Biological Assessment of Existing TMDL Streams

Kansas Biological Survey Report No. 136

December 2005

by

Donald G. Huggins
Niang Choo Lim

Central Plains Center for BioAssessment
Kansas Biological Survey
University of Kansas

for

Kansas Department of Health and Environment

Prepared in fulfillment of KDHE Contract 2004-TMDL4

Introduction

The semi-annual report for this project, which was submitted to the Kansas Department of Health and Environment (KDHE) in December 2004, summarized field activities from July to November 2004. The report presented general water-quality conditions and the diurnal dissolved oxygen (DO) profiles in Washington, Turkey, Bluff, Little Cow, and Cow Creeks, all of which are Total Maximum Daily Load (TMDL) DO-impaired streams in Kansas.

This final report is the elaboration of the semi-annual report and aims to further assess DO flux in these streams using the Production Calculator program and to provide a summary on the literature review of impacts of elevated salinity and selenium on High Plains streams in western Kansas.

Methodology

Field sampling started in late July and continued through mid-November 2004. Our stream monitoring sites were co-located at the KDHE monitoring sites specified in TMDLs (Figure 1) so that direct temporal comparisons can be made between previous and current water-quality conditions. All streams were sampled five times during the field season. On the first trip, a calibrated DO logger was deployed in each stream and was set to record both DO and water temperature at 10-minute interval. During each site visit the DO logger was retrieved and the data were uploaded to a laptop computer. The logger was then inspected and cleaned during the data retrieval process. If the current logger was found to be still functional and producing DO values in agreement with the field DO measurement, the logger was left in place. If a logger was determined to be "out of calibration" then it was replaced with a recently calibrated logger from our laboratory. At the logger installation site, DO, temperature, specific conductance, salinity, pH, and turbidity were measured *in situ* using a Horiba U-10 Water Quality Checker. The stream flow was measured using the Swoffer Model 2100 Velocity Meter. Five periphyton samples were taken from the dominant substrate type. In addition, a 1-liter grab sample of stream water was collected and transported on ice in a cooler to the Kansas Biological Survey (KBS) Ecotoxicology Laboratory for water chemistry analyses. Collected water samples were analyzed for nutrients (total and organic nitrogen and phosphorus, nitrate, nitrite, ammonia, and orthophosphate), total organic carbon (TOC), and chlorophyll *a*. Four sediment samples were collected within 20 m of the DO logger installation site using a hand-operated core sampler. These sediment samples were then composited into a single sample for potential sediment oxygen demand (pSOD) measurement. A summary of water-quality parameters, analytical methods, and detection limits associated with parameters measured in this project is provided in Table 1.

Results and Discussion

The study design for this project was based upon the assumption that the warmer water temperatures and low-flow conditions associated with summer and early fall would most likely produce low-oxygen periods due to increased biological activities and low flushing capacities during this time. However, it had been a relatively wet and mild year with respect to summer weather in 2004. The monthly precipitation in June and July were 7.0 and 6.9 inches, respectively (Figure 2). The summer precipitation (June-August) was 16.1 inches, which is the highest summer rainfall since 1999. The average temperatures in July and August 2004 were 77.3 and 75.4 °F, respectively. These temperatures were somewhat lower than the 1999-2003 average temperatures for July (83.0 °F) and August (82.6 °F).

Washington Creek in Douglas County

Water-quality data collected in August, October, and December of 1995 at KDHE's monitoring station 678 near Lawrence, Kansas, indicated the violation of the Kansas DO standard (5 mg/L) at Washington Creek. DO excursions appear to coincide with low-flow conditions. The desired endpoint at station 678 is to have biochemical oxygen demand (BOD) of less than 3.1 mg/L, which may result in DO levels of above 5 mg/L, especially during low-flow conditions that are common from late summer to early winter.

In this study, water-quality data were collected at five separate times at the same monitoring site as KDHE. During the five field measurements, DO concentrations were above 5 mg/L with an average of 6.7 ± 0.3 mg/L.

Date (2004)	July 29 10:30 a.m.	August 5 11:00 a.m.	September 2 2:20 p.m.	September 29 2:32 p.m.	November 8 2:50 p.m.
DO (mg/L)	6.75	6.41	6.36	6.98	6.84

On July 29, 2004, a DO logger was installed in the downstream portion of a very long pool with an estimated maximum depth of over six feet. However, due to a series of DO logger malfunctions and retrieval problems, all data prior to October 7 were lost. Figure 3 shows the diurnal DO and temperature fluctuations from October 7 to November 8. The DO concentrations were below 5 mg/L from October 24 to November 3, which was likely caused by heavy respiration from significant dead leaves in the fall. Nevertheless, the average daily DO concentration recorded by the DO logger between October 7 and November 7 was 5.1 mg/L.

Period	**Average Daily Max DO (mg/L)**	**Average Daily Min DO (mg/L)**	**Average Daily DO (mg/L)**
10/07/2004 – 11/07/2004	5.8	4.4	5.1

During the first three stream visits, water level was elevated and thus no periphyton samples could be taken. Average TP and TN were 103.52 ± 43.47 µg/L and 0.86 ± 0.32 mg/L, respectively (Figures 4 and 5). Average chlorophyll *a* concentration was 16.6 ± 16.0 µg/L (Figure 6) with an algal bloom observed in early September (41.8 µg/L). The warm weather, increased nutrients (TP = 173.24 µg/L and TN = 1.15 mg/L; highest concentrations recorded for this stream in this study), and stagnant water conditions could have promoted the algal growth. Average TOC concentration was 5.1 ± 1.8 mg/L (Figure 7).

Little Cow Creek in Rice County

Little Cow Creek near Lyons, Kansas had DO standard violations throughout the year based upon KDHE's 1992-1999 water-quality data. Low-flow conditions, high water temperatures, and nutrient/organic enrichment were listed by KDHE as the primary causes of the occasional DO problems. KBS collected water chemistry data for this stream as part of a previous TMDL stream assessment project (1999-2000) with KDHE. The average DO concentration estimated for the study was 3.49 mg/L based on three field-sampling events from July to November 1999.

The same stream site was re-visited in this study (Station 656; Figure 1) and the average DO concentration was 6.5 ± 0.8 mg/L for the five field visits in 2004.

Date (2004)	July 27 7:51 p.m.	August 18 1:37 p.m.	September 8 7:00 p.m.	October 12 7:20 p.m.	November 11 5:10 p.m.
DO (mg/L)	6.62	6.41	7.63	6.21	5.54

A DO logger was installed on July 27, 2004. Figure 8 shows the diurnal DO and temperature fluctuations from July 29 to November 11. Nighttime DO values were almost always found to be below 5 mg/L even into the cooler months of fall. In fact, the stream was nearly anaerobic from the end of October to early November probably due to heavy respiration from the accumulation of organic materials including dead leaves.

Period	**Average Daily Max DO (mg/L)**	**Average Daily Min DO (mg/L)**	**Average Daily DO (mg/L)**
07/29/2004 – 08/16/2004	7.8	4.8	6.1
08/19/2004 – 09/07/2004	7.4	4.1	5.5
09/09/2004 – 10/11/2004	6.4	3.9	5.0
10/14/2004 – 11/10/2004	5.1	3.6	4.3

Little Cow Creek was found to have high salinity and specific conductance. The average salinity and specific conductance were 0.08% and 1.88 mS/cm, respectively. These high values are associated with the high salt content in the water. The average chloride concentration was 318.81 mg/L during the 1999 field samplings.

Little Cow Creek continues to have high nutrient concentrations, especially phosphorus. In 1999, average TP and TN were 3309.82 ± 1509.33 μg/L and 11.74 ± 3.13 mg/L, respectively. In 2004, average TP was higher (4486.50 ± 1443.01 μg/L) whereas TN was 5.74 ± 1.38 mg/L. Approximately 60% of TP was in the dissolved form (PO_4^{3-}). This elevated nutrient concentration was attributed to the municipal wastewater discharge from Lyons, which is approximately 1.5 mile north of Little Cow Creek's sampling site. The design flow of the oxidation ditch is 0.55 MGD (million gallons per day). During the current study, water velocity and cross-sectional profiles were measured and stream discharges were calculated from these data. The average discharge rate was 0.16 MGD, suggesting that almost all flow from Little Cow Creek was from the sewage disposal. Thus, under low-flow periods, the water quality of this stream is very much dependent upon the water quality of the sewage discharge.

Despite the elevated nutrient levels, chlorophyll *a* concentrations were mostly below 5 μg/L but a relatively high chlorophyll *a* level was observed in mid-August (20.5 μg/L), which is due to warmer temperatures. Low chlorophyll *a* concentrations were also observed in 1999 (average is 7.7 ± 2.7 µg/L). This stream is well shaded upstream and at the sampling site and this may account for the limited algal production observed in this stream. The average TOC concentration was 10.5 ± 1.5 mg/L.

Cow Creek in Rice County

KBS also sampled Cow Creek in 1999 (Station 657; Figure 1) and found the average DO concentration to be 7.1 ± 1.1 mg/L. In this study, the five field DO measurements were always more than 5 mg/L.

Date (2004)	July 27 2:02 p.m.	August 18 12:15 p.m.	September 8 5:58 p.m.	October 12 7:02 p.m.	November 11 4:25 p.m.
DO (mg/L)	9.31	7.27	6.79	6.62	8.36

A DO logger was installed on July 27, 2004. Figure 9 shows the diurnal DO and temperature fluctuations from July 29 to November 11. In general, DO concentrations were higher and nutrient concentrations were lower than that of Little Cow Creek and these may have been related to the absence of municipal sewage effluent from the watershed as general land use is thought to be similar. In addition, there was more flow in Cow Creek that probably helped natural aeration and increased flushing of nutrients and organic materials. Similar to Washington and Little Cow Creeks, heavy respiration from leaf drop in the fall is thought to be a contributing cause of DO excursions at the end of October.

Period	**Average Daily Max DO (mg/L)**	**Average Daily Min DO (mg/L)**	**Average Daily DO (mg/L)**
07/29/2004 – 08/16/2004	7.0	6.3	6.6
08/19/2004 – 09/07/2004	7.1	5.7	6.3
09/09/2004 – 10/11/2004	6.2	5.2	5.6
10/14/2004 – 11/10/2004	6.6	5.6	6.1

Cow Creek also had high salinity (0.08%) and specific conductance (1.84 mS/cm). The average chloride concentration was also as high as Little Cow Creek’s (316.83 mg/L during the 1999 field samplings). Cow Creek and Little Cow Creek sampling sites were only half a mile apart. Hence, these two streams are under the same watershed influence and thus tend to have similar water chemistry.

Unlike Little Cow Creek, the average TP and TN of Cow Creek were 317.76 ± 28.79 µg/L and 1.03 ± 0.18 mg/L, respectively. This could be the background level of nutrients for Little Cow Creek without the influence of the sewage discharge. The nutrient levels in Cow Creek appear to have decreased since the average TP and TN concentrations in 1999 were 501.17 µg/L and 1.55 mg/L, respectively.

Although nutrient levels in Cow Creek were much lower than that of Little Cow Creek, the mean chlorophyll *a* concentration for this stream was much higher than that of

Little Cow Creek with values ranging from 4.3 μg/L in late fall to 65.4 μg/L during summer. The average TOC concentration was 8.6 ± 1.6 mg/L.

Turkey Creek in Harvey County

Turkey Creek near Alta Mills (Station 533; Figure 1) had low DO problems that are related to the presence of two NPDES permitted municipal wastewater dischargers and one industrial discharger within the watershed. KBS also sampled this stream in 1999 and found the average DO concentration was 4.1 ± 1.7 mg/L. DO concentrations were found to be less than 5 mg/L occasionally during the five field visits in 2004.

Date (2004)	July 28 12:03 p.m.	August 17 5:30 p.m.	September 8 3:27 p.m.	October 12 4:55 p.m.	November 11 2:40 p.m.
DO (mg/L)	6.56	4.95	5.25	4.72	4.69

DO loggers were installed between July 28 and November 11, 2004. However, due to DO logger malfunctions, data prior to September 8 were lost. Figure 10 shows the diurnal DO and temperature fluctuations from September 8 to November 11. These data indicate that DO values associated with Turkey Creek were seldom above 5 mg/L even during late afternoon when DO levels related to photosynthesis should be the greatest. Nighttime DO lows were often at or below 3.0 mg/L during most of the period for which data are available.

Period	**Average Daily Max DO (mg/L)**	**Average Daily Min DO (mg/L)**	**Average Daily DO (mg/L)**
09/09/2004 – 10/11/2004	3.8	2.1	2.8
10/14/2004 – 11/10/2004	3.4	2.4	2.8

On the first stream visit, the water level in Turkey Creek was elevated due to recent high rainfall and flood conditions. Under normal flow conditions, the mean stream flow was estimated to be 1.15 ± 0.22 MGD while the sum of design flows of the wastewater and industrial dischargers were 3.06 MGD. Based on this estimate, it appears that much of the stream flow is related to point source discharges and thus stream water quality would be greatly influenced by the effluent quantity and quality. This stream also had high specific conductance (1.23 ± 0.68 mS/cm) and salinity values (0.05 ± 0.03%). The average chloride concentration was 647.15 ± 413.15 mg/L during the 1999 field samplings.

Turkey Creek had an average water turbidity of 230 ± 109 NTU and was the most turbid stream in this study. These high turbidity measurements were, in part, associated with the frequent flooding and runoff events that were common during the study period. These high water events may also have resulted in scouring that reduced algal biomass. This may explain why Turkey Creek had the lowest average benthic chlorophyll *a* concentration (2.8 ± 2.4 mg/m^2) among all streams in this study (Figure 11).

