OKLAHOMA CONSERVATION COMMISSION

PAULS VALLEY CITY LAKE
PHASE III REPORT

SEPTEMBER 1994

PAULS VALLEY LAKE
EXECUTIVE SUMMARY

Pauls Valley City Lake is a milestone soil and water conservation program in the United States. The Pauls Valley Lake Clean Lakes Phase II Restoration Project was the first initiated in the United States and has provided a case study for the optimization of human resources and funding to implement effective conservation practices.

When the Phase II Restoration Project was initiated, Pauls Valley Lake was the primary drinking water source for the City of Pauls Valley and local rural water districts serving approximately 7700 people for drinking water and recreational use. Additional beneficial uses of Pauls Valley Lake and Washington Creek include warm water aquatic community, agriculture, municipal and industrial cooling water, primary recreation, and aesthetics (OWRB, 1991). Because of extreme siltation estimated to displace water at the rate of 27 acre-feet per year, beneficial uses of this reservoir were greatly unrealized.

Expensive drinking water treatment methods required to remove suspended solids necessitated that action be taken to reduce the sediment load into the lake. The City of Pauls Valley conducted a diagnostic/feasibility study on the lake from 1974 to 1976. The resulting study characterized Pauls Valley Lake as extremely polluted due to high turbidity and excessive sedimentation. Sources of sediment were found to be roadsides, soil erosion on abandoned cropland, and bank erosion on Washington Creek and its tributaries.

The City of Pauls Valley and the Garvin County Conservation District then applied for a Clean Lakes Phase II Restoration Project Grant from the United States Environmental Protection Agency (EPA) which was approved and funded on June 30, 1978. Because of limited funding, the Garvin County Conservation District concentrated their activities on private lands. Restoration work began in 1979 and was completed in 1984. The project resulted in the implementation of best management practices and the construction of 3 flood control structures and 9 sediment detention structures at strategic locations throughout the watershed. These structures control sediment from 31% of the Washington Creek watershed.

A Phase III Clean Lakes Study was conducted on the lake and its tributaries from 1991 to 1993. The purpose of this study was to measure the success of the Pauls Valley Lake restoration project and the overall health of the lake.

Data collected from Pauls Valley Lake reflect dramatic differences in water quality since Phase II implementation (1981-1984). Decreased turbidity, increased transparency, and decreased sedimentation testify to the remarkable efficiency and effectiveness of efforts undertaken by the City of Pauls Valley, the Garvin County Conservation District, the U.S.D.A. Soil Conservation Service, and the Oklahoma Conservation Commission. Other improvements have been made to this reservoir which local users and managers deem desirable. Obvious improvements to the local economy resulted from increased fee collection from anglers and boaters and decreased

water treatment costs. In addition, increased stability of storage in the reservoir has been observed. Other improvements realized by land managers in the watershed included increased flood and erosion control which ultimately resulted in increased top soil retention.

Presently this reservoir is experiencing optimum conditions which allow it to maintain a high degree of biological integrity. The combination of good water quality and no toxics is reflected by the presence of diverse phytoplankton, zooplankton, benthic macroinvertebrate, and fish communities. Overall, Phase II implementations have provided an additional lease on life (46 years) for this reservoir and immeasurable benefits to land management in the watershed.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

INTRODUCTION

Pauls Valley City Lake, a 750 acre reservoir (Table 1) on Washington Creek in Garvin County, Oklahoma, is a milestone soil and water conservation program in the United States. The Pauls Valley Lake Clean Lakes Phase II Restoration Project was the first initiated in the United States and has provided a case study for the optimization of human resources and funding to implement effective conservation practices.

Table 1. Characteristics of Pauls Valley Lake.

PARAMETER	VALUE
Surface Area	750 acres
Capacity	6623 acre-feet
Max. Depth	39 feet
Avg. Depth	6 feet
Watershed	14,193 acres

When the Phase II Restoration Project was initiated, Pauls Valley Lake was the primary drinking water source for the City of Pauls Valley and local rural water districts serving approximately 7700 people for drinking water and recreational use. The lake has been designated as a Sensitive Public and Private Water Supply (SWS), which prohibits additional point source discharges without approval by the Oklahoma Water Resources Board and suggests that best management practices be implemented. Additional beneficial uses of Pauls Valley Lake and Washington Creek include warm water aquatic community, agriculture, municipal and industrial cooling water, primary recreation, and aesthetics (OWRB, 1991). Because of extreme siltation estimated to displace water at the rate of 27 acre-feet per year, beneficial uses of this reservoir were greatly unrealized.

Expensive drinking water treatment methods required to remove suspended solids necessitated that action be taken to reduce the sediment load into the lake. The City of Pauls Valley conducted a diagnostic/feasibility study on the lake from 1974 to 1976. The resulting study characterized Pauls Valley Lake as extremely polluted due to high turbidity and excessive sedimentation. Sources of sediment were found to be roadsides, soil erosion on abandoned cropland, and bank erosion on Washington Creek and its tributaries.

The City of Pauls Valley and the Garvin County Conservation District then applied for a Clean Lakes Phase II Restoration Project Grant from the United States Environmental Protection Agency (EPA) which was approved and funded on June 30, 1978. The restoration project proposed the paving of all roads in the watershed, area mulching, grass planting on all roadside ditches, and the construction of flood control and sediment detention structures. Because of limited funding, the Garvin County Conservation District concentrated their activities on private lands rather than roadsides because of the greater degree of sediment reduction and cost effectiveness. Restoration work began in 1979 and was completed in 1984. The project resulted in the implementation of best management practices (i.e. grass planting, cross fencing, rotational grazing, pasture fertilization, weed and brush control) and the construction of three flood control structures and nine sediment detention structures at strategic locations throughout the watershed. These structures control sediment from 31% of the Washington Creek watershed (Appx. F-2).

Until this study, the success of the Phase II restoration work had only been measured by LANDSAT imagery, water quality data collected from runoff events (1982), and the decreased water treatment costs reported by Pauls Valley Public Works. The LANDSAT study (1985) indicated dramatic decreases in turbidity had occurred since the completion of the Phase II restoration activities. However, results of this study were limited to comparisons of imagery data collected on August 23, 1979 and August 31, 1984 (Hassell and Cooter, 1985). The water quality data collected from runoff events produced a sample size representative of 28 events over a period of two years. However, this data was inadequate because of the long-term nature of nonpoint source trends and the lack of pre-restoration data for comparison. Also, water treatment costs were not broken down among the different treatments performed at Pauls Valley Public Works, making it impossible to accurately determine the cost savings attributable to sediment reduction.

In an effort to adequately measure the success of the Phase II project, this two year study of Pauls Valley Lake was structured to collect accurate information regarding the sedimentation, turbidity, transparency, nutrients, contaminants (metals, organics, pesticides), biological integrity (fish, zooplankton, algae), and other traditional physical/chemical parameters of water from the lake and its tributaries.

This study also included LANDSAT imagery and Cesium-137 sediment dating which was conducted by the United States Department of Agriculture (USDA) Agricultural Research Service (ARS) in Durant, Oklahoma. Dr. Frank Schiebe, USDA-ARS, coordinated this component of the study. This information was used to test the effectiveness of LANDSAT imagery for turbidity trend analysis and measure the efficiency of silt traps constructed in the watershed.

MATERIALS AND METHODS

The purpose of this study was to measure the success of the Pauls Valley Lake restoration project which focused on sediment reduction from watershed sources. Cs-137 dating was used to compare pre-restorative and post-restorative sedimentation rates. Turbidity, transparency, and suspended sediment data from pre- and post-restoration were used to measure the success of sediment reduction efforts undertaken between 1979 and 1984. In addition, land use inventory (GIS), fish flesh analysis, chlorophyll *a*, and other water quality data were collected at Pauls Valley Lake. This data was used to assess the success of the Pauls Valley Lake restoration project and the overall health of the lake. Appendix F-3 shows the location of the reservoir, watershed, lake sampling stations, and sampling points on the tributaries.

Suspended Sediment

Reservoir suspended sediment was measured indirectly using LANDSAT to determine concentrations on various dates before and after sediment traps were constructed in the watershed as a part of the restoration project. Reservoir suspended sediment was measured directly to calibrate the remote sensing algorithm. For this, two liter water samples were collected at a depth of 30 cm, 30 m from the west shore and 500 m north of the dam. The amount of suspended sediment was determined from a 125 ml aliquot which was centrifuged and decanted. The suspended sediments were then dried and weighed.

