. The results of the sampling program are discussed in the following sections. Project data are included in the Appendixes.

1. Thermal Structure of the Lake

Surface water temperatures ranged from 4°C in late January to 31.6°C in late August (Appendix C). Thermal stratification was observed at sites T, R, and P from June through August under normal weather conditions. Thermal stratification occurred only once at Site N (July, 1992). Homogeneity at this site was likely due to wind mixing. Thermal stratification was observed only twice at site K (July 29, 1991 and July 15, 1992).

The thermocline was generally present between the depths of 0.1-1.0 m (~50% of the time) or 1.0-2.0 m (~20% of the time). It is likely that the shallowness of the thermocline is due to high turbidity which increases the absorption of light energy in the surface water and prevents light from penetrating to greater depths. In addition, sites T, R, and P are located in areas protected from the wind which greatly reduces wind mixing.

2. Dissolved Oxygen

Dissolved oxygen (D.O.) concentrations were present at sufficient concentrations throughout the Gaines Creek Arm study area from November to April (Appendix C). However, during the summer, lake sites exhibited relatively low surface D.O. concentrations. Stratified lake sites exhibited anoxic conditions in the hypolimnion that at times extended from the bottom to less than 1 m below the surface. Dissolved oxygen concentrations generally improved with distance from the Gaines Creek inflow. At Site R, the poorest D.O. concentrations were observed (Figure 4). The D.O. depletion observed in the lake likely resulted from decomposition of organic matter. Oxygen demand from reduced metals and algal blooms may have also contributed somewhat to the depletion of dissolved oxygen. Oxygen demand is discussed in Section I.10.E(6). Supersaturation at the surface of site R on July 29, 1991 and site T on July 15, August 14, and August 28, 1991 indicate algal blooms.

The low D.O. concentrations detected throughout the Gaines Creek Arm are responsible for the poor fishery in this part of the lake, because most fish cannot survive in water containing D.O. concentrations less than 2 mg/l (Wetzel 1983).

3. Turbidity, Secchi Depth, and Chlorophyll *a*

The Gaines Creek Arm is very turbid with an average turbidity of 104 NTU. Mean turbidities

(Appendix D) for the lake sampling sites are listed in Table 5. The OWQS state that turbidity from other than natural sources should not exceed 25 NTU in lakes (OWRB 1995). This numerical criteria for turbidity was exceeded at all lake sites.

Due to the extremely high turbidity, the Secchi depths throughout the study area were extremely low, ranging from only 1 to 14 inches. Mean Secchi depth increased only slightly with distance from the inflows (Table 5). Secchi depth also indicates the depth of the photic zone. The shallowness of the photic zone limits the area where primary productivity can occur. Secchi depth data are included in Appendix E.

Site	Secchi (inches)	Turbidity (NTU)	Chlorophyll-*a* (ug/l)
T	5.6	142	9.69
R	6.1	109	9.77
P	7.7	98	8.34
K	6.2	84	6.95
N	7.4	87	6.89

Mean chlorophyll *a* concentrations (Table 5) as well as algal biomass, decrease with distance from the Gaines Creek inflow (Figure 5). Chlorophyll *a* concentrations (Appendix F) were extremely variable at site T. This variability is likely due to the Gaines Creek inflow. At sites R, P, N, and K, peak chlorophyll *a* levels were observed during summer. Chlorophyll *a* concentrations were also used to determine the trophic state of the lake (see Section I.10.M).

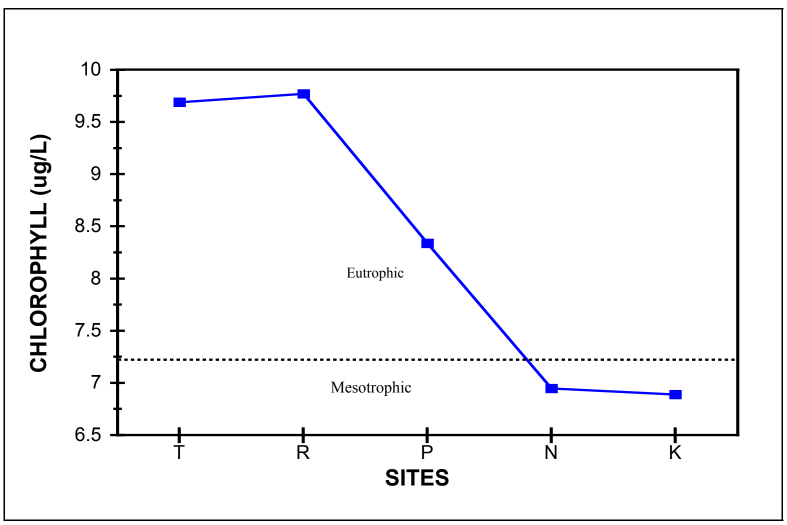

Figure 1. Chlorophyll-*a* Concentrations in Gains Creek Arm.

4. Nitrogen and Phosphorous

Total Kjeldahl nitrogen (TKN) concentrations ranged from 0.1 to 2.8 mg/l and averaged 0.8 mg/l. Ammonia (NH_4) concentrations, which ranged from 0.06 to 0.98 mg/l and averaged 0.17 mg/l, did not exceed the EPA numerical criteria (EPA 1986). Nitrate (NO_3) levels did not exceed the OWQS numerical criteria for drinking water of 10 mg/l (OWRB 1995). Total nitrogen (TN) concentrations, which were calculated by summing TKN, NO_2, and NO_3 values, ranged from 0.2 to 3.0 mg/l and averaged 1.1 mg/l. Mean TN concentrations and coefficients of variations (CV) for each lake site can be found in Table 6. Total nitrogen levels varied little throughout the Gaines Creek Arm.

Table 6. Total Nitrogen and Total Phosphorus Concentrations in the Gaines Creek Arm.