Turkey Creek had average TP and TN of 538.60 ± 207.98 μg/L and 1.15 ± 0.26 mg/L, respectively. TP concentration increased from 516.11 μg/L in mid-October to

862.90 µg/L in mid-November. Sestonic chlorophyll *a* concentrations ranged from 1.5 to 28.6 µg/L and the average was 13.4 ± 11.9 µg/L. The average TOC concentration was 11.5 ± 2.4 mg/L.

Bluff Creek in Sumner County

Bluff Creek was documented by KDHE to have DO problems based upon intermittent data between 1990-1999. Low DO excursions were observed at the sampling station (Station 530; Figure 1) near Caldwell under low-flow conditions in warmer months. The NPDES-permitted wastewater treatment facility in Anthony discharges very low levels of BOD to Spring Creek, a tributary of Bluff Creek.

The mean DO value calculated from the five field measurements was 7.6 ± 1.8 mg/L. DO loggers were installed between July 28 and November 16, 2004. However, DO logger malfunctions and placement of the DO probe within the stream bottom sediment limited diurnal DO data collection. Figure 12 shows the diurnal DO fluctuations between October 14 and October 26. DO never dropped below 5 mg/L even during the nighttime periods.

Date (2004)	July 28 3:00 p.m.	August 17 1:30 p.m.	September 8 12:25 p.m.	October 12 1:53 p.m.	November 16 11:20 a.m.
DO (mg/L)	5.22	6.70	7.56	8.38	9.94

Period	**Average Daily Max DO (mg/L)**	**Average Daily Min DO (mg/L)**	**Average Daily DO (mg/L)**
10/14/2004 – 10/25/2004	10.4	8.0	9.0

Unlike other streams in this study, Bluff Creek is relatively large and deep with a stream width often greater than 25 m. In addition, stream depths in the study area were always greater than 1.5 m making mid-stream velocity measurements impossible to be collected using our hand-held velocity meter. The average TP and TN were 210.40 ± 44.15 µg/L and 1.27 ± 0.67 mg/L, respectively. Chlorophyll *a* concentrations ranged from 1.4 to 9.9 µg/L. The average TOC concentration was 4.7 ± 0.8 mg/L.

Potential Sediment Oxygen Demand (pSOD)

Washington Creek has stable and firm silty-clay bottom sediment with little woody debris. Little Cow, Cow, and Turkey Creeks are full of woody debris and have sandy loam bottom whereas Bluff Creek has reddish brown silt loam bottom, a typical type of Oklahoma soil that has lots of iron in it (Bluff Creek sampling site is about 2 miles from the Kansas-Oklahoma state line).

Sediment samples were collected three times during the field season. At each site, four sediment samples were collected using a core sampler and these samples were then composited into a single sample for pSOD analysis (Matlock *et al*. 2003). PSOD was conducted within three days after the sample collection. The top 5 cm of sediment was used in pSOD analysis in this study. During the experiment, the sediment was intentionally suspended to remove oxygen diffusion limitation and thus this allowed oxygen to be consumed at a maximum rate much like it would be in a resuspension event in the stream. For the first 15 minutes, DO reading was recorded at 1-minute interval. PSOD is temperature-dependent and was conducted at 20 ^{o}C as this is the temperature found to be technically easier to deal with. At higher temperatures, the initial oxygen consumption rate is so fast that DO reading is hard to be recorded.

Figures 13-17 show the pSOD plots of the five streams. The initial rate of oxygen consumption is determined to be pSOD, which is generally not realized in a stream because sediment is usually oxygen-diffusion limited. Although Washington Creek had the highest average pSOD compared with other studied streams, oxygen consumption by sediment may not be as severe in reality because it has relatively firm and stable riverbed, i.e., oxygen diffusion is limited under normal flow conditions and sediment suspension may not be as significant during high-flow periods. SOD is a concern in Turkey, Little Cow, and Cow Creeks because these streams had relatively soft sediment. In addition, there was lots of woody debris in these streams that exerted additional oxygen demand in the water column.

Stream Name	**Average pSOD (kg O_2/m^3 sediment/day)**
Washington Creek	1590 ± 949
Turkey Creek	656 ± 109
Little Cow Creek	562 ± 434
Bluff Creek	499 ± 72
Cow Creek	243 ± 236

Measurement and Assessment of Community Productivity

A software program was developed in Microsoft Excel format by Central Plains Center for BioAssessment to calculate the gross primary production, net primary production, and respiration from the data obtained from the DO loggers. This program (The Production Calculator v. 1.5) estimates primary production and community respiration from diurnal dissolved oxygen and stream temperature measurements taken from the logger and other stream data collected upstream from the deployment site of the logger. The estimates of gross primary production and community respiration computed by the Production Calculator are calculated from diel oxygen and temperature data curves following the widely used and generally accepted method first proposed by Odum (1956). According to Odum, the rate of change of dissolved oxygen (Q) is affected by four main factors that include the rate of gross primary production (P), the rate of community respiration (R), the rate of oxygen diffusion (D), and the rate of drainage accrual (A). The majority of studies conducted on estimates of production derived from diel oxygen data follow the method set forth by Odum (1956).

The rate of change of dissolved oxygen can be determined by subtracting both the rate of community respiration (R) and the rate of oxygen diffusion (D) from the rate of gross primary production (P) plus the rate of drainage accrual (A).

$$Q = P - R - D + A \tag{1}$$

The fluctuation of dissolved oxygen levels in the stream due to drainage accrual is assumed negligible relative to the other factors, but as a precaution, monitoring days in which dissolved oxygen readings could have been impacted by runoff should be removed from the deployment period dataset. While we assume that groundwater accrual is zero this may not be true for all streams and potential groundwater contributions may have to be examined. Elimination of drainage accrual reduces Equation 1 to Equation 2, the basic equation used to compute gross production.

$$Q = P - R - D \tag{2}$$

There are several other factors that also affect the concentration of dissolved oxygen in streams and must be examined in order to provide more accurate estimates of production. These factors are reaeration, temperature, salinity, and pressure.

Reaeration of streams is primarily the result of two phenomena: entrainment of oxygen due to turbulent flow and the replacement of oxygen due to a deficit from saturation caused by the combustion of organic matter. Reaeration was originally defined in the Streeter-Phelps (1925) equation as the reoxygenation (k_2) of streams. Today it is largely understood that the effects of the hydraulic properties of water (i.e., turbulent flow) are expressed as the coefficient of reaeration, k_2 (Langbein and Durum 1967). The calculator uses a number of reaeration coefficients that can be selected for use in estimating individual stream reaeration. The choice of coefficients is governed by specific stream characteristics that include mean velocity, depth, and width.

The single most important factor regulating the concentration of dissolved oxygen in water is temperature (Horne and Goldman 1994). The concentration of oxygen in water is inversely proportionally to water temperature. Cold waters contain higher oxygen concentrations than the same volume of warm water at a given pressure. Water temperature measurements are obtain concurrently with the DO measurements collected by the logger for each time interval that is specified by the logger user.

Changes in barometric pressure alter the concentration of dissolved oxygen, since all gases are more soluble at higher pressures. This same principle is directly applicable to increases in altitude. In these instances where pressures are less due to increased altitude, concentrations of dissolved oxygen are reduced. Altitude is used as a surrogate for barometric pressure and is obtained from topographic maps or GPS readings taken at each stream site.

Salinity has a minor effect on dissolved oxygen concentrations in fresh waters when compared to the other constituents. Increases in dissolved salts reduce the intermolecular space with in the water molecules available to oxygen. Salinities must be high for increases in salt concentrations to affect dissolved oxygen concentrations. Conductivity was used in the calculator as an alternative input variable to salinity, because of its relationship to salinity and greater commonality of measure.

Table 2 shows the simulation results of the Production Calculator. Due to series of DO logger malfunctions between July and November 2004, Turkey Creek had two sets of data whereas Washington Creek and Bluff Creek only had a set of data. The ratio of gross production to respiration (P/R ratio) can be used to characterize the overall functional nature of a stream and other aquatic ecosystems. If P/R is more than one, the stream system is autotrophic dominated whereas if P/R is less than one, the stream system is heterotrophic in nature and is probably dominated by bacterial processes. Studied streams were mostly heterotrophic and little if any net production is produced by these stream systems. Based on the limited DO flux data for Bluff Creek, our calculations show that this stream has rather different P and R values. It is speculated that these differences may be related to this stream's different sediment characteristics and its size, which is at least doubled that of other streams in this study.

Figure 18 and Table 3 show the correlation results of various variables measured in this study. PSOD, P/R ratio, and TP appear to show some correlations with DO variables. In general, even "good" relationships have low correlation coefficients ($r > 0.50$) and are taken as significant if their p values are below an alpha of 0.10. As would be expected, the higher the pSOD, the lower the DO level in the water column, as seen in negative correlations between pSOD and DO variables despite p values are higher than 0.05 (they are 0.09 and 0.08) between pSOD and min and mean DO ($r > 0.55$). It is intuitive that the higher the DO level, the higher the P/R ratio as a high P/R value implies that the stream system is autotrophic driven and a portion of the stream DO is generated from photosynthetic processes. By inspection, pSOD and R appear to have a positive relationship although p value is 0.084 (Figure 19). However, since Bluff Creek is rather different from other studied streams in terms of stream size and sediment characteristics, the same correlation is generated without it and the relationship is found to be significant ($p < 0.05$). Another important but somewhat weak relationship is thought to exist between TP and min DO (Table 3). It appears that as TP values increase, minimum daily DO values for streams are decreased ($r = -0.55$, $p = 0.067$). This relationship between TP and stream DO values has been seen in other larger regional stream datasets. In other words, reducing TP load may help increase critical minimum evening DO levels in small streams.

Conclusions

All studied streams were determined to be heterotrophic based upon their P/R values that were always less than one. Turkey, Little Cow, Washington, and Cow Creeks (in the order of decreasing severeness of Kansas DO standard violation) were observed to have occasional DO excursions. The DO violation often occurred during nighttime and during fall after leaf drop that may have contributed to high community respiration. Correlation results show the negative relationship between pSOD and DO level and reducing phosphorus load in the watershed may help improve DO conditions in these streams. Bluff Creek was not observed to have low DO values but the small data set for this stream limits our extrapolation of this result to other warmer period of the year. 2004 was a wet and somewhat cooler year since 1999. This unusual weather might have helped promote aeration in these streams and thus DO problems could be more severe in dryer years, especially for Little Cow Creek and Turkey Creek, which are under the influence of point sources. Thus, additional water-quality monitoring in subsequent years may be necessary to better characterize the water quality of these streams under different hydrologic conditions.

Literature Review on Salinity and Selenium Impacts on High Plains Streams

In addition to the assessment of DO conditions of studied streams, the second part of this project is to perform a literature review on salinity and selenium impacts on aquatic biota inhabiting High Plains streams in western Kansas.

There are twelve major river basins in Kansas and each of the river basins has its own TMDL developed by KDHE to meet the federal requirements under the Section 303(d) of the Clean Water Act (CWA). The Arkansas and Solomon River basins in particular have salinity and selenium impairments.

During the past twenty years, limited studies related to salinity and selenium impacts on High Plains streams in western Kansas were performed. Nevertheless, KBS is currently assessing selenium levels in water, biota, and sediment of the Arkansas River in southwestern Kansas under a separate one-year project funded by KDHE (Contract 2005-TMDL4).

Salinity and Selenium

Salinity characterizes the amount of dissolved salts in water. Calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), bicarbonate (HCO_3^{-}), sulfate (SO_4^{2-}), and chloride (Cl^{-}) are common naturally occurring salts in water. Saline water has high amount of dissolved salts (>1000 ppm) and thus has limited usage.

Salinity problem is an important threat to water resources. It has significant social, economic, and environmental impacts. Decreased biodiversity, changes in the natural character of aquatic ecosystems, and lower productivity are common ecological effects.

Selenium (Se) is a natural nonmetallic trace element that can be found throughout the environment. Selenium has four oxidation states (-2, 0, +4, +6) and the two major inorganic forms of dissolved selenium normally observed in aquatic environment are selenate ion (SeO_4^{2-}) and selenite ion (SeO_3^{2-}). Human activities have increased the selenium level in waterbodies. High level of selenium in waterbodies has mostly been related to irrigation of western soils that are naturally high in selenium, disposal of ash produced by coal-fired power plants, petroleum refinery effluents, and runoff or discharges from certain mining activities. The massive poisoning of fish and wildlife at Kesterson National Wildlife Refuge, California in the early to mid-1980s was attributed to the high selenium content in irrigation drain water (Lemly 1997). Fish poisoning in Belews Lake, North Carolina, was caused by selenium contamination by the wastewater discharge from a coal-fired electric generating facility (Lemly 2002).

Selenium has become a constituent of interest throughout the United States since past few decades. Under Section 304(a) of the CWA, the Environmental Protection Agency (EPA) has to periodically revise water-quality criteria to accurately reflect the latest scientific knowledge on effects of pollutants. EPA has decided to revise the acute and chronic criteria for selenium because substantial selenium toxicity data become available since the aquatic life criteria for selenium was published in 1987. Due to the bioaccumulative property of selenium, fish-tissue based criterion has been proposed because fish tissue samples provide a better indicator of the presence of selenium in a particular waterbody. Fish move throughout a waterbody and contaminants such as selenium can be absorbed into their tissue. Thus, fish tissue effectively reflects the level and duration of a particular contaminant in a waterbody over time. According to the draft freshwater chronic criterion, if whole-body fish tissue samples exceed 5.85 µg/g dry weight (dw) during summer or fall, fish should be monitored during the winter to determine if selenium exceeds 7.91 µg/g dw. Nevertheless, the draft aquatic life criterion for selenium will not be finalized until EPA receives further broad scientific review.