Remote sensing information for the years of 1973, 1978, 1984, 1987, and 1988 were obtained from archived scenes of the LANDSAT series of polar orbiting satellites. Water years began in April and ended in October of the following calendar year. Information from 1973 and 1978 represented the pre-restoration period, while 1984, 1987, and 1988 represented the post-restoration period. Cloud free scenes from the different seasons of each year were analyzed. LANDSAT MSS data, which had been geometrically corrected so that each pixel covered a surface area of 57 by 57 meters, were obtained in digital format on computer compatible tapes. Subscenes of 5 by 5 meter pixel matrix arrays were used to obtain average values for given dates. Average values were then converted to radiance and exoatmospheric reflectance following procedures outlined by Robinove (1982).

The theoretically-derived relationship between exoatmospheric reflectance and suspended sediment concentration was used to determine suspended sediment. The relationship used was:

$$EREF_i = A_i + [(B_i)(1.0 - e^{(-SSc/Si)})]$$

where EREF = exoatmospheric reflectance,

i = wavelength band (MSS Band 3 was used),

A_i = average atmospheric path radiance,

B_i = range in reflectance response associated with the range of suspended sediment concentration,

SS_c = suspended sediment concentration, and
S_i = suspended sediment concentration constant equal to the concentration when reflectance is 63% of the difference between the average atmospheric path reflectance and the saturation reflectance value (Schiebe et al., 1992).

The equation was fitted to south central Oklahoma by calibrating the constants A_i, B_i, and S_i performing optimized least squares regression analysis (DeCoursey and Snyder, 1969) on data from Pauls Valley Lake and 15 other lakes in the region.

Sedimentation Rate

Reservoir sediments were sampled at four sites (Appendix F-2) using a 1.5 m long by 7.6 cm wide PVC plastic corer. The corer was manually pushed into the sediment and pulled from the sediment with a winch. The sediment cores were then pushed from the core tube by a piston. Compaction of the sediment cores was determined by comparing length of the core to the depth the corer went into the sediment and was not found to be significant. Three cores were taken at each site and divided into 10 cm sections beginning at the sediment surface. Core sections of like depth at each site were composited and placed into labeled plastic bags for transport to the laboratory.

In the laboratory, sediment core samples were first oven dried at 105^{o}C and then ground with a mortar and pestle until they passed through a 6 millimeter screen. Samples were then analyzed for Cs-137 with a multichannel analyzer using a lithium-drifted germanium detector (McHenry et al., 1980). Cesium-137 activity from each sample was counted twice for 4,000s and the two counts were then averaged. Cesium-137 analysis made it possible to date layers in the sediment profiles. Dating the profile was possible because Cs-137 produced identifiable markers in sediments when it first became detectable in 1954 from atmospheric nuclear tests and peaked in activity in 1963 (Larsen, 1984).

Sediment Trap Efficiency

Sediment deposition in the traps and reservoir was measured to determine the reduction in reservoir sedimentation resulting from sediment trap installation. Sediment retained by sediment trap ponds was measured in June 1992 with a 3 cm diameter metal probe. The easily probed soft top layer of bottom material, found above the dense probe resistant ground surface which existed when the traps were built, was considered the retained sediment. Water depth in the sediment traps was measured concurrently with the sediments sampling.

Transparency

Reservoir water transparency was measured in situ using a 20 cm Secchi disk to compare with remote sensing results since transparency is related to suspended sediment. Water transparency measurements and collection of water samples for suspended sediment were performed every 16 days to coincide with LANDSAT overpasses from July 1987 through June 1989.

Turbidity

Turbidities were measured in NTU from samples taken from 0.5 meters within 48 hours of collection. Turbidity data collected during the Phase III study (1991-93) were compared to pre-restoration turbidity data.

Lake Health Monitoring

Only a limited survey of the following parameters (Table 2) was performed prior to the initiation of restoration activities during the Phase II project (Appendix B). The collection of these parameters was necessary to measure overall lake integrity during the period the Phase III project was being performed. See the Workplan for a detailed description of the methods for sampling and analysis of these samples.

Table 2. Parameters Collected To Determine Lake Integrity.

MEDIUM	PARAMETER	UNITS
Water	Temperature	^oC
	Dissolved Oxygen	mg/L
	Specific Conductance	uS/cm
	Nutrients	mg/L as N or P
	Chlorophyll	ug/L
	SO_4, Cl, F	mg/L
	TDS & TSS	mg/L
	Alkalinity/Hardness	mg/L as $CaCO_3$
	Fecal Coliform	cfu/100ml
	Metals	ug/L
	pH	Std. units
	Pesticides/Organics	ug/L
	Zooplankton	orgs./L
Sediment	Nutrients	mg/kg as N or P
	Metals	mg/kg
	Pesticides/Organics	mg/kg
	Benthic Organisms	orgs./ft^2
Fish Flesh	Metals	mg/kg
	Pesticides/Organics	ug/kg
Macrophytes		genus

Lake and Tributary Sampling

At each lake station, temperature, specific conductance, pH, and dissolved oxygen profiles were determined by in situ measurements at 1-meter increments from the water surface to the lake bottom. Water transparency was determined with a 20 cm Secchi disc in situ. Water was also collected at 0.1 m, mid-depth, and just above the bottom, and then composited into a single sample. Where thermal stratification occurred, discrete samples were taken from 0.1 m and from just above the lake bottom. The samples were placed in appropriate containers and stored on ice until delivered to the contracted lab. Water samples were analyzed for nutrients, sulfate, chloride, fluoride, alkalinity/hardness, total dissolved solids, and total suspended solids. Additional water samples were analyzed on June 18, 1991 for metals and on December 9, 1992 for pesticides and organics. Water samples collected from the lake sites were also evaluated for sediment particle size and distribution with a Malvern Autosizer IIC instrument.

Water temperature, dissolved oxygen, pH, and specific conductance were measured in situ in the three tributaries. A single grab sample of water was also collected from 0.1 m below the surface at the three lake tributaries. These samples were delivered to the contracted lab for analyses of nutrients, sulfate, chloride, fluoride, alkalinity, total dissolved solids, and total suspended solids. Automated samplers were also located on each of the three tributaries for the collection of samples during high flow events (tripling of base flow).

Sediment

On June 11, 1992 sediment was collected from each lake station with a ponar dredge. The sediment was placed in 16 ounce glass jars with Teflon lids, and stored on ice until delivered to the lab for analyses of nutrients, heavy metals, and pesticides.

Phytoplankton

Water (500 ml) collected from the lake sampling sites were preserved in the field for subsequent identification and enumeration of phytoplankton. Phytoplankton was identified and enumerated by Phycotech.

Chlorophyll *a* was also analyzed as a measure of the phytoplankton standing crop at each lake location. An aliquot from unpreserved lake samples was filtered onto a glass fiber filter. The filter was ground in a glass tissue grinder and stored in a 90% acetone solution with magnesium carbonate. Ground samples were kept in a freezer until delivery to the laboratory.

Zooplankton

A bottom to surface vertical tow with a Wisconsin net was used to collect zooplankton at the dam 6 times during the study. The zooplankton samples were generally enumerated to the number of copepods, cladocerans, and rotifers present by Phycotech. Identification was made once (March 17, 1993) to the lowest practical taxon by the City-County Health Department

Laboratory of Oklahoma City.

Fish Flesh

On October 14, 1992 three 300 ft. experimental gill nets were set in different locations on the main body of the lake to collect fish for heavy metals and pesticide residues.

Benthic Macroinvertebrates

Benthic macroinvertebrates were collected on July 14 and 23, 1993 from the three lake sites. Three transect lines (lacustrine, transition, riverine) were established from which to collect benthic samples (Appendix F-4). Transect lines generally ran east to west, parallel to the dam. The lacustrine zone was the deepest and located about 200 meters upstream of the dam. The transition zone was located in the main body of the lake approximately 450 meters upstream of the dam and the riverine zone was in the shallow waters of Washington Creek and Whitefield Creek arms. Ponar dredge samples were collected at 10 evenly spaced locations on each transect line, avoiding aquatic vegetation. Samples were sieved in a 30 mesh sieve, preserved in 70% ethanol, then delivered to City-County Health Department Laboratory of Oklahoma City for enumeration and identification. Benthic macro-invertebrate densities were expressed as organisms per square foot of lake bottom.

Macrophytes

Aquatic macrophytes were surveyed for their general taxonomic composition, distribution, and abundance by field crews in situ.

