ABSTRACT

TRACY L. JACKSON. Evaluation of Organic Carbon Loadings in Two Reservoirs. (Under the Direction of Dr. PHILIP C. SINGER)

To effectively control TOC concentrations in the two reservoirs serving the Orange Water and Sewer Authority (OWASA), the sources of TOC must be known. This study used a simplified steady-state mass balance approach to compare the main sources of TOC in the University Lake and the Cane Creek Reservoir. The main TOC sources were the TOC which is directly loaded to the reservoirs from the watershed (allochthonous TOC) and the TOC which is produced in the reservoirs by algae generated as a result of nutrient influxes to the reservoirs (autochthonous TOC).

To determine the allochthonous TOC load, existing TOC and flow data was used along with TOC data from the sampling program. The sampling program involved monthly sampling of the tributaries of the University Lake and Cane Creek Reservoir for TOC over a five-month period. The autochthonous TOC load was determined by estimating the amount of algae which would grow in the reservoir due to the existing nutrient loadings.

The results of this study indicate that allochthonous TOC is the primary source of TOC in the reservoirs. The TOC load from the watershed accounts for 72 to 90 percent of the total TOC concentration in the reservoirs. The autochthonous TOC load accounts for only 10 to 28 percent of the in-lake TOC concentration.

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CHAPTER 1 - INTRODUCTION

1.1 PURPOSE

The Orange Water and Sewer Authority (OWASA) serves approximately 55,000 people in Chapel Hill, Carrboro, and southern Orange County. The University Lake and Cane Creek reservoirs are used as drinking water sources by OWASA. In treating the water, OWASA uses chlorine as the primary and secondary disinfectant. Thus, concern arises over formation of the potentially carcinogenic disinfection by-products trihalomethanes (THMs) and haloacetic acids (HAAs). The disinfection by-products are formed when chlorine reacts with natural organic material (NOM). The total organic carbon (TOC) concentration of the raw water is typically used as a surrogate for NOM.

The current maximum contaminant level (MCL) for total THMs, is 100 ug/l. The MCL is expected to be lowered to 80 ug/l with the Phase I regulations of the proposed Disinfectants-Disinfection Byproducts Rule. Phase I would also establish a new MCL for HAAs at 60 ug/l. Phase II would further lower the MCLs to 40 ug/l for total THMs and 30 ug/l for HAAs. To meet these new lower levels of THMs, certain treatment techniques may be required such as improved TOC removal by enhanced coagulation, granular activated carbon adsorption, or membrane filtration. These treatment techniques may be relatively costly. Another option is to control TOC at the source, by watershed management procedures. The first step in controlling TOC in the raw water source is to determine where the TOC is coming from.

The two main sources of TOC in reservoirs are allochthonous sources, or TOC which is directly loaded to the reservoirs from runoff, and autochthonous sources, or TOC which is produced within the reservoir by aquatic plants such as algae. The purpose of this study was to determine and quantify the sources of TOC in the University Lake and Cane Creek reservoirs.

1.2 RELATED WORK

A study by Randtke et al. (1986) was done to examine the sources of precursors in Kansas lakes. Sources of precursors studied included those entering lakes from streams, storm runoff, and wastewater effluents (allochthonous sources) and those formed in lakes by microbial activity and the decay of vegetation (autochthonous sources). The average THM formation potential (THMFP) for the lakes of Kansas was determined to be 0.42 umol/mg C which is equivalent to a THM concentration of 250 ug/L for a water having a TOC concentration of 5 mg/L. The average concentration of dissolved organic carbon (DOC) and TOC in the Kansas lakes was 4.4 and 5.0 mg/L, respectively.

THMFP in stratified lakes was also studied to determine if a difference could be found between the top and bottom waters. The THMFP was found to be identical in the bottom and top layers.

Elevated concentrations of organic carbon and THM precursors were observed in major inlet streams, near eroding shorelines, and in a bed of decaying weeds. Agricultural runoff was found to be the most significant source of THM precursors in Kansas. Farmland had the highest THMFP to carbon ratios ranging from 0.431 to 0.549 umoles/mg C. Cattle feedlot runoff had extremely high concentrations of organic carbon and THM precursors. The cattle feedlot runoff samples had TOC concentrations ranging from 120 to 380 mg/L and THMFP ranging from 4,700 to 13, 500 ug/L.