Selenium is a bioaccumulative pollutant as some chemical forms of selenium can accumulate in plant and animal tissues. Except for hepatic tissues, all fish and wildlife tissues normally have selenium concentrations of less than 2 µg/g (United States Department of the Interior (DOI) 1998). Selenium can be toxic to aquatic life (e.g., fish and invertebrates) at excessive levels. It is also toxic to birds that consume aquatic organisms that contain high level of selenium. Aquatic life is exposed to selenium primarily through food consumption rather than from direct exposure to selenium in the water column because the selenium level in water is generally insignificant to cause toxicity effects. Bioaccumulation and biomagnification play important roles in causing toxicity in fish and wildlife. Biomagnification of selenium normally ranges from 2 to 6 times between the primary producers (algae and plants) and the lower consumers (invertebrates and forage fish) (Lemly 1997). Western soil is naturally high in selenium and the baseline concentration has been identified as 0.23 mg/kg (Whitmer 2000). Selenium concentration in sediment greater than 4 mg/kg dw can be a concern because there is a potential for bioaccumulation in fish and wildlife (Lemly and Smith 1987).

For aquatic life, excessive selenium intake can have negative impacts on the growth and survival of juvenile fish and can cause skeletal deformities. Selenium can also be toxic to humans who drink water or eat fish that contain excessive level of selenium. The maximum contaminant level (MCL) for selenium in drinking water is 0.05 ppm.

Arkansas River

The Arkansas River originates near Leadville, Colorado. It flows east and southeast through Colorado, Kansas, Oklahoma, and Arkansas. With river miles of 1450 and drainage area of approximately 195,000 square miles, it is the fourth longest river in the United States. It is also known to be one of the most saline rivers in the United States. Major cities on the Arkansas River include Wichita, KS, Tulsa, OK, and Little Rock, AR.

DOI (Mueller *et al*. 1991) and the Kansas Geological Survey (KGS) (Whittemore 2000, Whitmer 2000) performed extensive studies on the Arkansas River within the past decade. Mueller *et al*. 1991 assessed selenium levels in water, bottom sediment, and biota whereas KGS focused on general chemical constituents (salinity) in the river water.

Mueller et al. 1991

In the 1980s, DOI had increasing concern about the potential impacts of irrigation drainage on fish, wildlife, and human health. In October 1985, the "Task Group on Irrigation Drainage" was formed within the DOI to identify the nature and extent of irrigation induced water-quality problems that might exist in western states. The middle Arkansas River basin within southeastern Colorado and southwestern Kansas region was one of the twenty locations selected for investigations because elevated selenium levels, which were associated with irrigation drainage, had been observed at several sites on the Arkansas River and its tributaries. For instance, the median selenium concentration of 51 samples collected from the Arkansas River near Coolidge, Kansas between 1975 and 1987 was 19 μg/L.

Initiated by DOI, the reconnaissance investigation on the middle Arkansas River basin was conducted by scientists from the United States Geological Survey (USGS), United States Fish and Wildlife Service (FWS), and the United States Bureau of Reclamation in 1988. Sampling sites extended along the Arkansas River from near Pueblo, Colorado to near Garden City, Kansas, a distance of about 250 miles. Water, sediment, and biota samples were collected from 7 sites at the Arkansas River, 2 sites at tributary streams, and 5 reservoir sites. Ground water samples were collected from 5 municipal wells within the study region.

Selenium was the only trace constituent associated with irrigation drainage that was observed to be at elevated levels in water, bottom sediment, and biota within the middle Arkansas River basin. Selenium is usually associated with the clay content in rocks and so high concentration of selenium is often found in shales. Cretaceous marine shales and limestone are exposed extensively within the region. Thus, the main natural selenium source is runoff from the shales. Selenium becomes concentrated along the Arkansas River due to loss of water to evapotranspiration and leaching of selenium by irrigation.

Measured selenium concentrations in surface water (Arkansas River, its tributaries, and reservoirs) within the study area ranged from 1 to 52 μg/L. Selenium concentrations in Arkansas River near Coolidge and Deerfield, Kansas, in August 1988 were 9 and 10 μg/L, respectively.

Biota samples (birds, fish, invertebrates, and aquatic plants) were collected from reservoir sites in June and October 1988. Among all collected biota samples, bird liver had the highest selenium concentration. Killdeer, mallards, and American coots were three most collected bird species in the study. Killdeer generally had the highest selenium levels (9.9 to 42 μg/g dw), followed by mallards (9.7 to 24 μg/g dw) and American coots (12 to 15 μg/g dw). Selenium concentrations in these three species were generally lower at the downstream end of the study area. The highest individual and mean selenium concentrations in mallards and killdeer were observed in samples from

Pueblo Reservoir in Colorado whereas the highest selenium concentrations in American coots were observed in samples from Lake Meredith, an off-channel reservoir in Colorado. Nevertheless, the overall highest selenium concentration (56 µg/g dw) was observed in the liver of a black-necked stilt from Lake Meredith. Of the collected 70 liver samples from 9 bird species, 10 samples from adults of 4 species (5 samples were from killdeer) had selenium concentrations exceeding or equaling 30 µg/g dw, a concentration usually associated with biological risk. The frequency of bird liver samples with at least 20 µg Se/g dw was 26 of 41 in June and only 4 of 29 in October, suggesting that birds found within the study area tend to be more contaminated in the spring than in the fall, most likely because residency during breeding season results in a greater degree of contamination than does transiency in the fall. Selenium concentrations were greater in the livers of many birds in the study than in the livers of mallards in laboratory experiments in which abnormal numbers of embryos died (9.0 µg/g dw for females) or were deformed (16.2 µg/g dw for females). Selenium concentrations in whole juveniles, juvenile livers, nestlings, and eggs were generally lower than in adult livers. Selenium concentrations in eggs of three species were elevated (greater than 3 µg/g dw) but not enough to indicate reproductive impairment (greater than 20 µg/g dw). The average selenium concentration of whole nestlings of yellow-headed blackbirds from Lake Meredith was 16 µg/g dw, which is only slightly less than the 20 µg/g selenium criteria for reproductive impairment. The average selenium concentrations in killdeer livers from three of the five reservoir sites in this study exceeded the 30.9 µg/g average for coot livers from the Kesterson National Wildlife Refuge in California.

At stream sites, only fish and invertebrates were collected. Selenium concentrations in fish from stream sites were not consistently high or low relative to location. Five fish species (common carp, shiners, long-nosed sucker, long-nosed dace, white sucker) from the Arkansas River had selenium concentrations ranging from 2.1 to 18.5 µg/g dw. The maximum selenium concentration of 18.5 µg/g dw was found in a common carp sample from the Arkansas River site near Lamar, Colorado. Composite samples of common carp from the Arkansas River near Coolidge and Deerfield had selenium concentrations of 3.4 and 12.7 µg/g dw, respectively. The composite sample of shiners from the Arkansas River near Deerfield had selenium concentration of 7.8 µg/g dw. Three fish species (shiners, long-nosed sucker, long-nosed dace) from the tributaries had selenium concentrations ranging from 3.6 to 16.9 µg/g dw. Thirteen fish species collected from reservoir sites had selenium concentrations ranging from 2.2 to 20 µg/g dw. It was observed that selenium concentrations in fish collected from reservoir sites were positively correlated to selenium concentrations in the reservoir water. The maximum concentration of 20 µg/g dw was found in a composite sample of gizzard shad from John Martin Reservoir in Colorado. Forty-nine of the fifty-nine fish samples from stream and reservoir sites had selenium concentrations exceeding the 4 µg/g dw in the diet that has been proposed to protect birds. Fifty-two percent of the fish samples had selenium concentrations that equaled or exceeded the dietary selenium concentration (about 9 µg/g dw) determined to potentially harm the embryos of mallards. However, selenium contamination in fish was progressively greater downstream, whereas the reverse pattern was observed for birds. Selenium concentrations of collected invertebrates (crayfish and aquatic beetles) from the Arkansas River, tributaries, and reservoirs ranged from 2.7 to

8.7 µg/g dw. The collected crayfish from the Arkansas River near Coolidge had selenium level of 5.6 µg/g dw.

Aquatic plants were only collected at reservoir sites. The highest selenium concentration observed in plants was 14 µg/g dw in a filamentous algae sample collected from Lake Meredith. Seven of the eight collected aquatic plants (filamentous algae and pondweed) had selenium concentrations exceeding 4 µg/g dw, the recommended dietary level for breeding birds. In general, selenium concentrations in collected biota samples were highest in bird livers, followed by fish, young birds or eggs, aquatic plants, and invertebrates. No evidence of deformity or reproductive failure was observed in any bird or fish species in the study. Nevertheless, the study was not designed specifically to assess reproduction or to determine the extent of embryonic deformities.

Whittemore 2000 and Whitmer 2000

KGS assessed the water quality of the Arkansas River from 1995 to 2000. The total dissolved solids (TDS) in the river near the Colorado-Kansas state line exceeded 4,000 mg/L under low-flow conditions. The water was usually extremely hard. The major dissolved constituents, in the order of decreasing mass concentrations that normally occur, were sulfate, sodium, bicarbonate, calcium, magnesium, chloride, and silica. Sulfate concentrations ranged between 700 and 2,600 mg/L during the last several decades. Selenium concentrations were observed to be usually exceeded 5 µg/L. The elevated TDS level is caused by evapotranspirative losses and irrigation return flows.

Solomon River

The Solomon River drains approximately 6,840 square miles of mainly agricultural land in north-central Kansas. North Fork Solomon River and South Fork Solomon River are two major tributaries of the Solomon River. There are three reservoirs in the Solomon River basin: Kirwin Reservoir on the North Fork Solomon River, Webster Reservoir on the South Fork Solomon River, and Waconda Lake on the Solomon River.

Christensen 1999

This study began in the spring of 1988 by USGS in cooperation with the Bureau of Reclamation to determine if Bureau-operated irrigation, which began in the early 1960's, has increased selenium or other constituents in the Solomon River basin. Sediment core samples were collected from Kirwin Reservoir, Webster Reservoir, and Waconda Lake for analyses of selenium and other constituents. Sediment quality is of concern because it reflects the quality of the overlying water column. Selenium concentration in sediment greater than 4 mg/kg is a concern because there is a potential for bioaccumulation in fish and wildlife (Lemly and Smith 1987).

In Kirwin Reservoir, selenium concentrations in bottom-sediment core samples ranged from less than 0.3 to 2.2 mg/kg. In Webster Reservoir, selenium concentrations in bottom-sediment core samples ranged from 0.3 to 4.0 mg/kg. In Waconda Lake, selenium concentrations in samples from bottom-sediment cores ranged from less than 0.4 to 3.4 mg/kg. Overall, there were increasing trends of selenium concentration in bottom reservoir sediment of these three reservoirs. Nevertheless, this increasing trend may or may not be related to the Bureau-operated irrigation due to limited historical irrigation data for the Solomon River basin.

Literature Cited

APHA, AWWA, WEF. 1998. Standard methods for the examination of water and wastewater, 20th Ed. American Public Health Association, American Water Works Association, and Water Environment Federation, Washington, D. C.

Christensen V. G. 1999. Deposition of selenium and other constituents in reservoir bottom sediment of the Solomon River basin, north-central Kansas. USGS Water Resources Investigation Report 99-4230. 46 pp.

DOI. 1998. Guidelines for interpretation of the biological effects of selected constituents in biota, water, and sediment: selenium. National Irrigation Water Quality Program Information Report No. 3. 184 pp.

Ebina, J. T., Tsuyoshi and T. Shirai. 1983. Simultaneous determination of total nitrogen and total phosphorus in water using peroxodisulfate oxidation. Water Research 17:1721-1726.

Horne, A. J. and C. R. Goldman. 1994. Limnology, 2nd Ed. McGraw-Hill, New York. 575 pp.

Langbein, W. B. and W. H. Durum. 1967. The aeration capacity of streams. U.S. Geological Survey Circular 542:6.

Lemly, A. D. 1997. Environmental implications of excessive selenium: a review. Biomedical and Environmental Sciences 10: 415-435.

Lemly, A. D. 2002. Selenium assessment in aquatic ecosystems: a guide for hazard evaluation and water quality criteria. Springer-Verlag. New York. 161 pp.

Lemly, A. D. and G. J. Smith. 1987. Aquatic cycling of selenium: implications for fish and wildlife. Fish and Wildlife Leaflet 12. United States Department of the Interior, Fish and Wildlife Service. Washington D.C. 10 pp.

Linsley, Jr. R. K., M.A. Kohler and J. L. H. Palhus. 1975. Hydrology for engineers, 2nd Ed. McGraw-Hill, New York. 482 pp.

Matlock, M. D., K. R. Kasprzak and G. S. Osborn. 2003. Sediment oxygen demand in the Arroyo Colorado River. Journal of the American Water Resources Association (JAWRA) 39(2):267-275.

Mueller, D. K., L. R. DeWeese, A. J. Garner and T. B. Spruill. 1991. Reconnaissance investigation of water quality, bottom sediment, and biota associated with irrigation drainage in the middle Arkansas River basin, Colorado and Kansas, 1988-89. USGS Water Resources Investigation Report 91-4060. 84 pp.

Odum, H. T. 1956. Primary production in flowing waters. Limnology and Oceanography 1(2): 102-117.