Fish

The fish population was sampled by the Oklahoma Department of Wildlife Conservation under contract to the OCC on October 10-12, 1993.

Laboratory Analysis

Chemical and biological samples collected by the OCC were analyzed by OCC employees or delivered to the Oklahoma City-County Health Department, USGS, or Oklahoma State Department of Health for analyses.

RESULTS AND DISCUSSION

Bathymetric Survey

On June 25, 1991 the OCC and USDA-ARS conducted a bathymetric survey (Appendix F-5) on Pauls Valley Lake. This was accomplished by running 12 transects across various sections of the lake. At normal pool, the volume of Pauls Valley Lake is 6,623 acre-feet, based on the depth contour data. This volume is considerably less than the 1961 storage capacity of 8,500 acre-feet. This shows that nearly 2,000 acre-feet of storage has been displaced by excessive sedimentation.

Public Access

Pauls Valley Lake (Appendix F-6) is easily accessible from U.S. Highway 77 or State Highway 19 via various paved county roads. The recreational area *(A)* northeast of the dam provides a boat ramp, boat and fishing dock, camping facilities, picnic area, playground, and concessions (OWRB, 1990).

Soils/Geology

Appendix F-7 describes the soils and their distribution in the Pauls Valley Lake watershed. Highly erodible soils (Stephenville fine sandy loams, Grainola and Clarita soils, and Lucien-Nash soils) are present on 2,876 acres (Table 3) encompassing 20 percent of the watershed.

Table 3. Pauls Valley Soils.

CATEGORY	ACRES
Grant Soils, 1-5% slopes	1433
Stephenville fine sandy loams, 1-20% slopes	1285
Bethany, Kirkland, and Wilson silt loams, 0-2% slopes	820
Grainola and Clarita soils, 2-20% slopes	1522
Konawa fine sandy loams, 2-8% slopes	1572
Lucien-Nash soils, 5-12% slopes	69
Newalla fine sandy loams, 1-5% slopes	198
Norge and Vanoss silt loams, 0-3% slopes	771
Port and Polaski soils, frequently-occasionally flooded	1354
Renfrow silt loams, 1-5% slopes	3440
Teller soils, 1-8% slopes	722
Zaneis loams, 1-5% slopes	208
Water	800

Potentially erodible soils (Grant soils, Konawa fine sandy loams, Teller soils, and Zaneis loams) encompass an additional 28% (3,934 acres) of the watershed. Forty-eight percent of the total watershed has the potential to erode without proper management.

Land Use

Appendix F-8 describes land uses in the Pauls Valley Lake watershed. Rangeland-open grassland and pastureland dominate present land uses comprising approximately 77% of the total watershed acreage (14,193 acres). Blackjack/post oak woodlands cover 1,671 acres and cropland constitutes only about 790 acres (Table 4).

This watershed, primarily pastoral and/or unmanaged rangeland, is not tilled to any significant extent. However, this was not the case during much of the pre-restorative period. The 1954 Pauls Valley Lake Work plan indicated that 24% (4249 acres) of the entire Washington Creek watershed (17,488 acres) was managed for cropland. By 1976, this had decreased to 8% (1317 acres). Presently, cropland constitutes only 6% (790 acres) of the Pauls Valley Lake watershed. Economic factors influenced this shift from farming to less intensive land management.

Table 4. Pauls Valley Lake Watershed Land Use.

CATEGORY	ACRES
Cropland	583
Cropland-Orchards, Groves, Horticultural Crops	207
Rangeland-Open Grasslands	6919
Rangeland-Blackjack/Post Oak Brush, LD-Can.<35%	959
Rangeland-Blackjack/Post Oak Brush, HD-Can.>35%	623
Rangeland-Cottonwood, Elm, Hackberry, Willow, HD-Can.>20%	49
Pastureland	3944
Blackjack/Post Oak-Cover Type	89
Urban and Built-Up Land	20
Water	800
Total	14193

The shift in land use occurred independently of the Phase II implementation project, but certainly had a major impact on the sediment loading to Pauls Valley Lake. Although this study did not quantify what decrease in sediment loading was attributable to land use changes, there should be no doubt that the shift from intensive farming to rangeland/pastureland utilization dramatically decreased the contribution of sediment resulting from the decrease of tillage.

Suspended Sediment

Comparison of remotely sensed water quality data before and after installation of the sediment traps made quantification of the reduction in suspended sediments possible (Figure 1). The average suspended sediment determined through remote sensing before installation of the sediment traps was 94 mg/L while afterward was 34 mg/L.

Sedimentation Rate

Cesium-137 dating was possible at three of the four USDA lake sampling sites. Cesium-137 analysis of sediments from Site 4 indicated the sediments at that location had sifted through time and were not suitable for dating. The average of the other three sites was represented by the findings at Site 2 (Figure 2). The reservoir sedimentation rates (as calculated from Cs-137) can be found in Table 5.

Table 5. Sedimentation Rate in Pauls Valley Lake as Determined by Cs-137. Post-Restoration Period is 1982-1992.

PERIOD (years)	**SEDIMENTATION RATE** (cm/yr)
1954 to 1964	2.5
1964 to 1982	1.8
1982 to 1992	1.3

Sediment Trap Efficiency

Combining the Cs-137 findings with measurements of sediment retained by the sediment traps made it possible to determine the effect the traps had on reservoir sedimentation rates. The sediment traps retained 128,000 m^3 of sediment which would have been transported over time to the reservoir (Table 6).

The sediment retained by the traps represented a 0.43 cm/yr reduction in reservoir sediment deposition. The amount of reduction in reservoir sedimentation resulting from the traps combined with Cs-137 data made possible the determination of reservoir sedimentation rates before and after the traps were built (Table 5). The mean year of trap completion was 1982 so it was used for computations. The structures reduced the sedimentation rate by 24%. Theoretically, the traps should retain about 28% of the sediment. The theoretical value was determined since the traps have an 85% percent trap efficiency (Brune, 1953) and intercept water from 33% of a watershed which has eroding areas uniformally distributed throughout.

FIGURE 1. SUSPENDED SEDIMENT.

FIGURE 2. CESIUM-137 SEDIMENT DATING

Table 6. The Year Sediment Traps Were Completed, the Sizes of Ponds Formed, and Amounts and Rates of Sedimentation.

Structure	**Complete d**	**Pond Area**	**Water Depth**	**Sediment Depth**	**Vol**	**Rate**	**Time to Fill**
	Year	ha	m	m	m^3	cm/yr	yrs
RC-1	1984	1	2.8	1.1	11,050	12.9	22
LE-3	1981	4	4.0	0.6	24,000	5.2	77
RM-1	1983	1	1.5	0.5	5,066	5.3	28
RM-2	1983	0.5	2.4	0.3	1,416	2.9	82
WM-2	1981	5	4.4	1.0	48,875	8.5	53
EP-1	1983	1	1.9	0.5	4,600	4.8	39
EP-2	1983	1.5	2.8	0.7	10,849	7.6	37
EP-3	1983	0.5	1.4	0.6	2,900	6.1	23
EP-4	1983	0.5	2.7	0.5	2,500	5.2	52
RH-1	1984	1.5	2.9	0.6	9,549	7.4	39
PS-1	1981	1.5	2.2	0.4	5,799	3.3	67
AW-1	1984	0.5	1.1	0.3	1,375	3.2	34

Study findings indicated that the conservation structures, on average, would protect the reservoir for another 46 years if sedimentation rates remain constant. The present structures have an average sediment accretion rate of 6 cm/yr " 2.7 cm/yr. Study findings further indicate that more structures are needed to collect sediment from the parts of the watershed not already treated.

Transparency and Turbidity

Prior to the restoration activities, turbidity and transparency were recorded at Pauls Valley Lake and provide a fair assessment of the effectiveness of the Phase II restoration project, given their relationship with sediment loading and suspended solids. Water clarity increased after structure installation, which supported the satellite findings (Figure 3). Values found from surface samples at the dam from both pre and post-restoration periods are used for comparison (Table 7).

Table 7. Mean Turbidity (*JTU-pre-restoration; NTU-post-restoration) and Transparency (inches: Secchi depth) from Pauls Valley Lake Dam: Pre- and Post-restoration.