Site	TN		TP		TN:TP
	Mean	CV	Mean	CV	
T	1.05	37	0.061	67	17
R	1.20	30	0.078	82	15
P	1.20	31	0.071	70	17
N	0.99	27	0.078	79	13
K	0.90	33	0.066	61	14

Total phosphorous (TP) concentrations were high in the lake water samples (Table 6). Total phosphorous concentrations of 0.025 mg/l or greater are known to cause eutrophication of lakes. Concentrations in the Gaines Creek Arm were present at two to three times this level. Total phosphorous concentrations ranged from below detection to 0.27 mg/l and averaged 0.07 mg/l in the Gaines Creek Arm. However, much of this phosphorous is likely bound to clay particles (which cause the high turbidity) and therefore is unavailable for biotic uptake. Total phosphorous concentrations were much more variable than the TN concentrations. The highest TP concentrations were measured at sites R and N. The higher TP concentrations at sites R and N were likely due to the inflow of Brushy Creek near site R, and the inflow of Mud Creek near site N. Ortho-phosphate concentrations, which ranged from below detection to 0.091 mg/l and averaged 0.014 mg/l, exceeded EPA's suggested criteria of 0.025 mg/l (EPA 1986) in 18% of the samples. The total nitrogen:total phosphorous ratio (TN:TP) averages 15 (Table 6) indicating that the lake is phosphorous limited.

5. pH, Alkalinity, Hardness, Conductivity, TDS, TSS, SO_4 and Cl

The OWQS state that pH should fall between 6.5 and 9.0. Eleven percent of the lake samples violated this criteria. Most violations were observed in the hypolimnions of sites T, R, and P (nearest the Gaines Creek inflow). Mean pH values ranged from 6.6 at site T to 7.5 at site N and 7.3 at site K. Mean alkalinities, which ranged from 27 mg/l at site T to 33 mg/l at site P, were low in the lake water. Hardness averaged 33 mg/l as $CaCO_3$; thus, the lake water is classified as soft (hardness < 60 mg/l). Due to the low hardness and alkalinity values, the lake water has a low buffering capacity and little capacity to mitigate metal toxicity. Conductivity averaged 115 uS/cm while TDS averaged 91 mg/l in the Gaines Creek Arm. Mean TSS levels ranged from 90 mg/l at site T to 56 mg/l at site K. Obviously, suspended solids are settling out of the water as it moves through the lake. Sulfate ˜(=27 mg/l) and chloride ˜(=10 mg/l) were not present in significant quantities in the Gaines Creek Arm. Low sulfate concentrations in the Gaines Creek Arm indicate that there is little direct effect from the AMD. Lake data is included in Appendix D.

6. Metals

Arsenic (<60 ug/l), cadmium (<5 ug/l), copper (<10 ug/l), chromium (<10 ug/l), mercury (<0.5 ug/l), silver (<7 ug/l), sodium (<10 mg/l), nickel (<25 ug/l), lead (<45 ug/l), and selenium (<70 ug/l) were not detected in lake water samples. However, barium, calcium, iron, magnesium, manganese, potassium, and zinc were detected in the lake samples (Table 7). Hypolimnetic metal concentrations were generally greater than epilimnetic concentrations (Appendix G). This results from anoxia and the accompanying reducing conditions which allow metals to become more soluble. Thus, metals diffuse from the sediments and particulate matter in the water column and accumulate in the hypolimnion.

Parameter	Site T	Site R	Site P	Site N	Site K
Barium (ug/l)	49	49	48	44	43
Zinc (ug/l)	6.3	5.3	6.0	ND	13.7
Calcium (mg/l)	5.3	6.3	5.7	6.0	5.3
Magnesium (mg/l)	2.7	2.3	2.3	2.5	2.3
Potassium (mg/l)	1.3	1.4	1.7	2.2	2.0
Iron (mg/l)	2.6	2.7	2.2	2.7	2.9
Manganese (mg/l)	0.25	0.19	0.17	0.12	0.13

Calcium, magnesium, and potassium were not present at notable concentrations. Barium concentrations did not exceed the OWQS. Zinc concentrations, with the exception of one sample (site K on August 12, 1992), did not exceed the OWQS. On August 12, 1992, the hypolimnetic zinc concentration at site K (31 ug/l) exceeded both the acute (26.1 ug/l) and chronic (23.6 ug/l) biological criteria. All iron concentrations exceeded the EPA Gold Book (EPA 1986) biological criteria (1.0 mg/l). Staff of the Pittsburg County Water Authority currently report that they are not experiencing problems in treating the water. In addition, the Oklahoma Department of Environmental Quality (DEQ) which regulates drinking water quality, reports that no violations for metals have occurred.

Redox potential was measured on July 30, 1993 at the lake sites. Redox at lake sites N and K ranged from 320-400 mV. However, redox at sites P, R, and T plummeted to less than 200 mv at 2 m and less than 100 mv at 3 m. Iron is present in its reduced state (Fe^{2+}) at redox levels below 300 mv (Engstrom and Wright 1984). The reoxidation of Fe^{2+} is rapid (Kuhn et al. 1994, Hsuing and Tisue 1994, Peiffer 1994). Thus, as oxygen enters the hypolimnion it is quickly stripped from the water column. In the Gaines Creek Arm, this occurred while the lake was stratified and stagnant. During thermal stratification (summer), reduced metals accumulated in the hypolimnion creating an oxygen trap which contributed somewhat to the observed D.O. depletion. This oxygen depletion provides a barrier for the development of adequate fisheries during the summer months when thermal stratification occurs.

F. Lake Sediment Quality

Chemical analysis was performed on sediment samples collected June 11-12, 1991. Arsenic, selenium, mercury, cadmium, sodium, phosphorous, nitrite, and nitrate were not detected in the sediment samples. Concentrations of chemicals detected in the lake sediments (Appendix H) were compared to EPA Sediment Screening Values (EPA 1995). Examination of Table 8 shows that none of the chemicals detected in the Gaines Creek Arm sediment exceeded EPA Sediment Screening Values.

The only problem that the sediments pose is that they supply iron, manganese, and other reduced metals during anoxia. Oxygen demand by reduced metal species (primarily iron and manganese), which diffuse from the sediments when reducing conditions develop, likely contribute somewhat to the observed D.O. depletion in the lake.