Streeter, H. W. and E. B. Phelps. 1925. A study of the pollution and natural purification of the Ohio River. U.S. Public Health Service. Public Health Bulletin 146. 75 pp.

Whitmer, J. M. 2000. Fate and transport of selenium and uranium in the upper Arkansas River valley of southwestern Kansas. Thesis. University of Kansas. 218 pp.

Whittemore, D. O. 2000. Water quality of the Arkansas River in southwest Kansas. A report to the Kansas Water Office. Kansas Geological Survey.

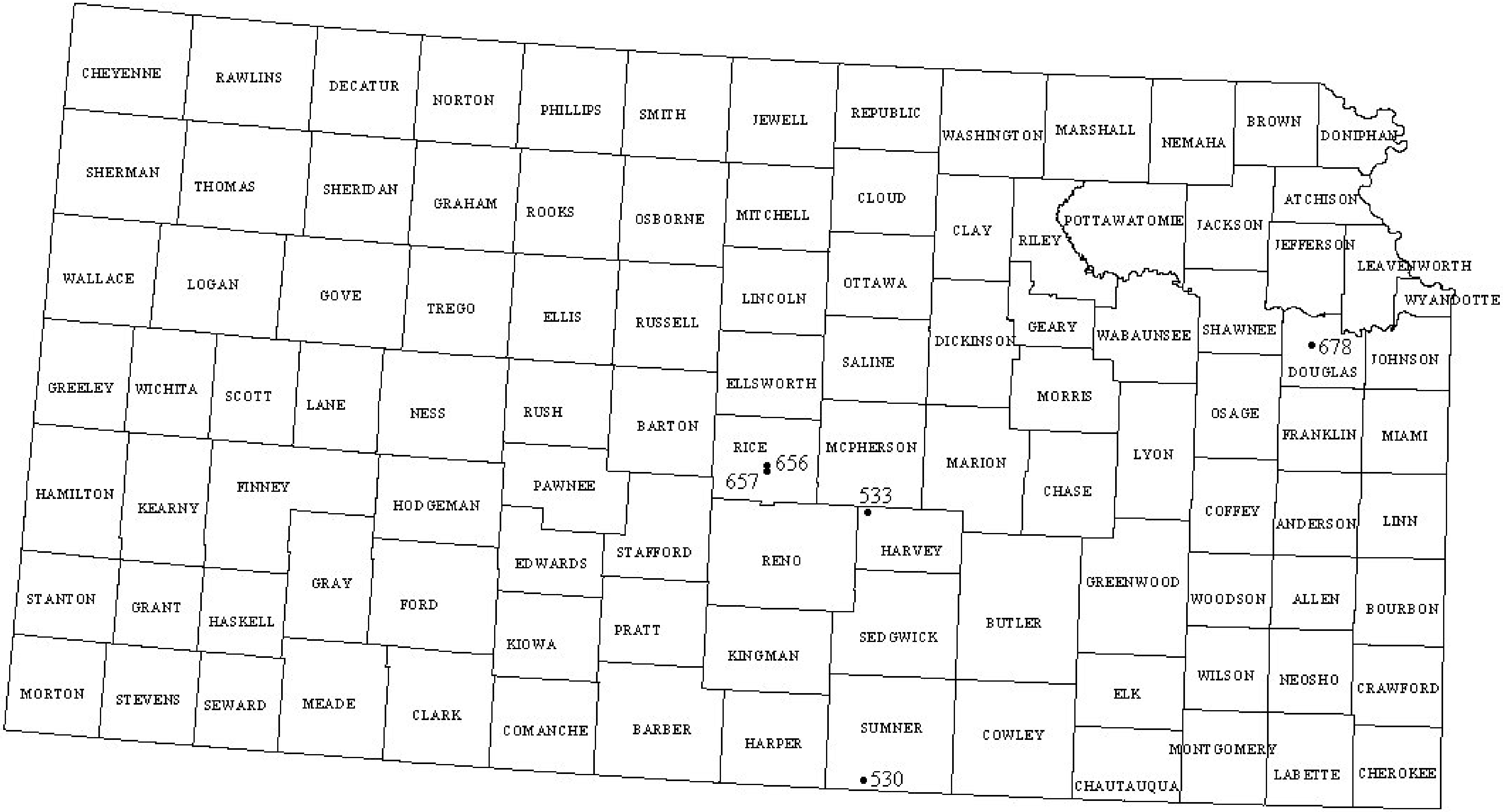

Figure 1 TMDL stream sampling sites for this project.

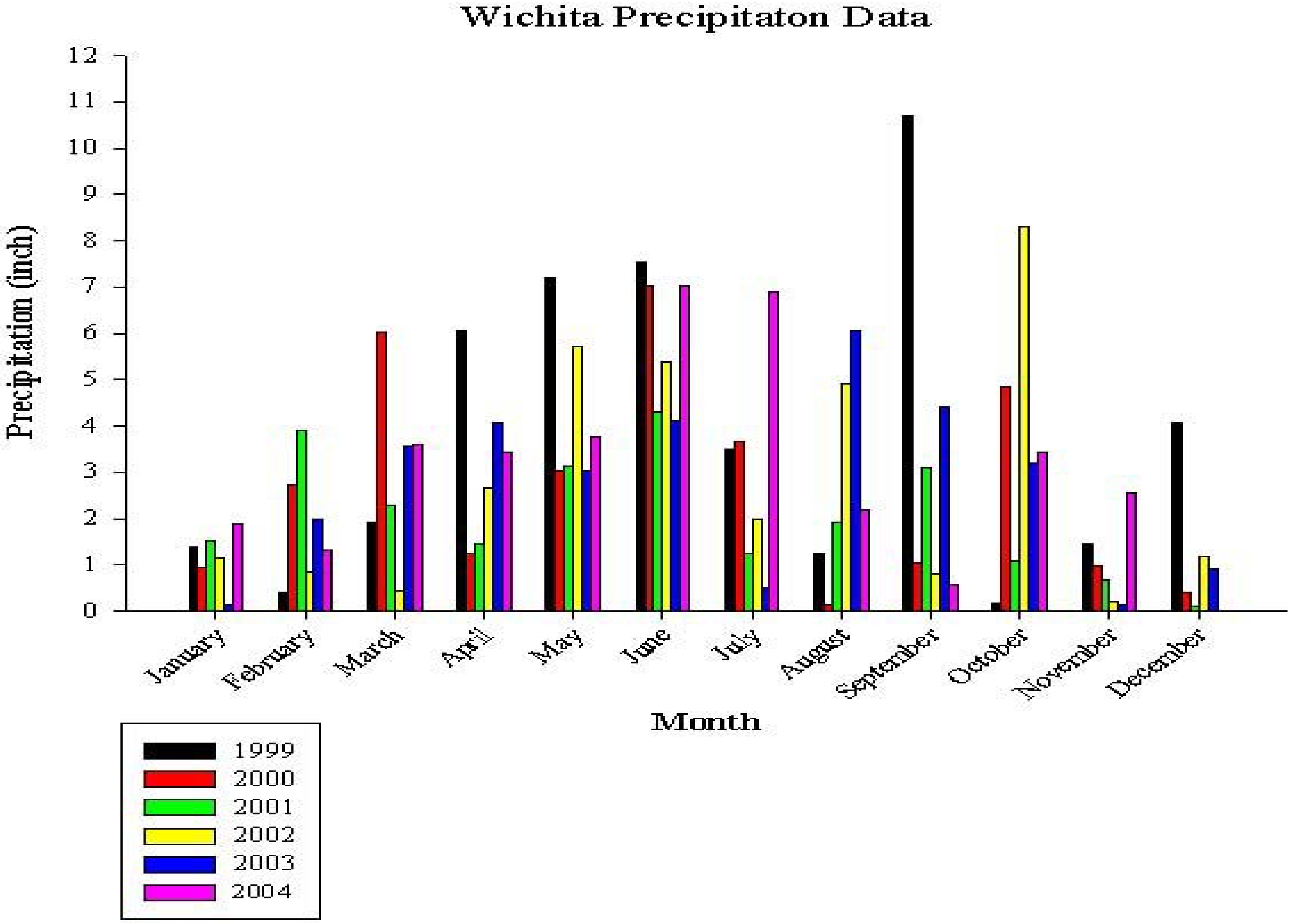

Figure 2 Monthly precipitation data from 1999 to 2004 for Wichita, Kansas.

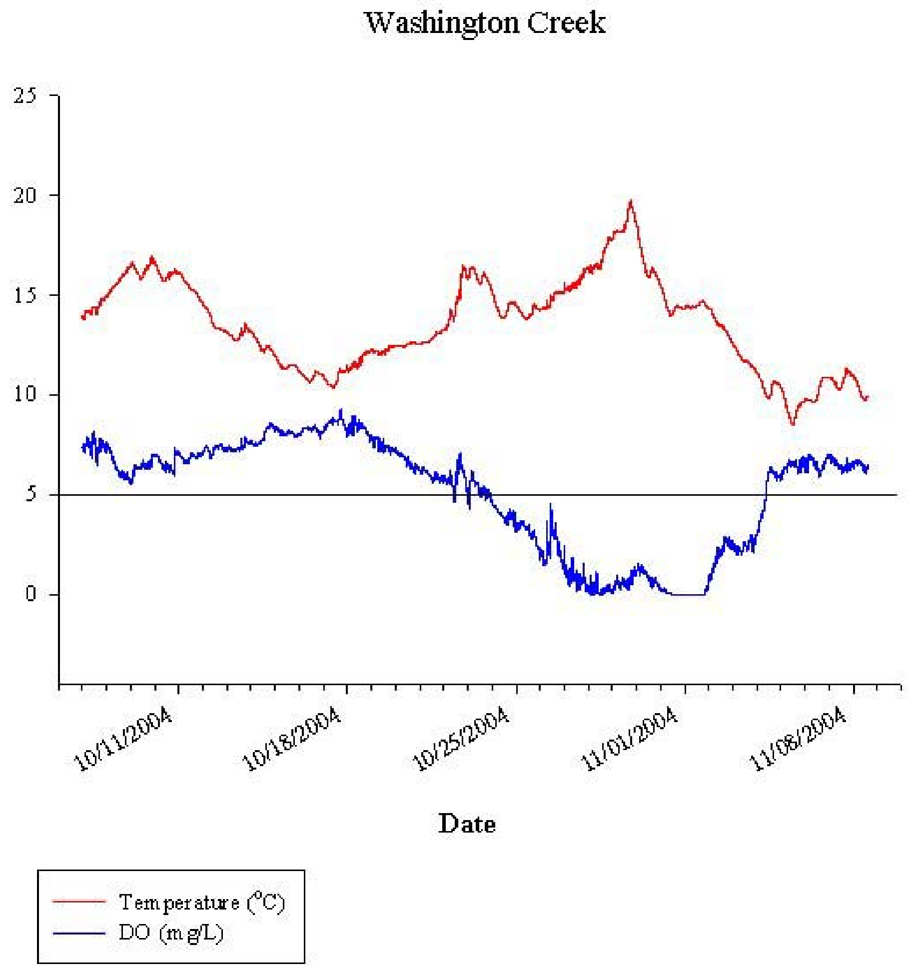

Figure 3 Diurnal DO and temperature fluctuations in Washington Creek near Lawrence, KS.

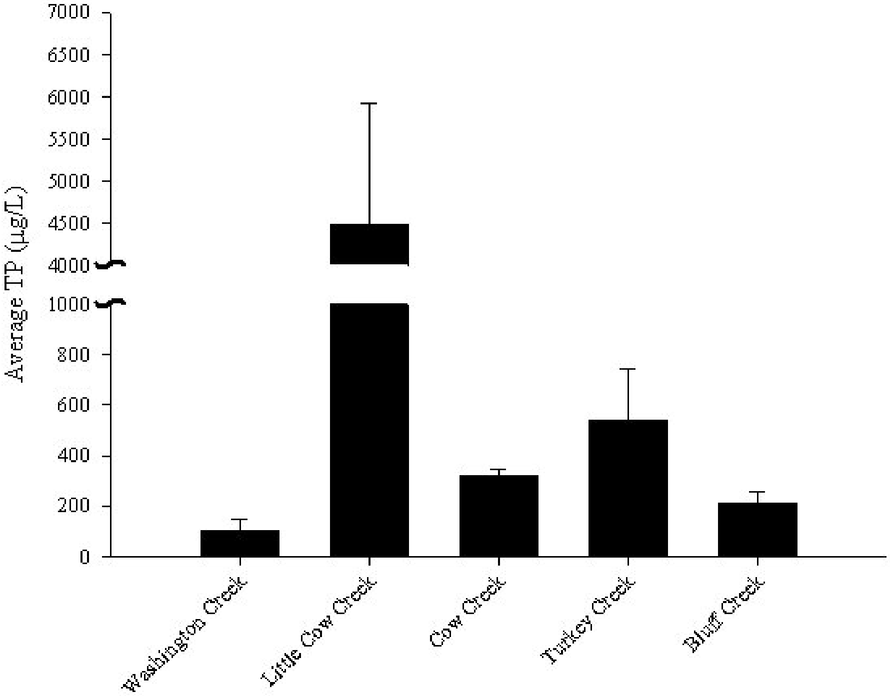

Figure 4 Average TP (July to November 2004) of studied TMDL streams.