	Pre-restoration		**Post-restoration**	
	Turbidity	Transparency	Turbidity	Transparency
Mean	98.6	12.0	16.4	27.2
Range	8.8 - 200	2.2 - 36.9	6.5 - 32	6.0 - 50
N	25	25	19	30

**Turbidity values obtained during the Phase III study were measured using "Standard Methods for the Examination of Water and Wastewater" 17th ed., 1989. Standards outlined in this publication recognize comparability between Jackson candle Turbidity Units (JTU) and Nephelometric Turbidity Units (NTU).*

FIGURE 3. SECCHI DEPTH.

From 1976 through 1980, Pauls Valley Lake was sampled 25 times wherein turbidity and transparency (Secchi depth) were measured. From May 1991 through March 1993, 19 surface samples for turbidity measurement and 30 Secchi depth readings were taken from the sample site at the dam. Since pre-restoration, turbidity has been markedly reduced from an average 98.6 JTU to 16.4 NTU. Values ranged from 8.8 JTU to greater than 200 JTU during the pre-restoration period whereas turbidities found during the Phase III study ranged from 6.5 - 32 NTU. Current turbidities reflect an 83% reduction from pre-restoration values. The range of turbidities found in the Phase III study was also reduced, indicating a lesser degree of variability. The maximum turbidity value found during the Phase III reflected an 84% reduction from the pre-restoration maximum turbidity. The post-restoration mean turbidity (16.4) is in compliance with Oklahoma's Water Quality Standard for turbidity in lakes (25 NTU). Restoration activities have been responsible for Pauls Valley Lake, which had a mean pre-restoration turbidity of 98.6, attaining compliance with the Oklahoma Water Quality Standard.

Transparency at Pauls Valley Lake has also improved since pre-restoration. Mean pre-restoration Secchi depth was 12.0 inches with a range of 2.2 - 36.9 inches. Mean Secchi depth during the post-restorative study was 27.2 inches with a range of 6.0 - 50 inches. The mean transparency value of the Phase III study is 56% greater than the pre-restoration mean, indicating much clearer water. There was a 26% increase in maximum transparency at Pauls Valley Lake since pre-restoration and the minimum transparency of the Phase III study was 63% greater than that of pre-restoration.

Changes in these parameters since lake restoration are dramatic. Lower turbidity and higher transparency indicate that the Pauls Valley Lake Restoration Project successfully reduced suspended sediment in the lake.

LAKE INTEGRITY

All water quality data collected during the Phase III study can be found in Appendix A. All pre-restoration data can be found in Appendix B.

Thermal Structure

Pauls Valley Lake is a monomictic lake. The deep area of the lake near the dam stratified from mid-May to mid-September during 1991 and from mid-June to mid-September during 1992. The Washington Creek and Whitefield Creek arms experience only short periods of stratification, remaining unstratified throughout most of the year due to shallowness and wind mixing action.

Dissolved Oxygen

The Washington Creek and Whitefield Creek arms of the lake remain well oxygenated throughout the year. However, at the dam a clinograde oxygen profile typical of eutrophic lakes was exhibited during thermal stratification. Dissolved oxygen concentrations of less than 2.0 ppm were found throughout the hypolimnion during this period.

pH

The mean pH was 8.1 in the arms of the lake and 7.85 at the dam, which is within Oklahoma's Water Quality Standards (6.5-9.0). However, during thermal stratification, the pH decreases markedly in the hypolimnion, which is characteristic of lakes possessing a clinograde oxygen curve. Data indicates that the pH of the lake has increased slightly since the pre-restoration period from a pH of 7.5 to the post-restoration pH of 8.0.

Specific Conductance

Conductivity is an index of total dissolved solids (TDS). From the mean conductivity, TDS was calculated as 192.4 mg/L at the dam, 192.0 mg/L in the Washington Creek arm, and 191.1 mg/L in the Whitefield Creek arm. Conductivity was also generally uniform from top to bottom indicating that no chemocline exists.

TDS (Residue Solids)

Measured TDS is consistent with the TDS calculated from conductivity. Mean TDS was 199.1 mg/L at the dam, 183.8 mg/L in the Washington Creek arm, and 189.4 mg/L in the Whitefield Creek arm. TDS is consistent throughout the lake, indicating that the lake is well mixed throughout. The TDS values are well below the recommended limit (500 mg/L) of the 1972 FWPCA Drinking Water Standards. TDS has increased slightly since restoration from a mean TDS of 178.6 mg/L during the pre-restoration study compared to an overall mean of 190.8 mg/L during the post-restoration study.

TSS (Residue Total Suspended)

Total suspended solids (TSS) were fairly consistent throughout the lake. Mean TSS was 16.5 mg/L at the dam, 15.6 mg/L in the Washington Creek arm, and 12.8 in the Whitefield Creek arm. Particle size was also measured by the UDSA-ARS at one lake station. The mean (n=5) undispersed particle diameter was 1809 nanometers (nm). The mean (n=11) dispersed particle diameter was 853 nm.

Alkalinity and Hardness

The mean alkalinity during the post-restoration study was 110.8 mg/L $CaCO_3$ at the dam, 110.1 mg/L $CaCO_3$ in the Washington Creek arm, and 102.6 mg/L $CaCO_3$ in the Whitefield Creek arm. Alkalinity experienced a slight increase from 106.4 mg/L $CaCO_3$ during the pre-restoration study to 107.8 mg/L $CaCO_3$ during the post-restoration study.

Hardness (90.5 mg/L $CaCO_3$) was measured only once (June 18, 1991) during the post-restoration study at the dam. This moderately hard water is slightly lower than the pre-restoration hardness of 97.6 mg/L $CaCO_3$.

Anions (SO_4, Cl, F)

Mean dissolved sulfate (SO_4) averaged 12 mg/L throughout the lake during the post-restoration study. This represents a major decrease from the pre-restoration sulfate mean of 28.3 mg/L and is likely due to decreasing soil erosion. The observed sulfate values were below concentrations having deleterious effects.

Mean dissolved chloride (Cl) averaged 20 mg/L in the arms and 18 mg/L at the dam. The post-restoration Cl concentration (19 mg/L) is slightly higher than the pre-restoration concentration of 14.5 mg/L. The chloride concentrations are also well below harmful levels.

The mean dissolved fluoride (F) concentration averaged 0.2 mg/L throughout the lake, which complies with the Oklahoma Water Quality Standard (4 mg/L F). Fluoride was not measured during the pre-restoration study, so no comparisons were made.

Nutrients

Total phosphorous (TP) levels were fairly consistent throughout the lake. The mean TP concentration was 0.027 mg/L at the dam, 0.029 mg/L in the Washington Creek arm, and 0.023 mg/L in the Whitefield Creek arm. The EPA suggests that total phosphorous concentrations in lakes not exceed 0.025 mg/L. Carlson's TSI-TP classifies the lake as eutrophic. Total phosphate averaged 0.06 mg/L during the pre-restoration period, which is consistent with the post-restoration phosphate concentration of 0.067 mg/L.

Total nitrogen (TN) concentrations were fairly consistent throughout the lake averaging 0.51 mg/L at the dam, 0.48 mg/L in the Washington Creek arm, and 0.43 mg/L in the Whitefield

Creek arm. The average post-restoration organic nitrogen concentration (0.42 mg/L N) is considerably less than the pre-restoration concentration of 1.64 mg/L N. The average post-restoration nitrate concentration (0.05 mg/L N) is also considerably lower than the pre-restoration concentration of 0.10 mg/L N. This possibly indicates that the sediment traps are effectively removing nitrogen as well as sediment and/or land use changes have resulted in the transport of less nitrogen.

The nitrogen to phosphorous ratio (N/P) was 18.9 at the dam, 16.6 in the Washington Creek arm, and 18.7 in the Whitefield Creek arm. These ratios indicate that the lake is phosphorous limited, therefore, TSI-TP should give an accurate estimate of trophic state.

Nutrient and hydrologic budgets could not be calculated due to insufficient flow data.

Metals

The metal concentrations found in Pauls Valley Lake (Table 8) comply with Oklahoma's Water Quality Standards for *Public and Private Water Supplies* and *Biological Criteria*. No metals analysis were performed during pre-restoration, so no comparisons can be made.

Table 8. Metals found in Pauls Valley Lake Water.