Metal	**Gaines Creek Arm**		**EPA**
(ug/g)	**Minimum**	**Maximum**	**Screening Value**
Pb	6	14	110
Zn	26	52	270
Fe	10,570	21,820	N/A
Cr	9	16	145
Cu	5	10	390
Ni	9	20	50
Mn	357	1,087	N/A
Ba	65	140	N/A
TKN	3,419	10,990	N/A

G. Lake Biological Resources

1. Algae

Phytoplankton samples were collected on January 22, May 12, and June 30, 1992 from site K. Algal genera identified in the Gaines Creek Arm include the blue green algae *Aphanizomenon* and *Oscillatoria*, centric and pennate diatoms, and the euglenoid *Trachelomonas*. Due to difficulties in collecting complete count data for these samples, only relative abundance was used to evaluate algal communities. This made biomass determination impossible. Although actual counts are not presented, algal biomass can be inferred from the chlorophyll *a* values obtained. Elevated chlorophyll *a* levels observed in the lake may indicate nuisance algal blooms. However, algal productivity is limited severely by the high turbidity. The Secchi depth is generally equal to one-half to one-third of the photic zone (Goldman and Horne 1983). If this is so, then the maximum photic zone in the Gaines Creek Arm was 42 inches, assuming the highest Secchi depth measured (14 inches) represented one-third of the photic zone.

2. Macrophytes

Extensive macrophyte populations were not present in the Gaines Creek Arm due to the high turbidity of the water. *Ludwigia* and cat-tails were the primary forms of macrophytes identified. Riparian vegetation consisted primarily of willows and button bush.

3. Zooplankton

Zooplankton were collected on January 22, May 12, and June 30, 1992 from site K for identification and enumeration. Results are listed in Table 9. Rotifers were consistently the most abundant.

Date	Cladoceran	Copepod	Rotifer
1/22/92	--	1	13
5/12/92	21	10	113
6/30/92	2	6	62

4. Benthic Macroinvertebrates

Benthic samples were collected once at lake sites N, K, P, and R on October 21, 1992. The benthic macroinvertebrate community in the Gaines Creek Arm consisted of 3 Phyla, 3 Classes, 5 Orders, 6 Families, and 12 genera (Table 10).

Species diversity increased with distance from site R. Four genera were collected at site R, 5 at sites P and N, and 6 at site K. This trend may indicate improving water and sediment quality with increasing distance from the Gaines Creek inflow. Only low D.O. tolerant genera (tubificids and chironomids) were collected at sites P and R. However, low D.O. intolerant genera were collected from sites N and K. The low D.O. intolerant and relatively long-lived genus *Sphaerium*, which was present at site N, indicates that some oxygen (> 1 mg/l) has been present at the sediment water interface throughout the life span of the clam. The presence of adequate D.O. levels at sites N and K was indicated by the presence of the megalopteran Sialis at site N and the ephemeropteran *Hexagenia* at site K. Abundance ranged from 5 at sites R and K to 47 at site P. Of the 47 individuals collected at site P, 44 were tubificids.

CLASS FAMILY	GENUS	SITE			
		R	P	N	K
Oligochaeta					
Tubificidae	Limnodrilus	1	42		
	Tubifex		2		
	Branchiura				1
	Aulodrilus				1
Pelecypoda					
Sphaeriidae	Sphaerium			2	
Insecta					
Ephemeridae	Hexagenia				1
Sialidae	Sialis			1	
Chaoboridae	Chaoborus	6	38	10	5
Chironomidae	Coelotanypus	1	5	1	
	Procladius	3	2		1
	Chironomus	1			
	Axarus		2		

5. <u>Fisheries</u>

a. <u>Past and Present Activities and Suitability of the Lake</u>

The Oklahoma Department of Wildlife Conservation (ODWC) is responsible for monitoring and managing the fishery in Lake Eufaula. Surveys are conducted routinely. Collection methods include spring electrofishing, summer seining, fall gill netting, and fall trap netting. The following discussion summarizes the results of past, as well as present studies.

Table 11 summarizes spring electrofishing catch rates in the Gaines Creek Arm as compared to the mean catch rates for Lake Eufaula from 1986-89 and the regional mean catch rates on lakes with surface areas greater than 2,000 hectares. As Table 11 indicates, the mean largemouth bass and gizzard shad catch rates in the Gaines Creek Arm from 1986-89 were less than mean catch rates for Lake Eufaula. However, catch rates for spotted bass, white crappie, and threadfin shad in the Gaines Creek Arm were greater than mean catch rates for Lake Eufaula. In addition, the mean Gaines Creek Arm catch rates exceeded the regional mean catch rates.

	Catch per Hour (Gaines)						Lake Mean	Regional
Fish	1986	1987	1988	1989	1990	Mean	**1986-89**	**Mean**
Largemouth Bass	9.16	22.16	48.50	40.67	N/A	30.12	**33.22**	**24.28**
Spotted Bass	6.68	12.16	25.17	32.33	N/A	19.09	**10.59**	**7.13**
White Crappie	11.16	22.84	22.50	39.00	N/A	23.88	**16.68**	**11.38**
Gizzard Shad	115.80	102.40	26.50	134.75	N/A	94.86	**105.23**	**86.97**
Threadfin Shad	10.48	111.20	7.83	11.25	N/A	35.19	**26.36**	**17.95**

Table 12 summarizes summer seining catch rates in the Gaines Creek Arm as compared to the mean catch rates for Lake Eufaula for 1986-90. As Table 12 indicates, the mean catch rates for largemouth bass, spotted bass, gizzard shad, threadfin shad, and inland silversides in the Gaines Creek Arm were less than the mean seining catch rates in Lake Eufaula.

	Catch per 100 square meters (Gaines)						Lake Mean	Regional
Fish	1986	1987	1988	1989	1990	Mean	**1986-90**	**Mean**
Largemouth Bass	1.24	1.01	0.11	0.34	0.69	0.68	**2.73**	**1.9**
Spotted Bass	0.66	0.43	0.17	0.06	0.09	0.28	**0.81**	**0.56**
White Crappie	1.09	0.03	0.00	0.06	0.47	0.33	**0.21**	**0.63**
Gizzard Shad	8.13	0.20	0.57	11.72	8.36	5.80	**12.32**	**14.94**
Threadfin Shad	2.71	12.39	0.11	14.97	12.07	8.45	**18.76**	**23.7**
Inland Silversides	3.68	53.10	17.79	11.24	4.31	18.02	**169.11**	**152.27**

However, white crappie seining catch rates in the Gaines Creek Arm exceeded the mean catch rate in Lake Eufaula. In addition, the mean summer seining catch rates in the Gaines Creek Arm were substantially less than the regional mean catch rates. The lower summer seining catch rates in the Gaines Creek Arm likely result from low dissolved oxygen levels.