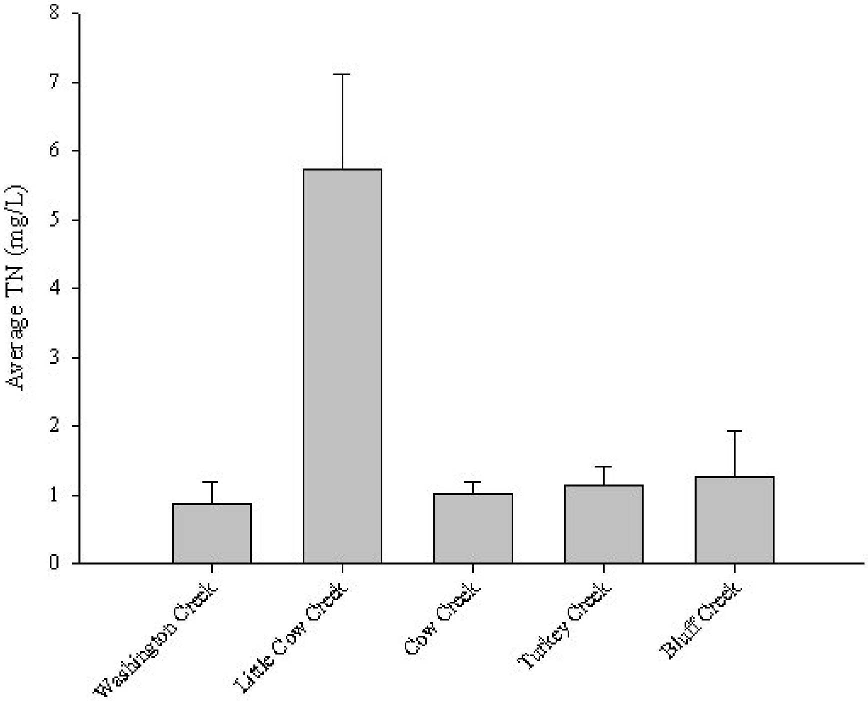

Figure 5 Average TN (July to November 2004) of studied TMDL streams.

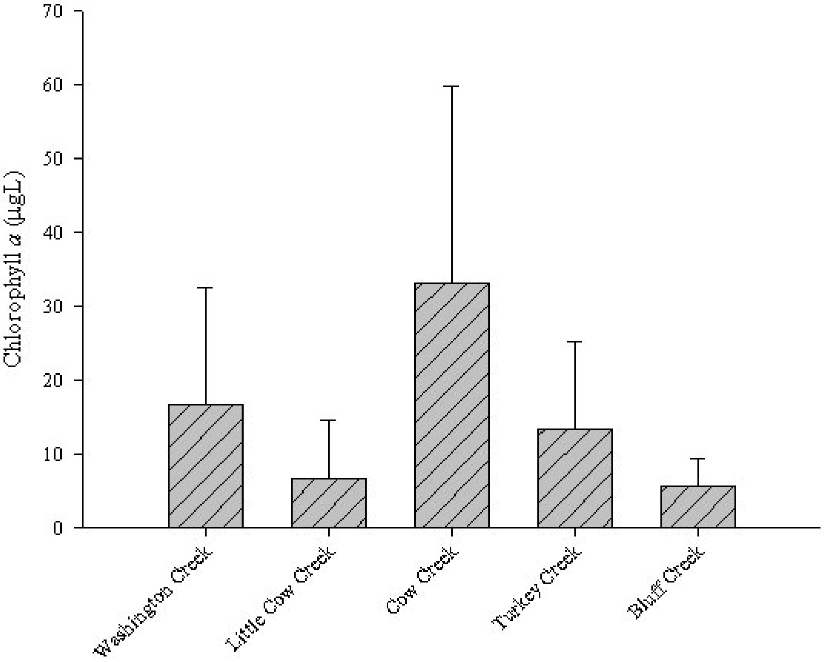

Figure 6 Average chlorophyll *a* concentrations (July to November 2004) of studied TMDL streams.

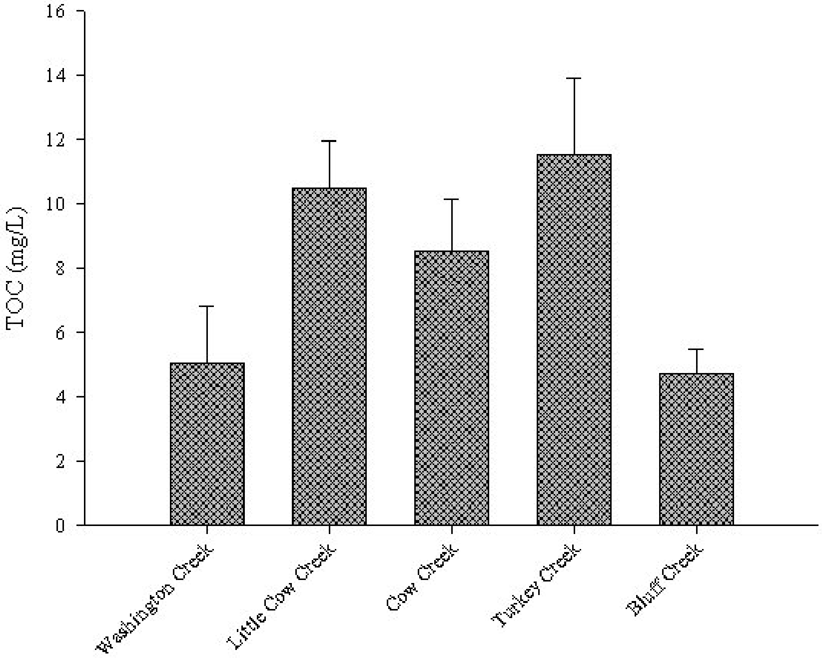

Figure 7 Average TOC concentrations (July to November 2004) of studied TMDL streams.

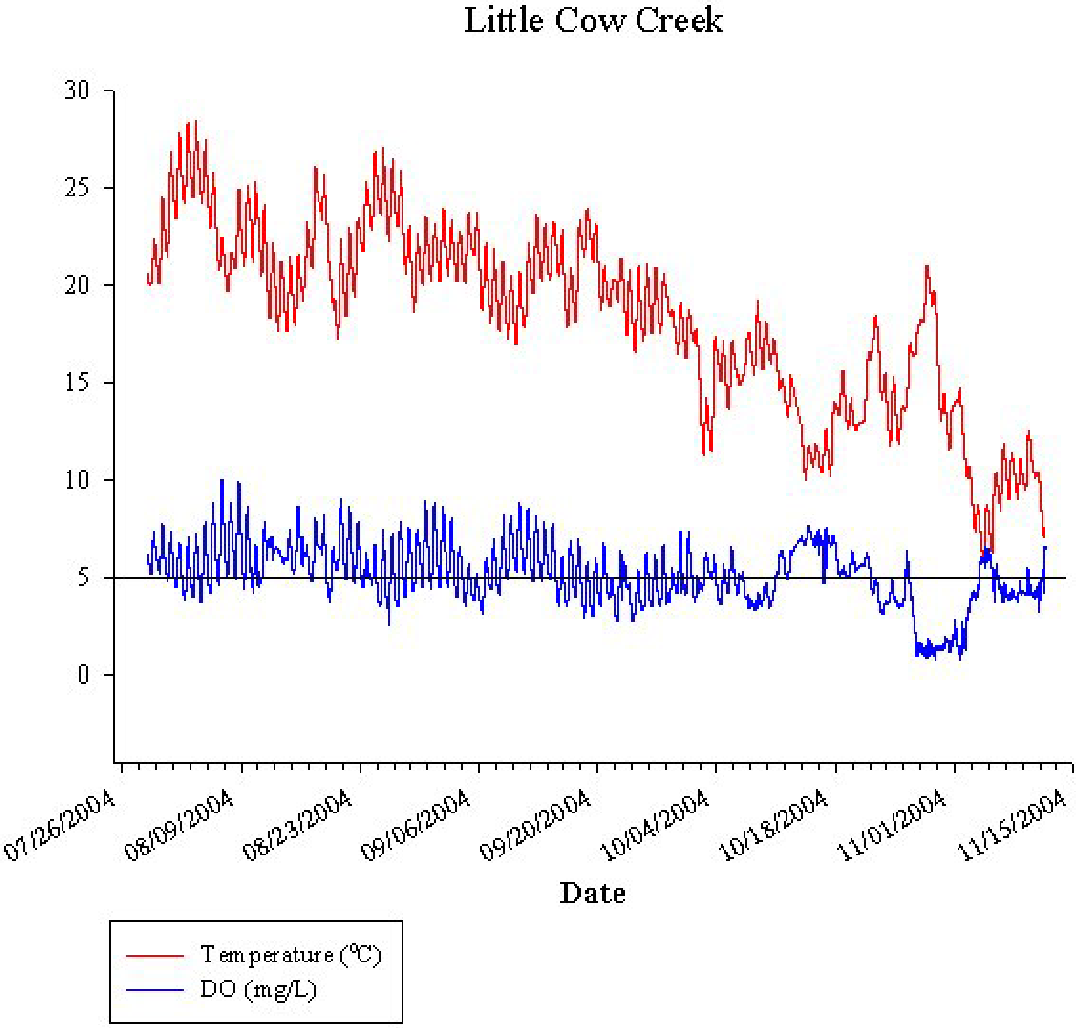

Figure 8 Diurnal DO and temperature fluctuations in Little Cow Creek near Lyons, KS.

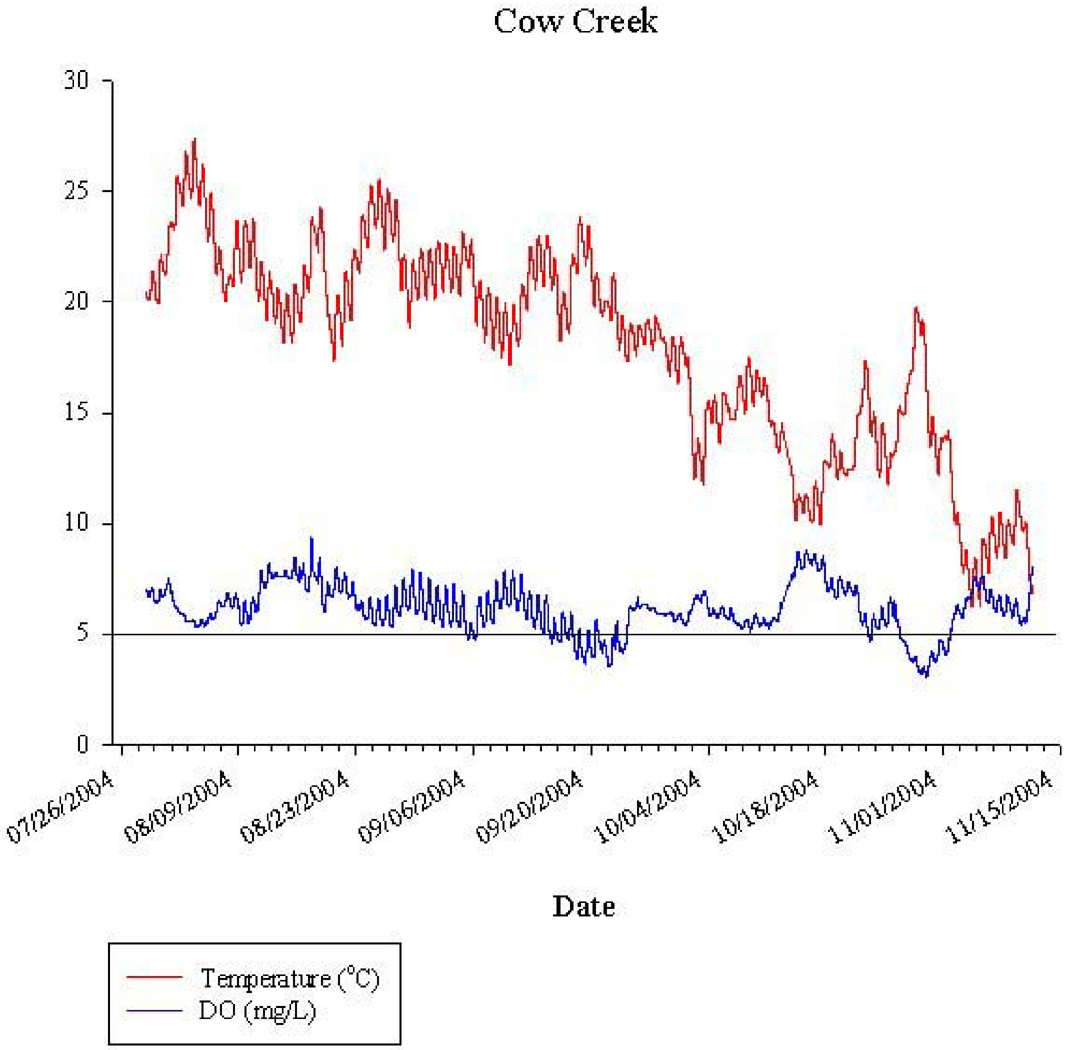

Figure 9 Diurnal DO and temperature fluctuations in Cow Creek near Lyons, KS.