METAL	DAM	WASHINGTON ARM	WHITEFIELD ARM
Ba (ug/L)	200	100	200
Cd (ug/L)	<1	<1	<1
Cr (ug/L)	2	<1	<1
Cu (ug/L)	5	4.5	3
Fe (ug/L)	870	715	545
Pb (ug/L)	3	2	1
Mn (ug/L)	855	100	45
Ni (ug/L)	4	2	3
Zn (ug/L)	<10	<10	<10
Ca (mg/L)	22.5	21	21
Mg (mg/L)	8.3	8.2	8.1
Na (mg/L)	21.5	21.5	21.5
K (mg/L)	2.8	2.8	2.7

The concentration of metals found in the lake sediment of Pauls Valley Lake can be found in Table 9. No sediment quality criteria have been established for metals at this time. However, the good water quality suggests that the sediments are not contributing significant amounts of metals to the water.

Table 9. Metals Found in Pauls Valley Lake Sediment.

METAL	DAM	WASHINGTON ARM	WHITEFIELD ARM
As (ug/g)	13	11	5
Cd (ug/g)	1	<1	<1
Cr (ug/g)	30	20	6
Cu (ug/g)	20	20	8
Pb (ug/g)	30	30	<10
Mn (ug/g)	1700	550	190
Ni (ug/g)	30	20	<10
Zn (ug/g)	60	50	10
Se (ug/g)	<1	<1	<1
Fe (ug/g)	21000	15000	5000
Hg (ug/g)	N/A	0.03	N/A
Ca (mg/kg)	N/A	3800	990
Mg (mg/kg)	N/A	3300	1100
Na (mg/kg)	N/A	150	60
K (mg/kg)	N/A	1200	<10

Pesticides/Organics

Pesticides/organics were measured in the lake water collected at the dam on December 9, 1992. Concentrations were generally below the detection limit in the water column with the exception of atrazine (0.1 ug/L) and 2,4-D (0.02 ug/L). The maximum contaminant level goal (MCLG) for drinking water is 0.003 mg/L for atrazine and 0.07 mg/L for 2,4-D (IRIS, 1994). The observed concentrations of the two pesticides were well below the MCLGs established for drinking water. However, their occurrence in December may indicate that higher concentrations were present in May or June just after they were applied.

Pesticides/organics in the sediment were measured at the dam and in the Whitefield Creek arm on June 11, 1992. Concentrations of pesticides in the sediment were also generally below detection limit. However, methoxychlor (0.5 ug/kg) was found in the dam sediment, and DDD (0.1 ug/kg) and DDE (0.7 ug/kg) were found in the Whitefield Creek arm sediment. No sediment quality criteria have been established for pesticides. Generally, organics bound to sediments are unavailable for biological uptake. The DDD found is at the detection limit, DDE is only 0.6 ug/kg above the detection limit, and methoxychlor is only 0.4 ug/kg above detection limit. Because of the low concentrations found and the general unavailability of sediment bound organics, these concentrations are considered to be unhazardous.

Fish Flesh

The following fish (Table 10) collected on October 14, 1992 were analyzed for metals, pesticides, and organics.

Table 10. Fish Collected For Fish Flesh Analysis.

FISH	NUMBER
Channel Catfish	6
Gizzard Shad	9
White Crappie	4
River Carpsucker	5

Table 11 summarizes the laboratory results of the fish analysis. Only mercury and zinc were found in measurable concentrations in the fish flesh. Mercury concentrations were below detection limit in all fish except the channel cat where a concentration of 0.11 mg/kg was found. This concentration is at the detection limit and is below the concern level established in the Oklahoma Water Quality Standards. Zinc was found in all of the fish. This is as expected, because zinc is an essential nutrient for fish. No zinc criteria has been set for fish flesh. Zinc is generally harmful only at extremely high concentrations, levels much higher than that found in the fish flesh.

Table 11. Analysis of Fish Tissue Collected on October 14, 1992 at Pauls Valley Lake.

Fecal Coliform Bacteria

Fecal coliform bacteria were sampled 8 times between May and September 1991 (Appendix C). Fecal coliform bacteria were generally low ($\leq$10) in Pauls Valley Lake throughout the study period. However, on May 16, 1991 fecal coliform values of 540 cfu/100ml at the dam and 180 cfu/100ml at the Whitefield Creek arm were observed. The fecal coliform observed at the dam exceeds the Oklahoma Water Quality Standard for *Primary Body Contact* (10% of the samples shall not exceed 400 cfu/100ml during a 30 day period).

Phytoplankton

Phytoplankton (Appendix D) was sampled 29 times between May 1991 and February 1993. The phytoplankton community is very diverse. No less than 20 species were identified in the lake and included both pollution tolerant and intolerant species.

Chlorophyll (Table 12) was also measured as an indicator of the standing crop of phytoplankton during the Phase III study. Planktonic chlorophyll values throughout the course of this study were consistently low, ranging from 0 to 9.2 *u*g/L. The overall mean surface chlorophyll *a* concentration was 4.3 *u*g/L at the dam, 5.0 *u*g/L in the Washington Creek arm, and 4.8 *u*g/L in the Whitefield Creek arm. Chlorophyll, which was measured only eight times, ranged from 1.45 to 16.9 *u*g/L and averaged 6.79 *u*g/L during pre-restoration study. Post-restoration chlorophyll has decreased slightly and experiences less variability than pre-restoration chlorophyll.

The Carlson TSI-chlorophyll classifies the lake as mesotrophic. This is contrary to the results of Carlson's TSI-TP, which classified the lake as eutrophic, and indicates that other factors, such as turbidity, could be limiting algal production. In turbid waters, light limitation suppresses plankton productivity and phosphorous sorbs onto clays making it unavailable to phytoplankton. Because of this, Pauls Valley Lake should be classified as argillotrophic (production limited by light limitation produced by high turbidity) (Carlson, 1991). In addition, the extensive macrophyte population in the lake may be utilizing the available nutrients to the extent that algal productivity is displaced.

Table 12. Chlorophyll *a* (*u*g/L) collected from Pauls Valley Lake.

The lowest chlorophyll values were generally observed between April and June (2nd quarter) at the dam and in the Washington Creek arm. This could be due to higher turbidities or the growth of macrophytes decreasing available nutrient levels during the warmer months. The highest chlorophyll values were generally observed between October and March (1st or 4th quarter). After the macrophytes die, many nutrients are released into the water column, which could have resulted in the observed chlorophyll peak during the colder months. Overall, the low chlorophyll levels and high diversity of the phytoplankton community indicates good water quality.

Zooplankton

Animals recovered from this study were identified to the lowest possible taxon only once, March 17, 1993. In this sample, Cyclopoids (12 org./L) and Nauplii (19 org./L) dominated Copepod populations. Bosmina (4.3 org./L) was the most abundant Cladoceran. Zooplankton communities (Table 13) appeared to be dominated by rotifers throughout most of the study.

Table 13. Zooplankton (organisms per liter) recovered from Pauls Valley Lake Dam, 1991-92.

Date	Cladocera	Copepoda	Rotifera
07-17-91	5	6	0
10-22-91	14	6	16
01-09-92	7	7	99
05-01-92	8	2	41
10-28-92	4	7	23
03-17-93	33.1	6.9	0

The planktonic insect Chaoborus (Order Diptera) was found in high numbers in the benthic samples. Chaoborus (the phantom midge) is capable of migrating vertically through the water column. During the day they migrate to the sediments to escape fish predation, and at night they migrate to the water surface where they feed. Their presence in the benthic samples indicates that the water at the sediment/water interface is good.

A number of factors can influence zooplankton communities in freshwater reservoirs. An important influence on the zooplankton populations could be direct and indirect inhibition caused by stands of Myriophyllum, found to be extensive at Pauls Valley Lake. This macrophyte, along with Elodea and Nitella, has been documented to have inhibitory effects on Daphnia. Other macrophytes influence competition between blue-green algae and other algal groups by excreting organic compounds which can be utilized by blue-green algae. This favors the dominance of certain blue-green algae and inhibits other algal groups (Wetzel, 1983). This can effect zooplankton communities by limiting available food sources to those which do utilize blue-green algae.

A more obvious influence on zooplankton abundance is fish predation. Pauls Valley Lake has a sizeable planktivorous fish community. Sunfish and gizzard shad along with the younger age classes of other game fish, can exert a great deal of predation pressure on the zooplankton community. Although there are no data regarding this predator-prey relationship at Pauls Valley

Lake, the presence of such a large community of planktivorous fish would certainly have an inhibitory effect on populations of large size zooplankton (ie. cladocerans and copepods).

Benthic Macroinvertebrates

The benthic macroinvertebrate community at Pauls Valley Lake is very diverse consisting of 4 Phyla, 5 Classes, 7 Orders, 9 families, and no less than 13 genera. The taxa and densities of the benthic organisms recovered from Pauls Valley Lake on July 14 and 23, 1993 are summarized in Appendix E. Nematodes were found at only 2 locations, one in the riverine and one in the lacustrine zones.