Table 13 summarizes the fall gill netting catch rates in the Gaines Creek Arm as compared to the mean catch rates for Lake Eufaula for 1986 through 1990. As Table 13 indicates, the mean catch rates for white crappie, white bass, channel catfish, flathead catfish, gizzard shad, and threadfin shad in the Gaines Creek Arm were less than the mean catch rates for Lake Eufaula.

	Catch per Net Hour (Gaines)						**Lake Mean**	**Regional**
Fish	1986	1987	1988	1989	1990	Mean	**1986-90**	**Mean**
White Crappie	0.17	0.73	0.15	0.34	0.24	0.33	**0.34**	**0.29**
White Bass	0.10	0.40	0.33	0.06	0.00	0.18	**0.38**	**0.3**
Channel Catfish	0.02	0.01	0.02	0.00	0.03	0.02	**0.13**	**0.17**
Blue Catfish	0.19	0.19	0.17	0.24	0.11	0.18	**0.17**	**0.16**
Flathead Catfish	0.03	0.01	0.02	0.03	0.01	0.02	**0.04**	**0.04**
Gizzard Shad	0.19	0.29	0.55	0.08	0.00	0.22	**0.98**	**0.88**
Threadfin Shad	0.01	0.01	0.05	0.03	0.00	0.02	**0.19**	**0.14**

However, the catch rate for blue catfish in the Gaines Creek Arm exceeds the Lake Eufaula mean. In addition, mean catch rates for white crappie and blue catfish in the Gaines Creek Arm exceeded the respective regional mean catch rates. However, mean catch rates for white bass, channel catfish, flathead catfish, gizzard shad, and threadfin shad were lower than their regional mean catch rates.

Overall, catch rates in the Gaines Creek Arm ranked highest in the spring and lowest in the summer and fall. Severe D.O. depletion in the Gaines Creek Arm likely results in the poor catch rates in the summer and fall.

b. Wholesomeness of Fish Tissue

On July 21, 1992, fish (blue catfish, white crappie, drum, river carpsucker, and smallmouth buffalo) were collected just south of site K for fish flesh analysis of metals, organochlorine pesticides, and PCBs.

The only metals detected in the fish flesh from the Gaines Creek Arm were zinc and mercury. Mercury, which was detected only in the river carpsucker (0.1 mg/kg), was well below the *Concern Level* (0.5 mg/kg) of the OWQS. Zinc, which was detected in all the fish, ranged from 2.5 to 6.3 mg/kg. The smallmouth buffalo had the highest zinc concentration (6.3 mg/kg). All other fish had zinc concentrations which were below 3.9 mg/kg. There are no fish flesh criteria for zinc in the OWQS. Zinc is an essential nutrient for plants and animals. The zinc concentrations found were comparable to the levels found in fish collected from other Oklahoma lakes (i.e. Pauls Valley Lake). In addition, zinc is generally harmful only at extremely high concentrations, levels much higher than those found.

The only organochlorine pesticides detected in fish flesh from the Gaines Creek Arm were DDT and P,P' DDE. These organics were detected in only the river carpsucker. The DDT concentration measured in the river carpsucker (0.06 mg/kg) was well below the *Concern Level* (2.5 mg/kg) of the OWQS. The P,P' DDE concentration was also 0.06 mg/kg in the river carpsucker. There are no fish flesh criteria for P,P' DDE, which is a degradation product of DDT, in the OWQS.

H. Sanitary Quality

Appendix I presents bacteriological data for Lake Eufaula Gaines Creek Arm during the summers of 1991 and 1992. To protect the use of *primary body contact,* the OWQS state that from May 1 to September 30, the monthly geometric mean of five samples over a 30 day period should not exceed 200/100ml and no more than 10% of the samples collected in a 30 day period should exceed 400/100ml (OWRB 1995). There were never enough samples collected at any one site to show a water quality standard violation, unless the 10% of samples is interpreted to consist of less than 5 individual samples. If it is interpreted in this way then the sample from Brushy Creek on July 29, 1991 was in violation. Mud Creek, Brushy Creek, and lake site P were in violation on May 12, 1992. Mud Creek was in violation on June 22, 1992. Finally, Brushy Creek, Pit Creek, Gaines Creek, Mud Creek, and lake sites T and R were in violation of the OWQS on June 29, 1992. No violations were found at lake sites N and K. Mud Creek and Brushy Creek had the most violations (3 each). In Gaines Creek, Pit Creek, and lake sites P, R, and T, the OWQS were violated only once. Because fecal coliforms are associated with BOD and nutrients, and may indicate their transport to the lake, the source of these bacteria should be identified and remediated.

I. Characteristics of Tributaries

Field, nutrient, and inorganic data for each stream are included in Appendix J.

1. Pit Creek

Pit Creek, a tributary to Gaines Creek, has a spring time discharge of approximately 4 cfs. Pit Creek drains an area receiving AMD and being actively mined. Numerous studies have documented that mining activities and the AMD have seriously impaired the aquatic community in Pit Creek (see Section I.10.A). Pit Creek, upstream of active mining operations and AMD, contains live aquatic vegetation and fish. However, from the mouth of Pit Creek to the area being actively mined and receiving AMD (8 miles), Pit Creek is void of aquatic life and stained red from iron precipitates (ODWC 1988). At Pit Creek, pH values of 3.0 and below have been documented routinely at low flow. Over 90% of the samples from Pit Creek contained pH values of less than 6.5 therefore violating the OWQS. Alkalinity was generally below detection indicating that the water has no buffering capacity.

Conductivities were extremely high reaching values as high as 3,130 *u*mhos/cm. The high conductivities indicate high levels of TDS in Pit Creek. Total dissolved solids reached levels as high as 1,806 mg/l. During base flow, the water would be considered brackish due to the high TDS concentrations. The water is also very hard (>180 mg/l).

Pit Creek exhibited low D.O. concentrations on numerous occasions. In base flow samples, the habitat limited aquatic community D.O. criteria was violated 4 times, while the warm water aquatic community D.O. criteria was violated 6 times. Low D.O. along with acidic conditions in Pit Creek explain the inability of this stream to support a biological community.

Mining operations included a precipitation process with anhydrous ammonia to extract metals. This resulted in the discharge of ammonia. Ammonia-nitrogen levels in Pit Creek ranged from 0.2 to 98.6 mg/l. Ten samples contained ammonia levels considered chronically toxic and two samples contained levels considered acutely toxic. This mine is no longer in operation. However, while in operation, this source certainly contributed a substantial quantity of nitrogen to the Gaines Creek Arm of Lake Eufaula. This is obvious in the total nitrogen concentrations found during the study which ranged from 1 to 105 mg/L. Nitrate concentrations did not exceed the OWQS numerical criteria for drinking water of 10 mg/l (OWRB 1995).