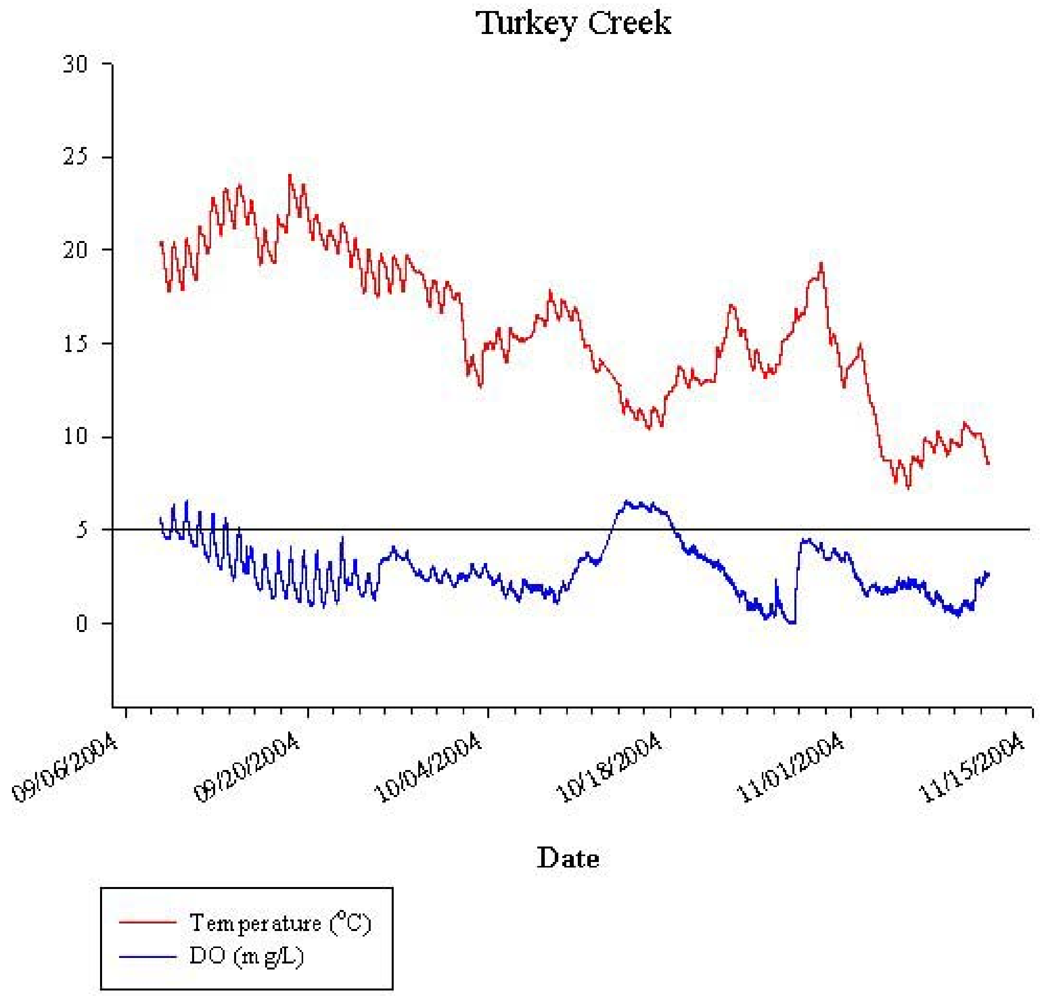

Figure 10 Diurnal DO and temperature fluctuations in Turkey Creek near Alta Mills, KS.

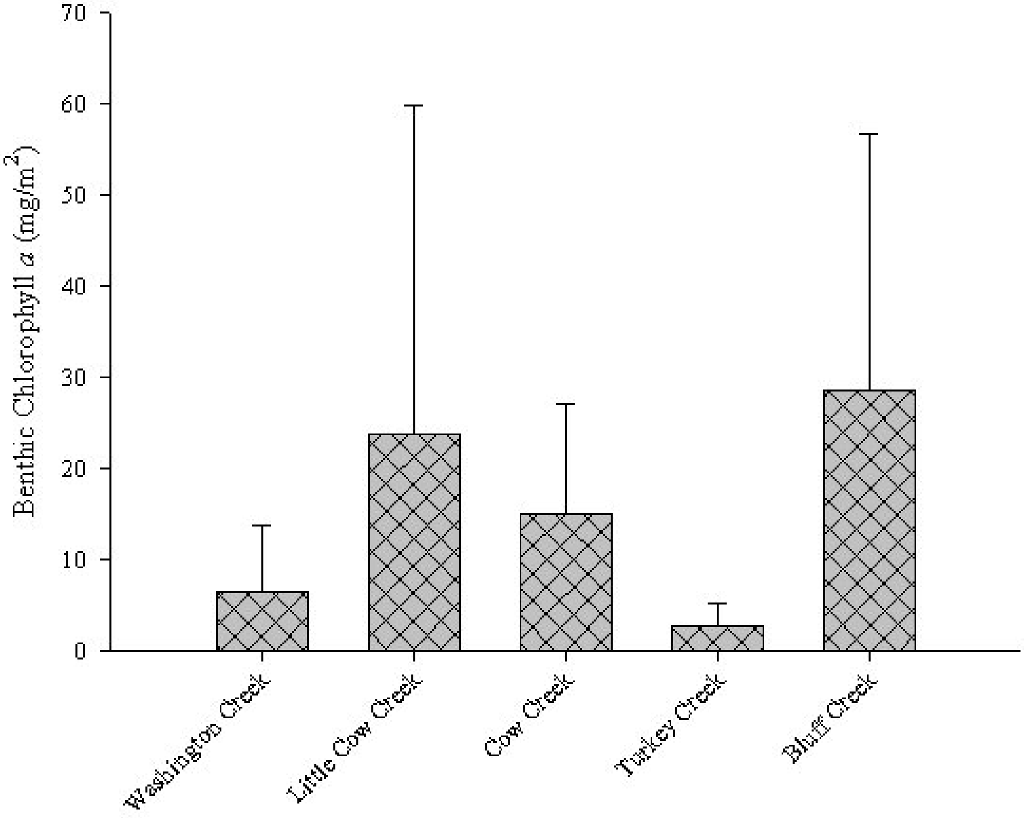

Figure 11 Average benthic chlorophyll *a* concentrations (July to November 2004) of studied TMDL streams.

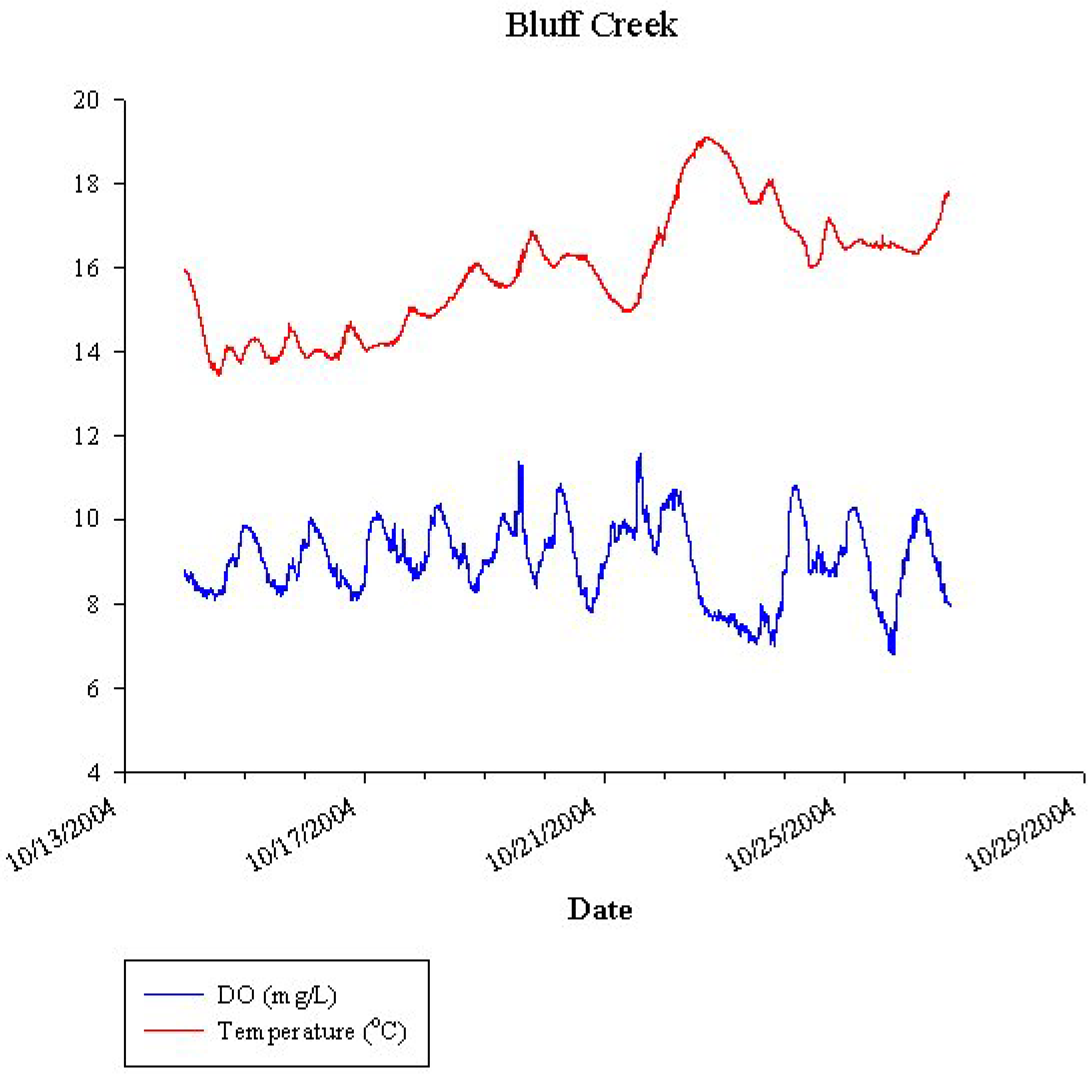

Figure 12 Diurnal DO and temperature fluctuations in Bluff Creek near Caldwell, KS.

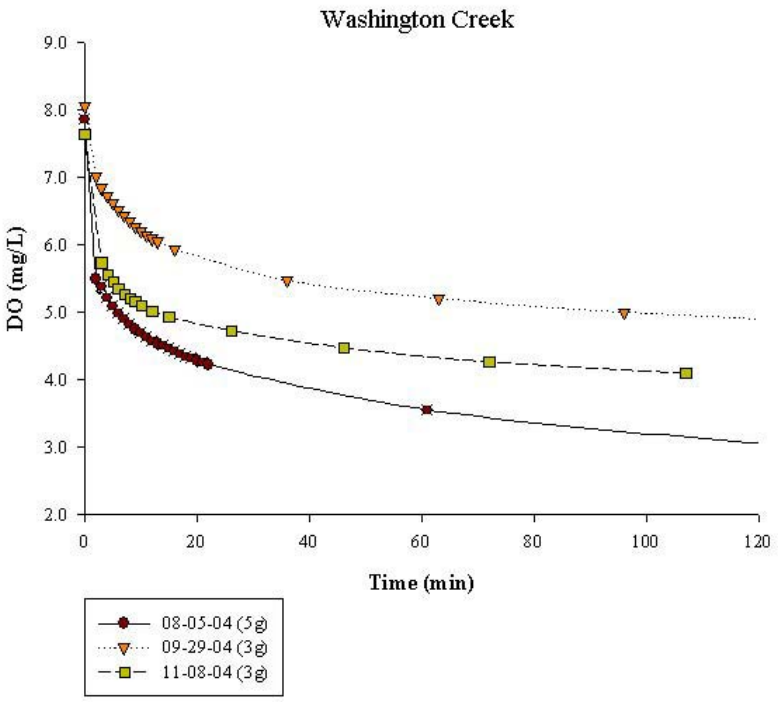

Figure 13 pSOD plot of Washington Creek.

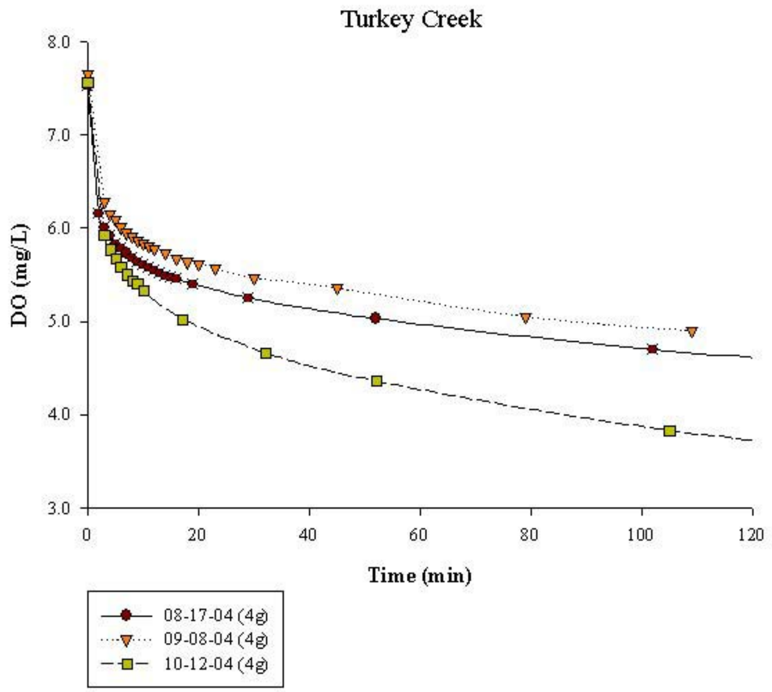

Figure 14 pSOD plot of Turkey Creek.