Oligochaetes are classified as tolerant according to Beck's Biotic Index (USDA, 1991) and are able to withstand low dissolved oxygen levels. Their abundance can indicate polluted environments with low dissolved oxygen levels. Tubificid oligochaetes were found in 53% of the samples, primarily in the lacustrine and transition zones of the lake. Their higher density in the lacustrine and transition zones possibly indicates more anaerobic and stressful conditions.

The clam Sphaerium (Phylum Mollusca) was very prevalent, found in 25 of 30 samples with an overall density of 3.4 organisms per square foot. This wide distribution of sphaerids suggests that some oxygen $\geq$1ppm was always present at the sediment water interface throughout the life span of the clam. However, sphaerium was more abundant in the riverine zone than in the transition or lacustrine zones. This again could indicate more anaerobic and stressful conditions in the transition and lacustrine zones. The clam Pisidium, in contrast, was most abundant in the littoral area of the lacustrine zone.

The most prevalent and abundant benthic macroinvertebrates were chironomids of the sub-family Tanypodinae (Class Insecta, Order Diptera) which were found in 93% of the samples and had an overall density of 6.4 organisms per square foot. Chironomids are considered tolerant benthic invertebrates (Beck's Biotic Index). The Ephemeropteran Hexagenia and the Megalopteran Sialis were most prevalent and abundant in the shallow waters of the riverine zone and in lacustrine and transition samples taken proximal to the shoreline. The ephemeropterans and megalopterans are very intolerant of low dissolved oxygen. Thus, their absence from the deeper waters of the transition and lacustrine zones possibly indicates low dissolved oxygen levels or stressful conditions. Ceratopogonids were the least abundant of all benthic macroinvertebrates identified and were recovered from only 2 samples.

The mean depths of the transition (5.2 m) and lacustrine (5.8 m) are similar, therefore it is expected that their benthic communities are similar (as was observed). In contrast, the riverine mean depth (2.7 m) is much shallower than the lacustrine and transition zones and therefore has a much different benthic community. This could explain the differences between the lacustrine/transition zone community and the riverine community. Another explanation for the differences between these communities is that the low dissolved oxygen of the deeper areas of the transition and lacustrine zones had an impact on the benthic community. However, the overall benthic community is very healthy, indicating good water quality. In a recent study, benthic macroinvertebrate metrics developed by the TVA (TVA, 1992) and the OCC were used to determine the biotic integrity of several small reservoirs (Lakes Taylor, Claremore, Bixhoma, Pawhuska, Pauls Valley). Of the five small reservoirs, Pauls Valley Lake scored highest for benthic community integrity.

Fish

A total of 15 species were collected from Pauls Valley Lake (Table 14). All species collected are classified as tolerant (Jester et al., 1992). Thirty-two percent of the fish were omnivores and sixty-four percent were invertevores/insectivores. A total of 657 individuals were collected.

A recent study used fish metrics developed by Drs. Jennings and Karr to determine the biotic integrity of the fish community of five small Oklahoma lakes (Lakes Taylor, Skipout, Pauls Valley, Pawhuska, and Claremore). Of these lakes, Pauls Valley Lake ranked second. Fish are good indicators of long-term (several years) water quality. The fish community at Pauls Valley Lake is good, indicating that water quality has been adequate to support the fish community for several years.

Table 14. Fish Collected from Pauls Valley Lake.

SPECIES	NUMBER
Largemouth Bass	22
White Crappie	35
Bluegill	311
Orangespotted Sf	1
Green Sunfish	2
Longear Sunfish	6
Redear Sunfish	48
Warmouth Sunfish	11
Channel Catfish	53
Flathead Catfish	2
Black Bullhead	1
Gizzard Shad	131
Drum	9
River Carpsucker	12
Carp	13

Macrophytes

Macrophytic production at Pauls Valley Lake was dominated by water milfoil (Myriophyllum sp.). This submergent aquatic plant thrives in a 5 to 20 foot wide continuous band which runs parallel to the shoreline on approximately 90% of the lake. A shore to shore stand of Myriophyllum sp. completely fills the shallow upper one-third of the Washington Creek arm during the growing season (May through September). Yellow water lily (Nuphar Luteum) and American water lotus (Nelumbo) were found abundantly in 3 coves of the Washington Creek arm in water about 2 to 6 feet deep. Pond weed (Potamogeton sp.) was found frequently dispersed among the dominant strands of Myriophyllum throughout the lake. The macrophytes utilize available nutrients, displacing algal productivity. The majority of shoreline vegetation is composed of upland grasses, shrubs, and trees common to this area.

Some water milfoil species (Eurasian water milfoil) are considered pest species in many lakes across the United States. However, at Pauls Valley Lake, water milfoil appears to be enhancing transparency of the water by filtering out fine particulate matter and protecting the shoreline from wave action. Local lake users have testified that this plant was not present throughout the pre-restoration period and that it is a recent invader. It is likely that the high turbidity of the pre-restoration period inhibited the establishment of this plant. It is probable that the successful establishment of this macrophyte is a product of the reduced turbidity and suspended sediment. Stands of this plant sometimes result in complaints by shore anglers because of the difficulties it causes by snagging fishing line. However, it can also be very beneficial to the fish community by providing a cooler habitat in the summer and a nursery for fry. At Pauls Valley Lake, water milfoil should be managed carefully in order to fully realize benefits such as clearer water and an enhanced fishery.

Characteristics of Pauls Valley Lake Tributaries

During the Pauls Valley Lake study, the three major streams in the watershed (Washington Creek, Whitefield Creek, and Fajt Creek) were sampled. All water quality data collected from these streams can be found in Appendix A. These streams are classified as having *Habitat Limited Aquatic Communities* due to the lack of flow during dry periods.

Dissolved Oxygen

Dissolved oxygen (DO) in Fajt Creek (a tributary to Washington Creek) ranged from 2.5-13.4 mg/L and had a mean of 8.1 mg/L (n=30). During the study period, Oklahoma's Water Quality Standard for dissolved oxygen was violated once (August 1, 1991) in Fajt Creek. Dissolved oxygen concentrations in Washington Creek, which ranged from 5.1-12.3 mg/L with a mean of 8.7 mg/L (n=29), were in compliance throughout the study. Whitefield Creek dissolved oxygen ranged from 1.5-10.9 mg/L and had a mean concentration of 6.9 mg/L (n=21). Six DO violations occurred in Whitefield Creek during the study period. The cause of the high number of dissolved oxygen violations in Whitefield Creek should be investigated further. It is likely that during periods of stagnation, high productivity leads to dissolved oxygen deficits during the night and early morning hours. Mean dissolved oxygen content ranks Washington Creek as the best and Whitefield Creek as the worst. It is likely that this ranking is due to the fact that Washington Creek maintains a more continuous flow compared to Fajt and Whitefield Creeks.

pH

The pH averaged 7.8 in Fajt Creek, 7.9 in Washington Creek, and 7.7 in Whitefield Creek, all of which are within Oklahoma's Water Quality Standards (6.5-9.0).

Conductivity

From mean conductivity, TDS was calculated as 277.2 mg/L for Fajt Creek, 366.3 mg/L for Washington Creek, and 406.6 mg/L for Whitefield Creek. Varying conductivities, ranging from 136 to 851 uS/cm in Fajt Creek, 202 to 939 uS/cm in Washington Creek, and 128 to 1110 uS/cm in Whitefield Creek, were observed during the study. TDS calculated from conductivity ranks Fajt Creek as the best, and Whitefield Creek as the worst.

TDS (Total Residue Solids)

Total dissolved solids (TDS) in Fajt Creek ranged from 166 to 786 mg/L averaging 344 mg/L (n=40). TDS in Washington Creek ranged from 203 to 4070 mg/L and averaged 675 mg/L. TDS in Whitefield Creek ranged from 189 to 921 mg/L averaging 450 mg/L. The mean TDS values are quite different from those calculated from the mean conductivities. The high TDS values generally correspond with high flow events. The TDS values were generally below the recommended limit (500 mg/L) of the 1972 FWPCA Drinking Water Standards, however, during high flow events, the TDS content exceeded this standard considerably. Mean TDS ranks Fajt Creek as the best and Washington Creek as the worst.