EPA suggests that TP concentrations not exceed 0.10 mg/l in streams not discharging directly into a lake (EPA 1986). Two base flow samples and three storm flow samples contained concentrations exceeding 0.10 mg/l. The mean base flow TP concentration was 0.037 mg/l, while the mean storm flow concentration was 0.108 mg/l in Pit Creek.

Chloride ˜(=11 mg/l) was not present in significant quantities. However, sulfate (SO_4) levels were extremely high in Pit Creek. Concentrations as high as 1,055 mg/l were observed. Sulfate gives water a bitter taste at concentrations greater than 300 mg/l and has a laxative effect at concentrations greater than 600 mg/l. Eleven samples contained concentrations exceeding 300 mg/l, and four samples contained SO_4 concentrations exceeding 600 mg/l. The high SO_4 concentrations likely result from the oxidation of sulfide present in AMD.

Pit Creek contained the lowest turbidity of the streams monitored, averaging 15 NTU in base flow samples and 88 NTU in storm flow samples. Base flow TSS concentrations averaged 21 mg/l. Storm flow TSS concentrations were usually less than 100 mg/l

2. Gaines Creek

Gaines Creek is the primary tributary feeding this southern-most arm of Lake Eufaula. However, mining activities and AMD have partially impaired the aquatic community in Gaines Creek (see Section I.10.A).

This stream is typically turbid averaging 41 NTU during base flow. The OWQS turbidity criteria was exceeded in four samples from Gaines Creek. In addition, TSS levels averaged 30 mg/l in base flow samples and 89 mg/l in storm flow samples. However, twice during the study, complaints that locations on Gaines Creek were "clearing up" were received. Each time, samples collected immediately downstream of the Pit Creek confluence revealed elevated ammonia-nitrogen levels which facilitated the precipitation of clay and other particles suspended in the water thus □clearing up□ the water. The mining operation in the Pit Creek watershed (as discussed in previous section) was found to be the source of the ammonia. As stated previously, this mine is no longer in operation.

Ammonia nitrogen levels in Gaines Creek ranged from 0.1 to 5.3 mg/l. Ammonia nitrogen was not present at toxic levels, except on March 15, 1991 where the concentration of 5.3 mg/l was observed downstream from the inflow of Pit Creek to Gaines Creek. This concentration, which exceeds EPA chronic criteria (EPA 1986), corresponds with the detection of ammonia levels in Pit Creek exceeding 70 mg/l. Total nitrogen concentrations, which were extremely variable, averaged 1.4 mg/l in base flow samples and 0.9 mg/l in storm flow samples. Nitrate concentrations in Gaines Creek did not exceed the OWQS numerical criteria for drinking water of 10 mg/l (OWRB 1995).

In Gaines Creek, total phosphorous concentrations averaged 0.037 mg/l in base flow samples and 0.083 mg/l in storm flow samples. EPA (1986) states that a desired goal for the prevention of plant nuisances in streams is 0.100 mg/l total phosphorous. Total phosphorous concentrations in Gaines Creek exceeded 0.100 mg/l in one base flow sample and one storm flow sample. EPA also suggests that phosphate phosphorous concentrations not exceed 0.05 mg/l in any stream at the point it enters a reservoir (EPA 1986). None of the phosphate phosphorous concentrations in Gaines Creek exceeded this suggested criteria.

The pH of base flow samples averaged 6.8. The OWQS pH criteria was violated in four samples. Due to the low alkalinities, which averaged 20 mg/l, the water had a low buffering capacity. The water in Gaines Creek is also soft (hardness < 60 mg/l) thus having little capacity to mitigate metal toxicity. Conductivities were relatively low (compared to Pit Creek) averaging 143 *u*mhos/cm in base flow samples and 92 *u*mhos/cm in high flow samples. TDS were also relatively low averaging 102 mg/l in base flow samples and 65 mg/l in storm flow samples. Sulfate and chloride were not present at significant levels.

Gaines Creek exhibited relatively low D.O. levels on various occasions, reducing its ability to support a diverse biological community. The warm water aquatic community D.O. criteria was violated in 5 base flow samples.

On February 8, 1991, benthic macroinvertebrates were collected from woody debris at four sites along Gaines Creek between the Pit Creek confluence and the lake. Although the collections were not quantitative or conducted according to OCC SOPs, they provide additional insight into the condition of Gaines Creek. At the two sites near the lake, several sensitive taxa, including plecopterans and molluscs, were identified indicating sufficient water quality. However, only tolerant taxa were identified at the two sites nearest to the Pit Creek inflow. These data indicate that water quality in Gaines Creek improves with distance from the Pit Creek inflow, and is sufficient at the point it enters the lake to support sensitive macroinvertebrate taxa.

3. Brushy Creek

Brushy Creek is also a significant hydrologic contributor to the Gaines Creek Arm. Brushy Creek drains the watershed occupied by the communities of Hartshorne and Haileyville, which discharge waste water effluent into the stream. There are also underground mines in the Brushy Creek watershed; however, impacts from AMD do not seem to be significant in the stream at this time. Just like Gaines Creek, Brushy Creek is typically turbid, tends to have low alkalinity (23-65 mg/l), low hardness (0-77 mg/l), relatively low conductivity (77-245 *u*mhos/cm), and a neutral pH. Base flow turbidities averaged 49 NTU, while storm flow turbidities averaged 142 NTU. The OWQS turbidity criteria was exceeded 3 times in Brushy Creek. TDS averaged 125 mg/l in base flow samples and 80 mg/l in storm flow samples. TSS averaged 32 mg/l in base flow samples and 170 mg/l in storm flow samples. Dissolved oxygen was present at sufficient levels during most of the study period; however, two low D.O. concentrations in August 1991 (3 mg/l) violated the OWQS. Significant fecal coliform counts have also been documented here (see Section I.10.H).