Palmstrom et al. (1988) examined THM precursor generation in Lake Rockwell, an Ohio water supply reservoir. A three year input-output study was undertaken to determine the amount of THM precursors generated in the reservoir. In 1985, the autochthonous summer THM precursor load in Lake Rockwell was determined to be 22 kg/d, while in the summer of 1986 it increased to 55 kg/d. The autochthonous precursor contributions were based on the difference between incoming and outgoing precursor loads from the reservoir.

It was determined that allochthonous precursors contributed as much as 66 percent of the total precursors per day in the summer, while the autochthonous THM precursors contributed only 33 percent. Based on a single net algal carbon production rate in Lake Rockwell of 0.33 $g/m^2/d$ and reported values of THM/carbon, a range of THMFP loadings from 16 to 305 kg/d was obtained. A range of loadings of 0.1 to 100 kg/d was estimated to be probable for Lake Rockwell, potentially making algae and their extracellular products the largest source of precursors to the reservoir. THM precursor contributions from live macrophyte extracellular release and littoral sediments appeared to be very small, with less than 1 kg/d contributed from each of the sources.

Martin et al. (1993) investigated the importance of lake and reservoir sediments as a source of THM precursors in Lake Rockwell and East Twin Lake in Ohio. Littoral sediments from Lake Rockwell were studied along with profundal sediments from Lake Rockwell and East Twin Lake to quantify the release of THM precursors from the sediments. It was found that aerobic THM precursor release was significantly greater than anaerobic sediment release for both of the sediment types. The average daily release rates of THM precursors under aerobic conditions were 0.153 and 0.082 $ug/m^2/d$ for Lake Rockwell littoral and profundal sediments, respectively, and 0.077 $ug/m^2/d$ for profundal sediments in East Twin Lake. Under anaerobic conditions, THM precursor release rates were 0.033 $ug/m^2/day$ for Rockwell littoral sediments and 0.010 and 0.007 $ug/m^2/day$, respectively for profundal sediments from Rockwell and East Twin Lake.

A THM precursor loading from the lake sediments of Lake Rockwell was determined to be 0.49 kg/day. This sediment THM precursor loading was estimated to be less than 1% of the summer total daily precursor loading to Lake Rockwell. Martin et al. concluded that for most water supplies where littoral zones are insignificant, profundal sediments are an insignificant THM precursor source and that management of sediments to reduce THM precursor release would appear to be unjustified.

Karimi and Singer (1991) explored the effect of algae on THM formation in an open distribution reservoir used as part of the Los Angeles, California water supply. Significant increases in THM concentrations were found in the reservoir. These increases were attributed to the growth of algae in the reservoir and the application of chlorine to control these growths.

Peak THM formation in the reservoir was found to correspond to peak chlorine applications. The average THM level in the reservoir was 54.4 ug/L, which was three to four times greater than the THM level originally present in the inlet water (16.3 ug/L). The reservoir maximum THMFP was noticeably greater than the inlet maximum THMFP with an average increase of 18.7 ug/L. The THMs formed in the reservoir were most likely the result of the reaction between chlorine and the algae in the reservoir. An association between algal population and maximum THM formation potential was determined to be, on average, about 25 ug/L of THMFP produced per 1,000 areal standard units/mL of algal cells.

A study on the Occoquan Reservoir in northern Virginia by Hoehn et al. (1980) found that the summer THM concentrations in the finished water after treatment correlated well with the chlorophyll-a concentrations in the reservoir. This relationship strongly implicated algae as an important source of THM precursors for the water supply. However, the correlation between THM formation potential and chlorophyll-a concentrations was found to hold for only one summer; the relationship did not hold for subsequent summers.

Hoehn et al. also studied the THM-yielding capacities of algae. It was found that for algal biomass, the chloroform-carbon yield was 0.2 to 4.0 percent, while algal extracellular products had a chloroform-carbon yield of 0.04 to 5.0 percent.

Camp Dresser & McKee (CDM) completed a management plan for the University Lake watershed in 1989 for OWASA (CDM, 1989). In the study, chlorophyll-a levels in the reservoir were modeled using the known nutrient loads, a nutrient model developed by Reckhow (Reckhow, 1988), and a chlorophyll-a model developed by Walker (Walker, 1985). The nutrient model yielded a mean total phosphorus concentration in the reservoir of 0.057 mg/L and a mean total nitrogen concentration in the reservoir of 1.0 mg/L. The chlorophyll-a model yielded a mean chlorophyll-a concentration in the reservoir of 19.0 ug/L. Table D-4 in Appendix D summarizes the CDM results. The nutrient model and chlorophyll-a model used in the CDM study were also used for this study.