TSS (Suspended Residue Total)

Total suspended solids (TSS) in Fajt Creek ranged from <1 to 452 mg/L and averaged 61 mg/L (n=40). TSS in Washington Creek ranged from <1 to 3360 averaging 278 mg/L (n=39). TSS in Whitefield Creek ranged from 4 to 688 mg/L and averaged 90.8 mg/L (n=31). High flow generally corresponds with high TSS concentrations. TSS ranks Fajt Creek as the best and Washington Creek as worst.

Turbidity

Turbidity ranged from 6 to 240 NTU in Fajt Creek and averaged 50 NTU (n=37). In Washington Creek, turbidity ranged from 3.6 to 730 NTU averaging 112 NTU (n=35). Turbidity ranged from 13 to 200 NTU in Whitefield Creek and averaged 87.8 NTU (n=26). The mean turbidities of all these streams exceeded Oklahoma's Water Quality Standard of 50 NTU. Mean turbidity ranks Fajt Creek as the best and Washington Creek as the worst.

Alkalinity and Hardness

Alkalinity averaged 238 mg/L $CaCO_3$ in Fajt Creek, 275 mg/L $CaCO_3$ in Washington Creek, and 331 mg/L $CaCO_3$ in Whitefield Creek. Hardness averaged 108 mg/L $CaCO_3$ in Fajt Creek, 137 mg/L $CaCO_3$ in Washington Creek, and 121 mg/L $CaCO_3$ in Whitefield Creek. The water of the tributaries is classified as hard water and has a high buffering capacity.

SO_4, Cl, and F

Dissolved sulfate (SO_4) concentrations averaged 7.1 mg/L in Fajt Creek, 40 mg/L in Washington Creek, and 9.6 mg/L in Whitefield Creek. These sulfate concentrations are not harmful.

Dissolved chloride (Cl) concentrations were insignificant averaging 9.9 mg/L in Fajt Creek, 20 mg/L in Washington Creek, and 31 mg/L in Whitefield Creek.

Dissolved fluoride (F) concentrations, which averaged 0.26 mg/L in Fajt Creek, 0.25 mg/L in Washington Creek, and 0.24 mg/L in Whitefield Creek, are not harmful.

Nutrients

Total nitrogen generally ranged from 0.2 mg/L to 1.9 mg/L in the three streams. The nitrogen concentration average 0.73 mg/L in Fajt Creek, 0.61 mg/L in Washington Creek, and 0.78 mg/L in Whitefield Creek.

Total phosphorous (TP) concentrations ranged from <0.01 to 0.31 mg/L in Fajt Creek, <0.01 to 0.4 mg/L in Washington Creek, and <0.01 to 0.29 mg/L in Whitefield Creek. The mean TP was 0.063 mg/L in Fajt Creek, 0.070 mg/L in Washington Creek, and 0.082 mg/L in Whitefield Creek. The concentration of 0.05 mg/L in tributary streams is generally considered to cause eutrophication in lakes. EPA recommends that phosphorous concentrations should not exceed 0.025 mg/L in streams flowing into lakes.

Pesticides

Pesticides were generally below detection limit, however, on December 9, 1992 diazinon was found at a concentration of 0.01 ug/L in all three streams. The occurance of diazinon in December possibly indicates that higher concentrations were present in the water when it was applied in the spring and early summer. 2,4-D (0.01 ug/L) was also found in Washington Creek on December 9, 1992. No standards exist for these compounds at this time.

Metals

Metals were measured on December 12, 1991 and May 9, 1991 in Fajt and Whitefield Creek, and on May 9, 1991 alone in Washington Creek. Mean metal concentrations can be seen in Table 15. All metal concentrations comply with Oklahoma's Water Quality Standards for *Public and Private Water Supplies*. All metal concentrations also comply with Oklahoma's Water Quality Standards for *Fish and Wildlife Propagation*, with the exception of copper (Cu) and lead (Pb). Copper concentrations in Fajt and Washington Creeks were present at levels considered both acutely (>17.3 ug/L) and chronicly toxic (>11.7 ug/L) by Oklahoma's Water Quality Standards. Lead (Pb) concentrations in all three streams were also present at levels considered chronicly toxic (>2.8 ug/L) by Oklahoma's Water Quality Standards. The Standards are for total metals even though strong evidence indicates that only a fraction of the total concentration is toxic. Because these samples represent high flow events, it is likely that copper and lead concentrations did not remain elevated long enough for acute or chronic toxicities to be observed. However, more samples are needed to support this. It is possible that the sources of the Cu and Pb are natural. There are deposits of copper, uranium, and lead in the part of the red beds that run through Pauls Valley. At any rate, the sources should be identified and remediated if possible.

Table 15. Mean Metal Concentrations in the Pauls Valley Lake Tributaries.

METAL	FAJT CR	WASHINGTON CR	WHITEFIELD CR
Zn (ug/L)	60	80	30
Se (ug/L)	<1	<1	<1
Ni (ug/L)	6	22	5.5
Hg (ug/L)	<0.1	<0.1	<0.1
Mn (ug/L)	490	1700	477
Pb (ug/L)	8.5	28	4
Fe (ug/L)	4300	12000	3650
Cu (ug/L)	19	25	4
Cr (ug/L)	4.5	14	4.5
Cd (ug/L)	<1	1	<1
Ba (ug/L)	300	900	200
As (ug/L)	<1	1	<1
Ca (mg/L)	18.3	32	19.7
Mg (mg/L)	7.1	15	6.9
Na (mg/L)	11.7	17.5	16.4
K (mg/L)	4.4	4.3	4.9

Fecal Coliform Bacteria

Fecal coliform bacteria were sampled in the three tributaries (Washington Creek, Whitefield Creek, and Fajt Creek) between May and September 1991 (Appendix C). High fecal coliform bacteria values were observed in the tributaries. Washington Creek had the highest values ranging from 140 to 7800 cfu/100ml and averaging 1264 cfu/100ml. Whitefield Creek had the second highest values ranging from 0 to 1600 cfu/100ml and averaging 540 cfu/100ml. Fajt Creek had the lowest values of the three tributaries ranging from 0 to 860 cfu/100ml and averaging 267 cfu/100ml. All three tributaries exceed Oklahoma's Water Quality Standard for *Primary Body Contact*. However, they do not exceed the standard for *Drinking Water*. The source of these high values should be investigated further. It is probable that these high fecal coliform bacteria values are caused by animal waste and/or leaking septic systems.

Quality Assurance Summary

All QA data collected during the Phase III Clean Lakes study on Pauls Valley Lake is listed in Appendix G. The QA for the study consisted of the analysis of blanks, duplicates and spikes.

Blanks were analyzed for sulfate, nitrate, total kjeldahl nitrogen, total phosphorous, and chloride eight times during the study. Nitrate and total kjeldahl nitrogen were below their detection in all blanks. Sulfate and total phosphorous were below detection limit in all samples except one. On June 16, 1992, sulfate was found in the blank for the Whitefield Creek Arm of Pauls Valley Lake at a concentration of 6.48 mg/L. On June 4, 1992, phosphorous was found in the blank for Whitefield Creek at a concentration of 0.020 mg/L. Chloride was found in all blanks. The mean blank chloride concentration was 2.8 mg/L (sd = 3.4). The detection limits are 0.025 mg/L for nitrate, 0.100 mg/L for total nitrogen, 0.005 mg/L for total phosphorous, and 2.5 mg/L for sulfate.

Duplicate samples were analyzed for nitrate, total kjeldahl nitrogen, total phosphorous, sulfate, chloride, and hardness. The percent difference between the duplicates was then determined. The mean percent differences between the duplicates were 6% for nitrate (sd=16; n=29), 15% for total nitrogen (sd=20; n=30), 34% for total phosphorous (sd=40; n=30), 22% for sulfate (sd=50; n=29), 4% for chloride (sd=5; n=27), and 0.5% for hardness (n=1). The high variability of total phosphorous is expected at the low concentrations observed.

The percent recovery was determined by dividing the observed by the expected concentrations of spiked samples. The mean percent recoveries were 100% for nitrate (sd=30; n=24), 105% for total nitrogen (sd=10; n=23), 99% for total phosphorous (sd=21; n=23), 122% for sulfate (sd=53, n=20), and 100% for chloride (sd=34; n=22).

With the exception of a few samples, all QA analysis indicates that the data is of sufficient quality. Blanks were generally below detection limit, except for chloride which, in most cases, was insignificant compared to the concentrations found in the samples. The duplicate percent differences, although highly variable, indicated that the data is fairly precise. Lastly, the percent recoveries averaged around 100% indicating that the data is accurate and within the acceptance criteria specified in the QA Project Plan.