Sulfate, chloride, ammonia, and nitrate were not present at notable levels in Brushy Creek. Total nitrogen concentrations averaged 0.9 mg/l in base flow samples and 1.3 mg/l in storm flow samples. Brushy Creek contributes significant quantities of phosphorous to the lake. Total phosphorous concentrations averaged 0.06 mg/l in base flow samples and 0.19 mg/l in storm flow samples. EPA (1986) states that a desired goal for the prevention of plant nuisances in streams is 0.100 mg/l total phosphorous. Total phosphorous concentrations in Brushy Creek exceeded 0.100 mg/l in 2 base flow samples and 4 storm flow samples. EPA also suggests that phosphate phosphorous concentrations not exceed 0.05 mg/l in any stream at the point it enters a reservoir (EPA 1986). Phosphate phosphorous concentrations in one base flow sample and one storm flow sample exceeded this suggested criteria. A recent study detected a downward trend in the nitrogen:phosphorous ratio, COD, TKN, and total nitrogen concentrations. In addition, an upward trend was detected in turbidities in Brushy Creek (Wright 1994).

4. Mud Creek

Mud Creek, like Brushy Creek, receives waste water effluent from local municipalities (Krebs and McAlester, OK). This waste water effluent is likely a major source of TN concentrations which ranged from 1.3 to 2.6 mg/l and the TP concentrations which averaged 0.189 mg/l in base flow samples and 0.223 mg/l in storm flow samples.

Mud Creek is very turbid with mean base flow turbidities of 51 NTU and mean storm flow turbidities of 120 NTU. Total suspended solids averaged 37 mg/l in base flow samples and 115 mg/l in storm flow samples. Mud Creek exhibited the highest alkalinity (averaging 96 mg/l in base flow samples and 67 mg/l in high flow samples), moderately hard water, a neutral pH, moderate conductivities (374 uS/cm in base flow), and low dissolved oxygen.
The warm water aquatic community D.O. criteria was violated in four base flow samples. Fecal coliforms have also been documented here [see Section I.10.H]. Total dissolved solids, nitrate, ammonia, sulfate, and chloride were not present in significant quantities.

5. Toxics in Tributaries

Arsenic, copper, mercury, silver, and selenium were not detected in water collected in the tributaries to the Gaines Creek Arm. The concentrations of metals detected in the tributaries are listed in Table 14. Barium concentrations in the tributaries, which ranged from 22 to 401 ug/l, did not exceed the OWQS or EPA water quality criteria. Cadmium was detected only once, in water collected from Pit Creek on December 19, 1991 during a high flow event. The cadmium concentration (8 ug/l) exceeded the OWQS chronic criteria and approached acute levels. Zinc and nickel were detected in three stream samples: in Pit Creek on December 19, 1991 and August 13, 1992 and in Gaines Creek on February 14, 1991. The detected nickel concentrations ranged from 127 to 375 ug/l, exceeding the OWQS chronic criteria. The detected zinc concentrations ranged from 475 to 778 ug/l, exceeding the OWQS acute and chronic criteria.

Chromium was detected only once, in water collected from Gaines Creek on February 14, 1991. The chromium concentration (160 ug/l) exceeded the OWQS raw water numerical criteria, as well as the chronic criteria. Lead was detected only once, in a sample collected from Gaines Creek on February 14, 1991. The lead concentration (130 ug/l) exceeded the OWQS raw water, chronic, and acute criteria. Aluminum, which was analyzed only once during the study (on February 14, 1991 in Gaines Creek) was found at a high concentration (208 mg/l).

Obviously, the potential for metal toxicity is present in both Pit Creek and Gaines Creek, while Brushy Creek and Mud Creek seem to be free of elevated levels of metals. However, direct effects of low pH and D.O. concentrations likely result in the impairment of the biological communities observed in Pit and Gaines Creek.

All the tributaries contain relatively high iron (1.5 to 388 mg/l) and manganese (0.09 to 10.86 mg/l) concentrations; although, Pit Creek and Gaines Creek contained the highest concentrations. All iron concentrations exceeded EPA's chronic criteria (EPA 1986). It is estimated that Gaines Creek contributes 2,460 kilograms (2.7 tons) of iron per day to the lake, while Brushy Creek contributes approximately 1,088 kilograms (1.2 tons) of iron per day.

Pesticides were measured only once during the study. No pesticides were detected in high flow samples collected from Gaines, Pit, Brushy, and Mud Creeks on May 11-12, 1992.

J. Ambient Toxicity Testing of Lake and Tributaries

Sediment from lake sites N and R, and water and sediment from Gaines Creek and Pit Creek were tested for toxicity using *Ceriodaphnia dubia*, *Daphnia pulex*, and *Pimephales promelas* (EPA 1994). Sediment from lake sites N and R exhibited no toxic effects on the test organisms.

Gaines Creek samples exhibited toxic characteristics on two occasions. On February 28, 1991, toxicity testing of the water resulted in 60% mortality of *Ceriodaphnia dubia*. The *Ceriodaphnia dubia* females, which were exposed to either the sediment elutriate or water, also produced significantly fewer young. On July 28, 1991, toxicity testing of the sediment elutriate from Gaines Creek resulted in 50% mortality of *Ceriodaphnia dubia*. The remaining *Ceriodaphnia dubia* females produced significantly fewer young.

All toxicity tests of water and sediment elutriate from Pit Creek resulted in 100% mortality of all organisms tested.

K. Characteristics of Seeps in the Lake Eufaula-Gaines Creek Arm Watershed

Water samples were collected from 10 seeps in the Gaines Creek Arm watershed (Appendix K). Their locations are listed in Appendix B and displayed in Figure 3. The Adamson Seep was sampled 9 times during the study, while eight additional seeps were sampled on only one occasion. Seep A was located east of Adamson. Seep B was located 1.5 miles south of Gaines Creek. Seep D was located west of Gowen. Seepage from the Gowen Strip Pits (Seep C), #7 Mine near Gowen (Seep E), McHugh Mine (Seep F), Haileyola Mine (Seep G), Stafford-Hall Mine (Seep H), and the #8 Mine west of Adamson were also sampled.

Dissolved oxygen concentrations were low in the seeps, averaging 2.1 mg/l and ranging from 0.5 to 8.2 mg/l. The pH values measured in the seeps were also low, averaging 5.1 and ranging from 2.8 to 6.4. The lowest pH values were measured near Gowen in seeps C and D. Conductivities in the seeps were high, averaging 1,895 *u*mhos/cm and ranging from 136 to 8,160 *u*mhos/cm. Temperature was fairly consistent in the seeps, averaging 19^{o}C.