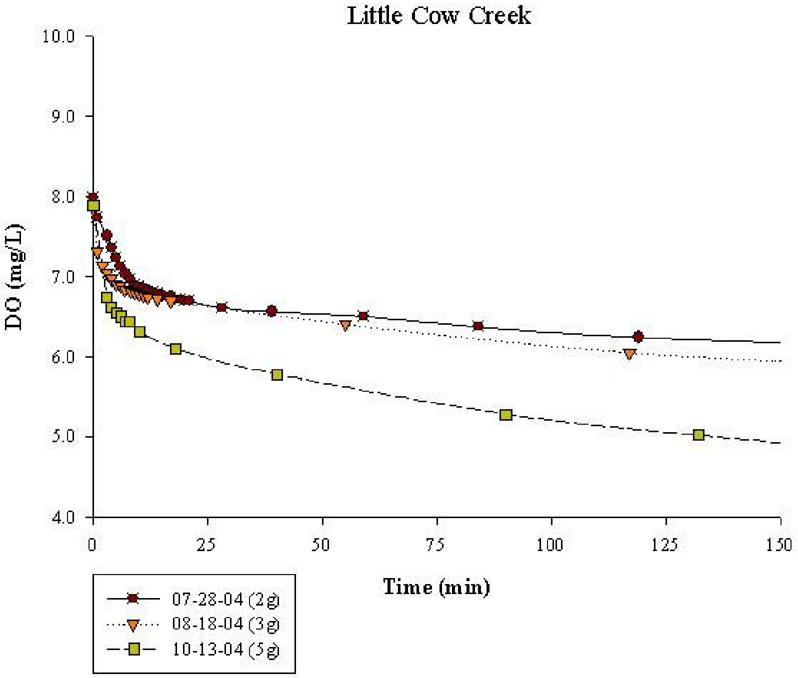

Figure 15 pSOD plot of Little Cow Creek.

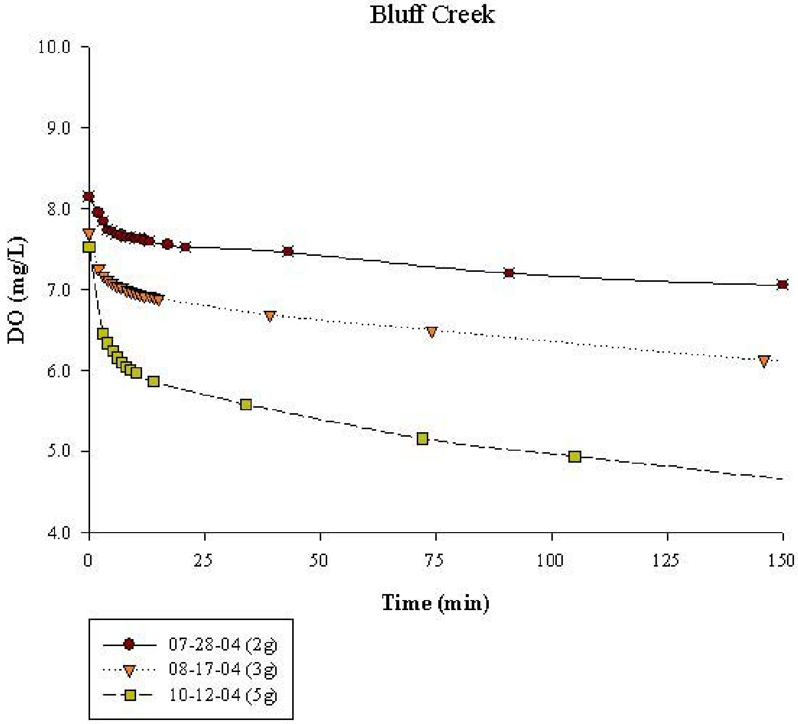

Figure 16 pSOD plot of Bluff Creek.

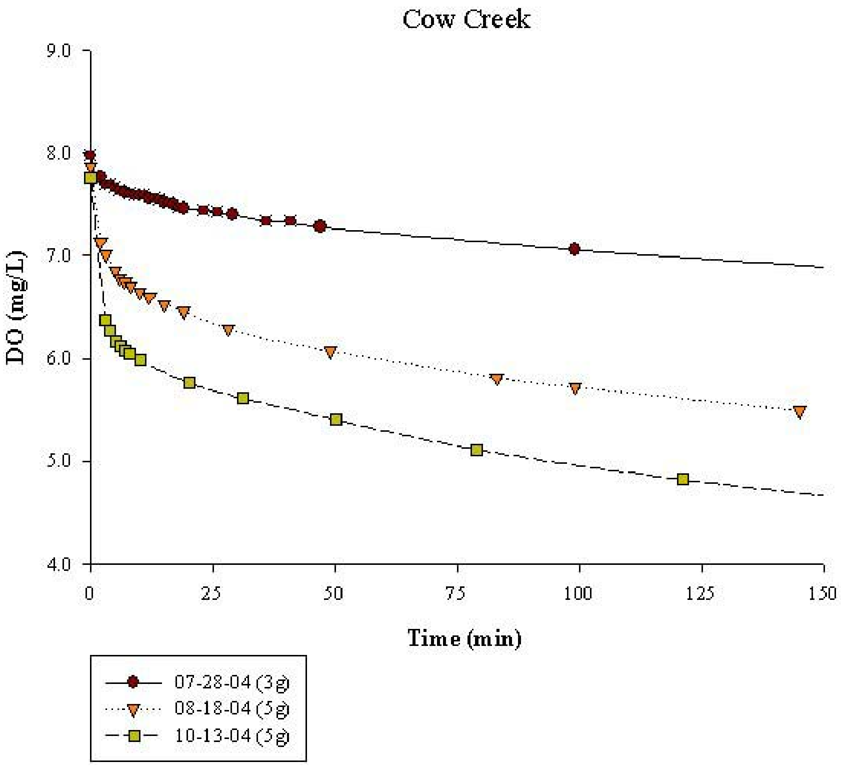

Figure 17 pSOD plot of Cow Creek.

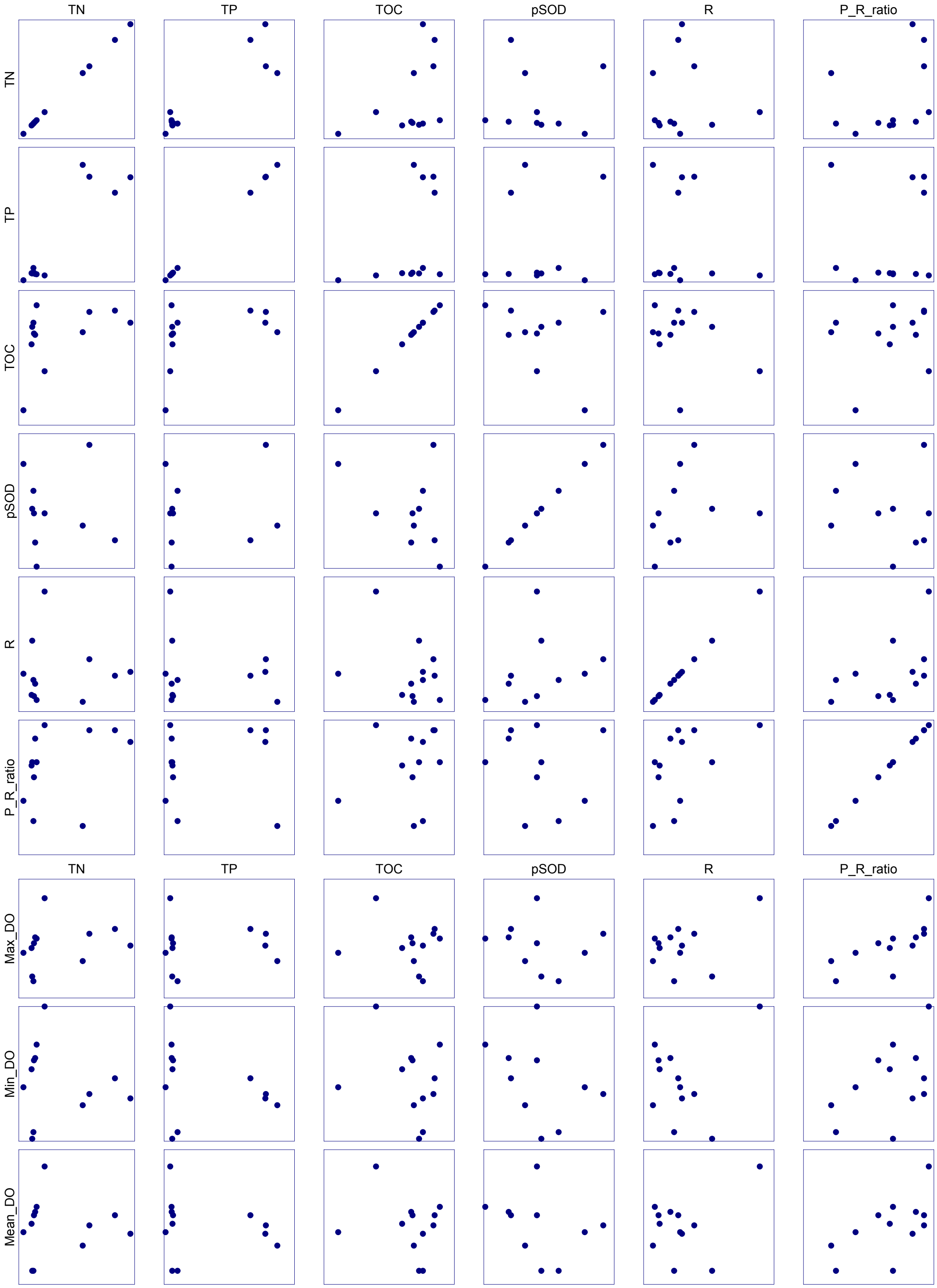

Figure 18 Correlation plots of various variables measured in this study.

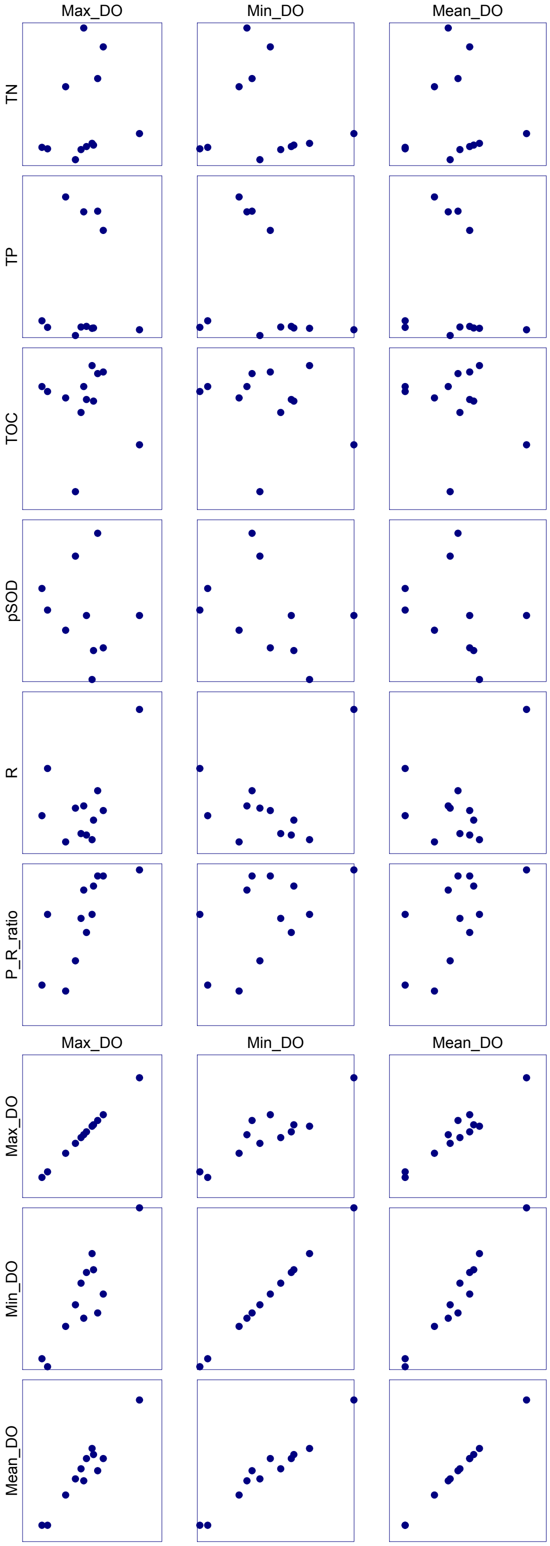

Figure 18 cont’d

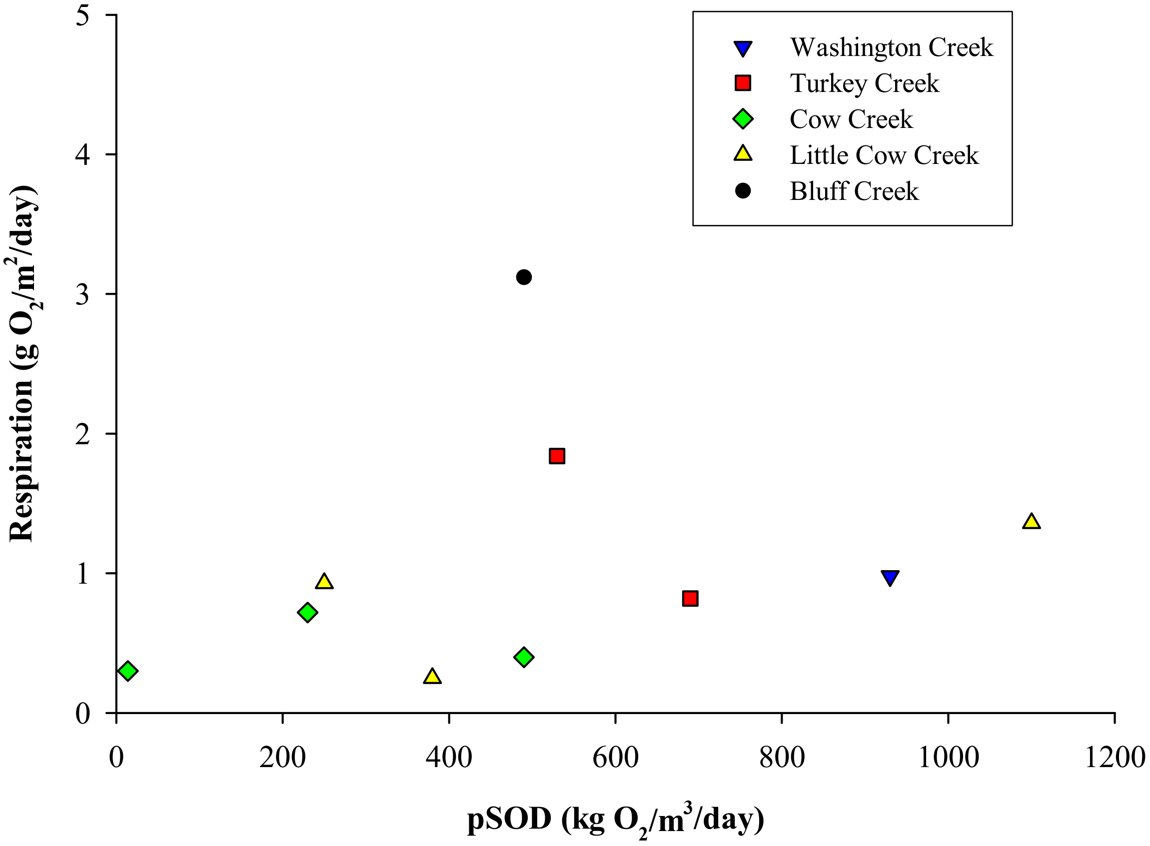

Figure 19 Respiration rate vs. pSOD of studied streams.