Impact of Phase II Restoration Activities on Biological Resources

No biological monitoring was conducted during the pre-restoration study, therefore, no comparisons can be made between the pre- and post-restoration biological communities.

However, it is probably safe to say that the restoration activities have been beneficial to the biological resources. The retention structures provide good habitat for waterfowl and a nursery for fish. In addition, the increased clarity should bring about increased productivity in the lake. Increased clarity promotes increased growth of plankton and other plants which provide food for the food chain. The increased clarity has been responsible for the successful establishment of macrophytes in the lake. The benthic and fish communities are healthy indicating a positive biological impact.

Comparison To Other Lakes

Comparisons to other lakes have already been made in the previous **Fish** section and the **Benthic**

Macroinvertebrate section. Another recent study evaluated the trophic status (based on Carlson's TSI-chlorophyll) and turbidity of 100 small lakes in Oklahoma (OCC, 1994). Pauls Valley Lake ranked 45th for TSI-chlorophyll and was classified as mesotrophic for FY 1993. The lake ranked 30th for mean turbidity for FY 1993 and was compliant with Oklahoma's Water Quality Standard for turbidity. All comparisons of Pauls Valley Lake to other lakes of comparable size indicate that it is in good condition.

CONCLUSIONS

Data collected from Pauls Valley Lake over the past 15 years reflect dramatic differences in water quality since Phase II implementation, 1981-84. Decreased turbidity, increased transparency, and decreased sedimentation testify to the remarkable efficiency and effectiveness of efforts undertaken by the City of Pauls Valley, the Garvin County Conservation District, the U.S.D.A. Soil Conservation Service, and the Oklahoma Conservation Commission.

Several improvements have been made to this reservoir which local users and managers deem desirable. Obvious improvements to the local economy included increased fee collection from anglers and boaters and decreased water treatment costs (maintenance and operation: $118,143 in 1976; $81,612 in 1981). Increased stability of storage in the reservoir occurred because of a slower and more constant delivery of water due to the control of discharge from flood control and sediment retention structures. This benefits the local population because the consistently full reservoir eliminated the need to ration water during periods of drought and low flow. Other improvements realized by land managers in the watershed included increased flood and erosion control which ultimately resulted in increased top soil retention. Throughout the Phase II and Phase III activities (1981-93), land use trends shifted from intense agriculture to rangeland/improved pasture. This certainly resulted in decreased sediment loading into Washington Creek and its tributaries.

This project was also a subject of analysis by newer technologies being developed to increase the scope of environmental assessment and reduce overall costs. The use of LANDSAT imagery and Cs-137 dating at Pauls Valley Lake made it possible to analyze water transparency and sedimentation rates during a period for which no raw data were available. These technologies improve environmental investigation by providing the tools with which to quantify conditions at a time and place at which nothing is known. This was valuable here, as there were many periods of unavailable data which these technologies were able to address.

Even though sedimentation has been greatly reduced by limiting the input of fine clays into the inflows, this lake is a product of its watershed and should not be expected to demonstrate a high degree of clarity throughout the year. Pauls Valley Lake Dam is oriented east to west and creates a long and narrow impoundment which runs northwest to southeast from the uppermost Washington Creek arm to the spillway. The main body is vulnerable to the predominant north and south winds which effectively mix this relatively shallow reservoir. This resuspends deposited sediments, including fine clays, throughout much of the year.

Presently this reservoir is experiencing optimum conditions which allow it to maintain a high degree of biological integrity. The overall water quality is above average when compared to similar lakes across the state of Oklahoma. Pesticides are generally undetectable in the lake, and metals are present in insignificant concentrations. This combination of good water quality and no toxics is reflected by the presence of diverse phytoplankton, zooplankton, benthic macroinvertebrate, and fish communities. Carlson's TSI-TP classifies Pauls Valley Lake as eutrophic, while, Carlson's TSI-chlorophyll classifies the lake as mesotrophic. This is likely due to turbidity suppressing planktonic productivity by limiting light and phosphorous binding to clays making it unavailable to phytoplankton. Because of this, Pauls Valley Lake should be classified as argillotrophic. In addition, macrophytes may be utilizing available nutrients in the lake to the extent that algal productivity is displaced. The dense stands of water milfoil (Myriophyllum sp.) serve the heterotrophic community as cover and provide a comfortable environment during hot weather. Water milfoil also provides a filter for fine particulate matter (clays) entering the lake from inflows. Although some macrophytes inhibit zooplankton, it does not appear to negatively effect planktivorous fish populations at Pauls Valley Lake which depend upon zooplankton success.

The tributaries, in contrast, experience several problems, generally related to their sporadic flows. Dissolved oxygen violations occurred in Fajt Creek and Whitefield Creek which are most likely due to stagnation and high productivity. Conductivity, total dissolved solids, total suspended solids, and turbidity are highly variable and likely dependent on flow. Generally, Fajt Creek ranked the best and Washington Creek ranked the worst for the above parameters. Nutrients were present in the tributaries at levels known to cause eutrophication in lakes. Metals (copper and lead) were present at levels which could possibly be toxic. And lastly, fecal coliform bacteria were present at high levels, some of which exceeded Water Quality Standards. The sources of the metals and fecal coliform bacteria should be located and remediated. Additional sediment retention structures would also be beneficial to control highly erodible areas of the watershed as funds become available. The overall water quality is good, and restoration activities have had a positive impact on the biota. Overall, Phase II implementations have provided an additional lease on life (46 years) for this reservoir and immeasurable benefits to land management in the watershed.

REFERENCES

Brune, G.M. 1953. Trap efficiency of reservoirs. Transactions American Geophysical Union. 34(3):407-417.

Carlson, R.E. 1991. Expanding the trophic state concept to identify non-nutrient limited lakes and reservoirs. Enhancing the States' Lake Management Programs, 1991. pg. 59-71.

DeCoursey, D.G. and W.M. Snyder. 1969. Computer-oriented method of optimizing hydrologic model parameters. Journal of Hydrology. 9:34-56.

Hassell, J. and W. Cooter. 1985. A Trial Use of LANDSAT Imagery to Assess Changes in Turbidity on the Pauls Valley Lake: Addendum to the Final Report for the Pauls Valley Phase III Clean Lakes Project. Oklahoma Conservation Commission.

Integrated Risk Information System (IRIS). 1994.

Jester, D.B., A.A. Echelle, W.J. Matthews, J. Pigg, C.M. Scott, and K.D. Collins. 1992. The Fishes of Oklahoma, Their, Gross Habitats, and Their Tolerance of Degradation in Water Quality and Habitat. Proceedings from the Oklahoma Academy of Sciences. 72:7-19.

Larsen, R.J. 1984. Worldwide deposition of Sr-90 through 1983. Environmental Measurements Laboratory. U.S. Department of Energy Report EML-430, p. 168.

Masters, A.E. 1992. Reservoir Vital Signs Monitoring-1991: Benthic Macroinvertebrate Community Results. Tennessee Valley Authority. Water Resources Division.

McHenry, J.R., J.C. Ritchie, and C.M. Cooper. 1980. Rates of recent sedimentation in Lake Pepin. Water Resources Bulletin. 6:1049-1056.

Oklahoma Water Resources Board (OWRB). 1990. Oklahoma Water Atlas. Publication 135. pp. 363.

Oklahoma Water Resources Board (OWRB). 1991. Oklahoma's Water Quality Standards 1991. pp. 87.

Robinove, C.J. 1982. Computation of physical values for LANDSAT digital data. Photogrammetric Engineering and Remote Sensing. 48:781-784.

Schiebe, F.R., J.A. Harrington, Jr., and J.C. Ritchie. 1992. Remote Sensing of suspended sediments: the Lake Chicot, Arkansas project. Int. J. Remote Sensing. 13:1487-1509.

Scott, E.M. 1992. TVA Reservoir Monitoring Program Fish Community Results-

1991. Tennessee Valley Authority. Water Resources Division.

U.S. Department of Agriculture. 1985. Soil Survey of Garvin County Oklahoma. USDA SCS. U.S. Government Printing Office: 1985 0-440-946 QC3.

U.S. Department of Agriculture (USDA). 1991. Water Quality Indicators Guide: Surface Waters. Soil Conservation Service. SCS-TP-161. pp. 129.

Wetzel, R.G. 1983. Limnology Second Edition. pp. 760.