Ammonia-nitrogen and NO_2/NO_3-nitrogen, which were analyzed in only the Adamson seep, were not detected. Ortho-phosphorous (0.028 mg/l) and TP (0.171 mg/l), which were measured only in the Adamson seep, were high. Sulfate concentrations in the Adamson seep, which averaged 619 mg/l, were present at high concentrations. The water in the Adamson seep is very hard. The TDS concentrations in the Adamson seep were also very high (>1000 mg/l), making the water brackish. Chloride was generally below detection in the Adamson seep. Turbidity in the Adamson seep was variable ranging from 5 to 214 NTU. Alkalinity concentrations in the Adamson seep averaged 45 mg/l. Total suspended solids, which were measured in only the Adamson seep, were moderately high (54 mg/l). The seep water was generally extremely hard.

Arsenic, selenium, barium, copper, mercury, silver, and lead were not detected in water collected from the seeps. Iron, manganese, zinc, and cadmium were the most commonly found metals, although nickel, aluminum, and chromium were also found. Nickel was not present in significant concentrations. Aluminum was measured only once during the study (at Adamson seep) at a concentration of 300 ug/l. Excluding the chromium level found at Seep H (160 ug/l) which exceeded both the OWQS raw water numerical criteria and chronic criteria, chromium concentrations did not exceed the OWQS.

Except for the zinc concentration (886 ug/l) found at seep C (Gowen strip pits) which exceeded the OWQS acute and chronic criteria, zinc levels did not exceed the OWQS. Nine samples contained cadmium levels which exceeded the OWQS chronic criteria. In addition, cadmium levels in three seeps (D, F, and H) exceeded the OWQS raw water numerical criteria. The EPA Gold Book (EPA 1986) was used to evaluate the significance of iron concentrations. All iron concentrations in the seeps, which ranged from 15 to 1,230 mg/l, exceeded the EPA biological criteria (1.0 mg/l).

Although much uncertainty exists due to such a limited sampling, the following loadings for cadmium, iron, manganese, and zinc from each seep were estimated based on concentrations and flows measured in September and October, 1992 (Table 15). Based on the estimated loadings, Seeps H (Stafford-Hall Mine) and C (Gowen Strip Pits) are contributing the largest loads and thus remediation of these should be considered a high priority. The Adamson Seep also contributes large quantities of iron and manganese and should also be given high priority for remediation. Additional sampling is needed to confirm these findings.

SEEP	Date	Discharge (L/day)	Cd (ppb)	Cd load (kg/day)	Fe (ppm)	Fe load (kg/day)	Mn (ppm)	Mn load (kg/day)	Zn (ppb)	Zn load (kg/day)
Adamson	3/10/92		5		144.6		6.03		24	
Adamson	4/29/92		5		75.4		5.80		5	
Adamson	5/20/92		6		133.6		5.96		29	
Adamson	6/22/92		5		135.3		5.75		16	
Adamson	6/29/92		5		134.6		4.76		19	
Adamson	7/15/92		5		132.5		5.57		9	
Adamson	8/13/92		10		129.8		5.34		21	
Adamson	9/01/92		12		132.2		5.52		21	
Adamson	9/30/92	457,561	10	0.0046	121.9	55.78	4.98	2.28	20	0.0092
A	9/30/92	244,685	8	0.0020	120.6	29.51	4.48	1.10	14	0.0034
B	9/30/92	97,874	5	0.0005	15.4	1.51	0.35	0.03	6	0.0006
C	9/30/92	3,303,245	15	0.0495	159.7	527.53	0.80	2.63	886	2.9267
D	9/30/92	36,703	31	0.0011	434.8	15.96	26.43	0.97	62	0.0023
F	10/01/92	2,447	107	0.0003	1230.0	3.01	31.27	0.08	130	0.0003
G	10/01/92	327,878	5	0.0016	39.1	12.81	1.52	0.50	5	0.0016
H	10/01/92	1,492,577	80	0.1194	1178.0	1758.26	25.30	37.76	80	0.1194
I	10/20/92	182	10	0.0000	150.2	0.03	2.10	0.00	48	0.0000
TOTAL		**5,963,150**		**0.1790**		**2404.39**		**45.35**		**3.0635**

L. Estimated Phosphorous Loading

Because discharge was not measured during the study and total phosphorous concentrations measured in the streams were highly variable, estimating the phosphorous load to the Gaines Creek Arm was a difficult task and contains much uncertainty.

Based on USGS discharge data collected at Gaines Creek from 1943-63, it was estimated that approximately 12.5% of the total annual discharge results from base flow and 87.5% of the total annual discharge results from runoff. Assuming that these percentages applied to all the streams assessed during the period of study, estimates of runoff and baseflow volumes for each stream were made (Table 16).

Creek	Baseflow Volume		
Mud	2,531	17,719	20,250
Brushy/Peaceable	28,300	198,097	226,397
Gaines	18,570	129,987	148,557
Unassessed area	6,766	47,365	54,131

Estimated baseflow and runoff discharges were then multiplied by the mean total phosphorous concentrations measured during baseflow and runoff to calculate phosphorous loading from each stream (Table 17). Total phosphorous concentrations from Gaines Creek were used to estimate loading from the unassessed area because neither receive point source discharges.

ESTIMATED ANNUAL PHOSPHOROUS LOAD (kg)

Creek	Baseflow	Runoff	Total
Mud	590 (362)	4,874 (962)	5,464 (1,324)
Brushy/Peaceable	2,094 (2094)	46,428 (32,255)	48,522 (34,349)
Gaines	848 (779)	13,308 (8498)	14,156 (9,277)
Unassessed area	309 (284)	4,849 (3096)	5,158 (3,380)
TOTAL			**73,300** (48,330)

Based on the loading estimates (Table 17), it was calculated that the annual phosphorous load to the Gaines Creek Arm was approximately 73,300 kg (48,330 kg). Due to the variability of the data, confidence in the loading estimates is low. However, the relativity of the loads should be somewhat accurate because the loading estimates were based on the same assumptions. According to Table 17, Mud Creek contributes approximately 7.5% of the total phosphorous load, Brushy/Peaceable Creeks contribute roughly 66.2%, Gaines Creek contributes around 19.3%, and the unassessed area contributes approximately 7.0%. This compares to Mud Creek contributing 4% of the total annual input of water, Brushy/Peaceable contributing 49%, Gaines Creek contributing 32%, the unassessed area contributing 12%, and rainfall contributing 3%. When the relative contributions of phosphorous are compared to the relative contributions of water, it is obvious that Mud Creek and the Brushy/Peaceable system are contributing greater amounts of phosphorous relative to their discharge.