Table 1 Water-quality parameters measured in this project

Parameter	**Container**	**Instrument/Method**	**Method Citation**	**Detection Limit**	**Holding Time**	**Preservation**
Laboratory measurements and analyses						
Total Phosphorus	1L Amber Glass	Digestion @ 250°F and 15 psi, Lachat QuikChem 4200*	Ebina *et al.* 1983	5 µg/L	5 days	4 °C
Orthophosphate-P	1L Amber Glass	Lachat QuikChem 4200*	20th ed. Standard Methods 4500-P	1 µg/L	48 hrs	4 °C
Total Nitrogen	1L Amber Glass	Digestion @ 250°F and 15 psi, Lachat QuikChem 4200*	Ebina *et al.* 1983	0.01 mg/L	5 days	4 °C
Ammonia-N	1L Amber Glass	Lachat QuikChem 4200*	20th ed. Standard Methods 4500NH_3	1 µg/L	24 hrs	4 °C
Nitrate-N	1L Amber Glass	Lachat QuikChem 4200*	20th ed. Standard Methods 4500NO_3	0.01 mg/L	48 hrs	4 °C
Nitrite-N	1L Amber Glass	Lachat QuikChem 4200*	20th ed. Standard Methods 4500NO_2	0.01 mg/L	48 hrs	4 °C
Chlorophyll *a*	1L Amber Glass	Optical Tech. Devices, Ratio-2 System Filter Fluorometer	20th ed. Standard Methods 10200-H	1.0 µg/L	30 days	4 °C
TOC	1L Amber Glass	Shimadzu TOC Analyzer (TOC-5000A)	20th ed. Standard Methods 5310	0.1 mg/L	7 days	4 °C, add H_3PO_4 pH < 2
pSOD	Core Sampler	DO measurement	Matlock *et al*. 2003	-	-	4 °C
In situ measurements						
pH	none	Horiba U-10 Water Quality Checker	20th ed. Standard Methods 4500-H^+	0.1	-	-
Specific Conductance	none	Horiba U-10 Water Quality Checker	20th ed. Standard Methods 2510 A-B	0.1 mS/cm	-	-
DO	none	Horiba U-10 Water Quality Checker	20th ed. Standard Methods 4500-O G	0.1 mg/L	-	-
Turbidity	none	Horiba U-10 Water Quality Checker	20th ed. Standard Methods 2130-B	1 NTU	-	-
Water/Air Temp.	none	Horiba U-10 Water Quality Checker	20th ed. Standard Methods 2550-B	0.1 °C	-	-
Flow rate	none	Swoffer Model 2100 Velocity Meter	Linsley *et al*. 1975	0.1 ft/s	-	-

* Flow Injection Analyzer

Table 2 Summary of primary production and respiration estimated using Production Calculator v. 1.5

Stream Name	**Period**	**Net Production ($g\ O_2/m^2/day$)**	**Respiration, R ($g\ O_2/m^2/day$)**	**Gross Production, P ($g\ O_2/m^2/day$)**	**P/R**
Washington Creek	10/07/2004 – 11/07/2004	-0.48	0.98	0.51	0.52
Turkey Creek	09/09/2004 – 10/11/2004	-0.46	1.84	1.38	0.75
	10/14/2004 – 11/10/2004	-0.49	0.82	0.33	0.40
	Average				0.58
Cow Creek	07/29/2004 – 08/16/2004	-0.07	0.30	0.22	0.75
	08/19/2004 – 09/07/2004	-0.08	0.72	0.64	0.89
	09/09/2004 – 10/11/2004	-0.12	0.43	0.32	0.73
	10/14/2004 – 11/10/2004	-0.13	0.40	0.26	0.66
	Average				0.76
Little Cow Creek	07/29/2004 – 08/16/2004	-0.06	0.93	0.87	0.94
	08/19/2004 – 09/07/2004	-0.08	1.36	1.27	0.94
	09/09/2004 – 10/11/2004	-0.13	1.03	0.90	0.87
	10/14/2004 – 11/10/2004	-0.16	0.25	0.09	0.37
	Average				0.78
Bluff Creek	10/14/2004 – 10/25/2004	-0.09	3.12	3.03	0.97

Table 3 Correlation report of various variables measured in this study

Spearman Correlations Section (Row-Wise Deletion)

	TN	TP	TOC	pSOD	R	P_R_ratio
TN	1.000000	0.601399	0.567426	-0.328269	0.104895	0.522810
	0.000000	0.038588	0.054324	0.354418	0.745609	0.081157
	12.000000	12.000000	12.000000	10.000000	12.000000	12.000000
TP	0.601399	1.000000	0.504379	0.079028	-0.181818	-0.112281
	0.038588	0.000000	0.094485	0.828202	0.571701	0.728275
	12.000000	12.000000	12.000000	10.000000	12.000000	12.000000
TOC	0.567426	0.504379	1.000000	-0.237083	-0.115587	0.182777
	0.054324	0.094485	0.000000	0.509561	0.720555	0.569640
	12.000000	12.000000	12.000000	10.000000	12.000000	12.000000
pSOD	-0.328269	0.079028	-0.237083	1.000000	0.571431	-0.122325
	0.354418	0.828202	0.509561	0.000000	0.084412	0.736383
	10.000000	10.000000	10.000000	10.000000	10.000000	10.000000
R	0.104895	-0.181818	-0.115587	0.571431	1.000000	0.603512
	0.745609	0.571701	0.720555	0.084412	0.000000	0.037732
	12.000000	12.000000	12.000000	10.000000	12.000000	12.000000
P_R_ratio	0.522810	-0.112281	0.182777	-0.122325	0.603512	1.000000
	0.081157	0.728275	0.569640	0.736383	0.037732	0.000000
	12.000000	12.000000	12.000000	10.000000	12.000000	12.000000
Max_DO	0.545455	-0.118881	0.108582	-0.279637	0.230769	0.852637
	0.066612	0.712884	0.736944	0.433926	0.470532	0.000425
	12.000000	12.000000	12.000000	10.000000	12.000000	12.000000
Min_DO	0.041958	-0.545455	-0.231174	-0.559273	-0.160839	0.449126
	0.896986	0.066612	0.469733	0.092789	0.617523	0.143009
	12.000000	12.000000	12.000000	10.000000	12.000000	12.000000
Mean_DO	0.185966	-0.459652	-0.096661	-0.571868	-0.094737	0.580986
	0.562806	0.132737	0.765062	0.084120	0.769625	0.047587
	12.000000	12.000000	12.000000	10.000000	12.000000	12.000000

Table 3 cont'd

Spearman Correlations Section (Row-Wise Deletion)

	Max_DO	Min_DO	Mean_DO
TN	0.545455	0.041958	0.185966
	0.066612	0.896986	0.562806
	12.000000	12.000000	12.000000
TP	-0.118881	-0.545455	-0.459652
	0.712884	0.066612	0.132737
	12.000000	12.000000	12.000000
TOC	0.108582	-0.231174	-0.096661
	0.736944	0.469733	0.765062
	12.000000	12.000000	12.000000
pSOD	-0.279637	-0.559273	-0.571868
	0.433926	0.092789	0.084120
	10.000000	10.000000	10.000000
R	0.230769	-0.160839	-0.094737
	0.470532	0.617523	0.769625
	12.000000	12.000000	12.000000
P_R_ratio	0.852637	0.449126	0.580986
	0.000425	0.143009	0.047587
	12.000000	12.000000	12.000000
Max_DO	1.000000	0.741259	0.845619
	0.000000	0.005801	0.000530
	12.000000	12.000000	12.000000
Min_DO	0.741259	1.000000	0.978953
	0.005801	0.000000	0.000000
	12.000000	12.000000	12.000000
Mean_DO	0.845619	0.978953	1.000000
	0.000530	0.000000	0.000000
	12.000000	12.000000	12.000000

Table 3 cont'd

Pearson Correlations Section (Row-Wise Deletion)

	TN	TP	TOC	pSOD	R	P_R_ratio
TN	1.000000	0.909015	0.449113	-0.013234	-0.067829	0.289070
	0.000000	0.000042	0.143021	0.971055	0.834097	0.362149
	12.000000	12.000000	12.000000	10.000000	12.000000	12.000000
TP	0.909015	1.000000	0.400157	0.148459	-0.211272	0.002611
	0.000042	0.000000	0.197425	0.682309	0.509798	0.993575
	12.000000	12.000000	12.000000	10.000000	12.000000	12.000000
TOC	0.449113	0.400157	1.000000	-0.386441	-0.348375	0.193618
	0.143021	0.197425	0.000000	0.269991	0.267106	0.546545
	12.000000	12.000000	12.000000	10.000000	12.000000	12.000000
pSOD	-0.013234	0.148459	-0.386441	1.000000	0.272465	-0.133927
	0.971055	0.682309	0.269991	0.000000	0.446293	0.712234
	10.000000	10.000000	10.000000	10.000000	10.000000	10.000000
R	-0.067829	-0.211272	-0.348375	0.272465	1.000000	0.515823
	0.834097	0.509798	0.267106	0.446293	0.000000	0.086048
	12.000000	12.000000	12.000000	10.000000	12.000000	12.000000
P_R_ratio	0.289070	0.002611	0.193618	-0.133927	0.515823	1.000000
	0.362149	0.993575	0.546545	0.712234	0.086048	0.000000
	12.000000	12.000000	12.000000	10.000000	12.000000	12.000000
Max_DO	0.270541	0.041682	-0.145655	-0.170178	0.457317	0.748692
	0.395056	0.897659	0.651500	0.638330	0.134972	0.005084
	12.000000	12.000000	12.000000	10.000000	12.000000	12.000000
Min_DO	-0.058376	-0.248119	-0.216632	-0.375271	0.277261	0.543738
	0.856992	0.436819	0.498863	0.285261	0.382950	0.067646
	12.000000	12.000000	12.000000	10.000000	12.000000	12.000000
Mean_DO	0.093986	-0.115868	-0.200988	-0.284894	0.356618	0.642759
	0.771408	0.719898	0.531073	0.424961	0.255174	0.024177
	12.000000	12.000000	12.000000	10.000000	12.000000	12.000000

Cronbachs Alpha = 0.059537 Standardized Cronbachs Alpha = 0.664343

Table 3 cont'd

Pearson Correlations Section (Row-Wise Deletion)

	Max_DO	Min_DO	Mean_DO
TN	0.270541	-0.058376	0.093986
	0.395056	0.856992	0.771408
	12.000000	12.000000	12.000000
TP	0.041682	-0.248119	-0.115868
	0.897659	0.436819	0.719898
	12.000000	12.000000	12.000000
TOC	-0.145655	-0.216632	-0.200988
	0.651500	0.498863	0.531073
	12.000000	12.000000	12.000000
pSOD	-0.170178	-0.375271	-0.284894
	0.638330	0.285261	0.424961
	10.000000	10.000000	10.000000
R	0.457317	0.277261	0.356618
	0.134972	0.382950	0.255174
	12.000000	12.000000	12.000000
P_R_ratio	0.748692	0.543738	0.642759
	0.005084	0.067646	0.024177
	12.000000	12.000000	12.000000
Max_DO	1.000000	0.903748	0.969664
	0.000000	0.000055	0.000000
	12.000000	12.000000	12.000000
Min_DO	0.903748	1.000000	0.980469
	0.000055	0.000000	0.000000
	12.000000	12.000000	12.000000
Mean_DO	0.969664	0.980469	1.000000
	0.000000	0.000000	0.000000
	12.000000	12.000000	12.000000

Cronbachs Alpha = 0.059537 Standardized Cronbachs Alpha = 0.664343