Both Mud Creek and Brushy Creek receive discharges from municipal wastewater treatment plants. To estimate phosphorous loading from these facilities, the design flows for each plant was multiplied by the mean TP concentrations associated with their treatment type.

The mean total phosphorous concentrations associated with each treatment type were obtained from Gakstatter□s publication in the Journal of the Water Pollution Control Federation (Gakstatter et al. 1978). Information used to calculate the phosphorous load for each facility is provided in Table 18.

Facility	Treatment Type	Mean TP Conc. (mg/L)	Design Flow (mgd)
Krebs	Lagoon-stabilization pond	6.60.81	0.215
McAlester East	Activated sludge	6.80.51	2.000
Haileyville	Activated sludge	6.80.51	0.045
Hartshorne	Activated sludge	6.80.51	0.270
Pittsburg	Activated sludge	6.80.51	0.035
Savanna	Lagoon-stabilization pond	6.60.81	0.095

Based on the data given in Table 18, the following phosphorous loads were calculated: Krebs discharges approximately 1960241 kg of phosphorous per year, McAlester (East) discharges 19,7891,409 kg per year, Haileyville discharges 42332 kg per year, Hartshorne discharges 2,536190 kg per year, Pittsburg discharges 32925 kg per year, and Savanna discharges roughly 886106 kg of phosphorous per year. As Section I.8 discussed, Krebs and McAlester (East) discharge into the Mud Creek watershed, while Haileyville, Hartshorne, Pittsburg, and Savanna discharge into the Brushy Creek watershed. Based on this, it was calculated that Mud Creek receives approximately 20,7491,650 kg of phosphorous per year from municipal discharges. This compares to the estimated annual phosphorous loading of 5,4641,324 kg from Mud Creek to the lake (Table 17) based on OCC stream data. Obviously, one (if not both) of the phosphorous loading estimates is incorrect. Despite the uncertainty, it is safe to say that the elevated phosphorous levels in Mud Creek likely result from point source discharges. Based on the phosphorous loading estimates for the municipal waste water treatment facilities, it was calculated that Brushy Creek receives roughly 4,174353 kg of phosphorous per year from municipal waste water discharges. This compares to the estimated annual phosphorous loading of 48,52234,349 kg from Brushy Creek based on OCC stream data. Obviously, a great deal of phosphorous load from Brushy Creek is originating from sources other than municipal point source discharges. Therefore, despite the uncertainty of the estimates, it is likely that the source of much of the elevated phosphorous loading from the Brushy Creek watershed is NPS pollution, although the municipal point source discharges certainly contribute.

M. Assessment of Lake Trophic State

Carlson's (1977) trophic state indices (TSI) were used to assign a trophic state classification. The following scale is used to assign trophic state class:

Carlson Chlorophyll *a* TSI	Trophic State
0-39	Oligotrophic
40-49	Mesotrophic
50-59	Eutrophic
>60	Hypereutrophic

TSI values, which were calculated from mean chlorophyll *a* concentrations, Secchi depth, and total phosphorous concentrations are as follows:

	TSI	Trophic State
chlorophyll *a*	51	Eutrophic
Secchi depth	86	Hypereutrophic
observed TP	66	Hypereutrophic

Trophic state predictions ranged from eutrophic to hypereutrophic. The discrepancies between the TSIs resulted from the high inorganic turbidity of the water. The high inorganic turbidity caused the Secchi TSI to be invalid. The turbidity also limited algal productivity to the extent that even though phosphorous concentrations were present at levels which can cause hyper-eutrophication, chlorophyll *a* was present at levels considered slightly eutrophic. The clay particles, which cause the turbidity, binds phosphorous making a portion of the phosphorous unavailable for biotic uptake. The turbidity also limits the available light. The turbidity limits the algal productivity to such the extent that it is doubtful that the Gaines Creek Arm could ever become hypereutrophic. Because lake productivity is limited by light caused by high turbidity, the most appropriate trophic classification of the lake would be **argillotrophic** (Carlson 1991).

N. Overall Discussion of Problems in Lake

The diagnostic study identified several problems in the Gaines Creek Arm of Lake Eufaula. Severe D.O. depletion during summer thermal stratification, which is responsible for the poor fish and macroinvertebrate communities, was identified as the lake□s worst problem. The severe D.O. depletion results primarily from the decomposition of organic matter and lack of mixing (little inflow during summer; little wind mixing action due to surrounding terrain). Algal blooms and oxygen consumption by reduced metal species likely contribute somewhat to D.O. depletion.

The Mud Creek and Brushy/Peaceable Creek watersheds are obviously contributing elevated levels of nutrients to the Gaines Creek Arm. The source of the elevated nutrient levels in Mud Creek likely originate primarily from municipal waste treatment facilities, while the elevated nutrient levels in Brushy Creek likely originate from nonpoint source pollution. The elevated levels of nutrients have not seriously impacted the Gaines Creek Arm, because algal productivity is severely limited by the extremely high turbidity. Therefore, because productivity is limited by turbidity, the trophic state of the Gaines Creek Arm was classified as argillotrophic.

Resuspension of bottom sediments contributes heavily to the turbidity within the lake. Although sedimentation may have been a problem in the past, this study found no evidence of current sedimentation problems. Landuse changes in the watershed, such as the conversion of most of the crop land to pasture land and paving of many county roads, have likely done a great deal to reduce sedimentation rates within the lake.

One of the primary goals of the diagnostic study was to evaluate the impacts of AMD on the lake and to locate major sources of AMD. The study indicated that the pH standard was violated at lake sites T, R, and P (hypolimnion). In addition, excessive levels of iron were found at all sites in the lake. Acid mine drainage (AMD) is likely responsible for the low pH values and excessive levels of iron in the lake. The study indicated that the major sources of AMD were the Stafford-Hall Mine, Gowen Strip Pits, and the Adamson seep.

Despite the problems identified, the Gaines Creek Arm is currently supporting its beneficial use as a drinking water supply and partially supporting its beneficial use as warm water aquatic community.