CHAPTER 2 - METHODS

2.0 INTRODUCTION

To effectively control TOC concentrations in the two reservoirs serving the Orange Water and Sewer Authority (OWASA), the sources of TOC must be known. This study used a simplified steady-state mass balance approach to compare the main sources of TOC in the University Lake and the Cane Creek Reservoir.

2.1 THE RESERVOIRS

University Lake was created in 1932 by the impounding of Morgan Creek with an 811-foot dam. The storage volume of the reservoir was increased in 1955 by the addition of flashboards to the dam. Additional tributaries which feed University Lake are Phils Creek, Neville Creek, Pritchards Mill Creek, and Price Creek. The reservoir and its watershed can be seen in Figure 2-1. The drainage area of the watershed is 30 square miles. The current storage capacity of the reservoir is 570 million gallons with a mean depth of 9 feet and a surface area of 0.3 square miles.

The Cane Creek Reservoir was built in 1989 to meet the growing demand for water in Chapel Hill, Carrboro and southern Orange County. The Cane Creek Reservoir was formed by the impounding of Cane Creek with a 900-foot earthen dam. Additional

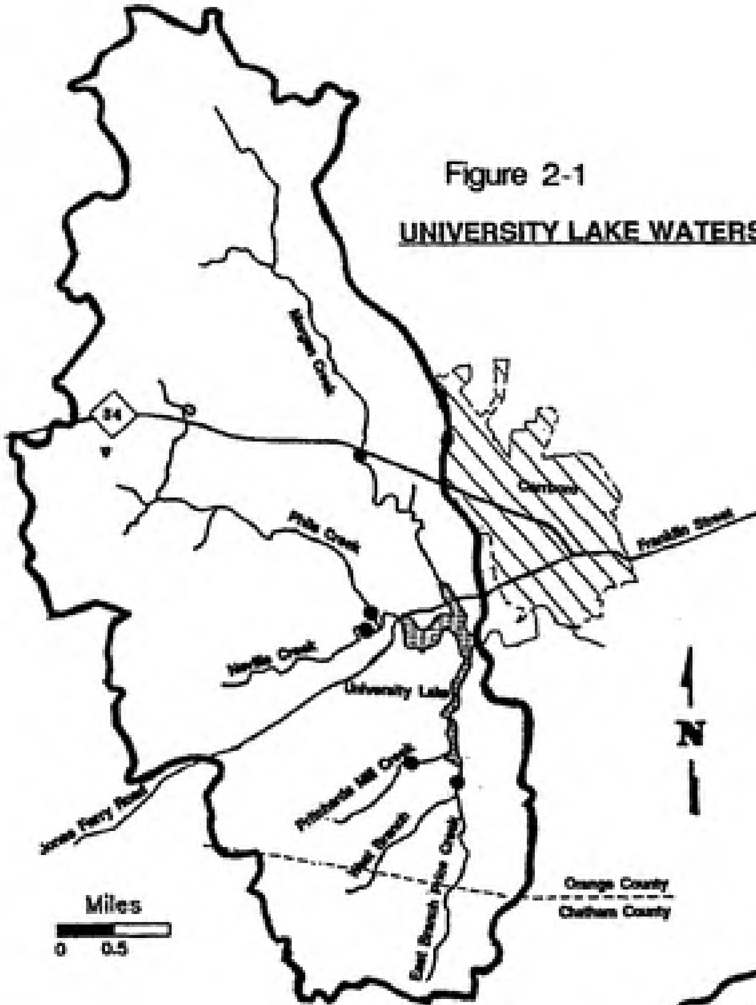

Figure 2-1

UNIVERSITY LAKE WATERSHED

● Sampling Location

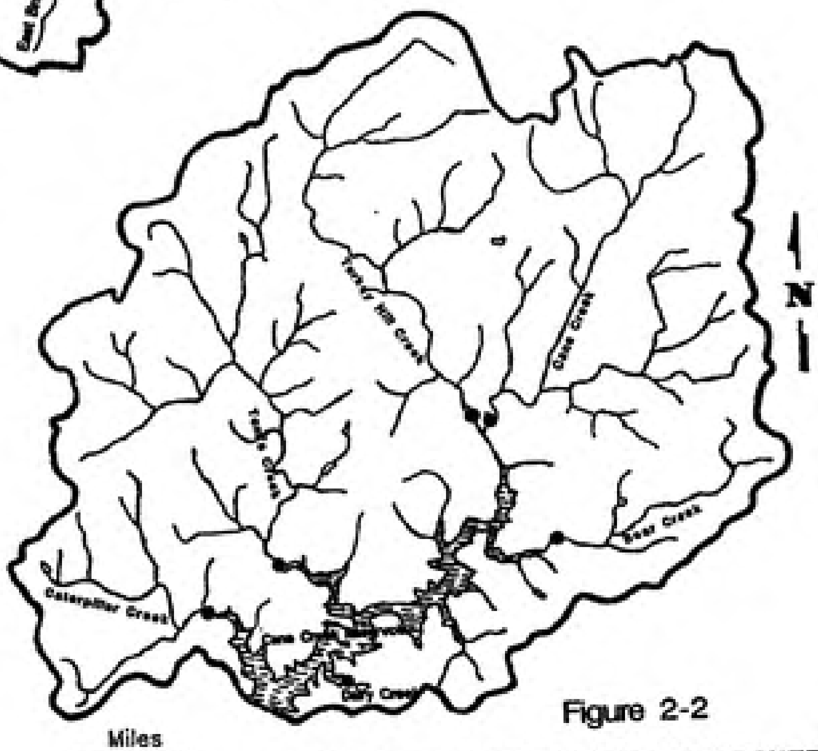

Figure 2-2

CANE CREEK RESERVOIR WATERSHED

tributaries which feed the Cane Creek Reservoir are Bear or Watery Fork Creek, Turkey Creek, Tom's Creek, Caterpillar Creek, and Dairy Creek. The drainage area served by the reservoir is similar to that of University Lake at 30 square miles. The storage capacity of the reservoir is 3,000 million gallons with a mean depth of 18.4 feet and a surface area of 0.75 square miles. The reservoir and its watershed are shown in Figure 2-2.

2.2 MASS BALANCE APPROACH

The purpose of this study was to determine the relative magnitudes of the different TOC loads to the reservoirs. To compare the TOC which was loaded to the reservoir from the watershed (allochthonous TOC) and the TOC which was produced by algae in the reservoir (autochthonous TOC), a simplified steady-state mass balance approach was used. The mass balance on TOC in the reservoir has a term for each load or loss of TOC to or from the reservoir. The mass balance equation is as follows:

Mass Change of TOC in the Reservoir per year	=	Mass of TOC Produced by Algae per year	+	Mass of TOC Loaded from Tributaries and Runoff per year	-	Mass of TOC Loss from Outflow, Withdrawal, and Sedimentation per year	(2-1)

The mass of TOC produced by algae per year, or the autochthonous load, is equal to the product of the yearly average concentration of TOC in the reservoir created by algae and the total yearly flow to the reservoir.

The mass of TOC loaded directly from the tributaries and indirect runoff per year, or the allochthonous load, is equal to the product of the total yearly flow from the watershed to the reservoir and the average yearly concentration of the TOC in the inflow. The average yearly concentration of TOC in the inflow is equal to the sum of the tributary and the indirect runoff contributions. The tributary contribution is equal to the yearly average concentration of TOC in the tributary inflow multiplied by the tributary flow rate. The indirect runoff portion of the watershed is the portion of the watershed which is not drained by the tributaries. The indirect runoff TOC contribution is equal to the product of the average yearly TOC concentration per acre for the watershed and the total acreage of the indirect runoff portion of the watershed.

The mass of TOC loss from the reservoir is equal to loss from outflow, withdrawal by OWASA, and sedimentation of TOC. The loss of TOC due to sedimentation was assumed to be negligible since the majority of the TOC in the tributaries and the reservoirs was expected to be soluble in nature, i.e. particulate TOC was assumed to be negligible. The loss of TOC from the settling of dead algae was also assumed to be negligible. Thus, the mass of TOC loss is equal to the loss from outflow and withdrawal, or total outflow, which is equal to the product of the average yearly concentration of TOC in the outflow and the total yearly outflow.

To simplify the mass balance equation, three further assumptions were made. First, it was assumed that the TOC concentration in the reservoir remains constant with time. The second assumption was that the reservoir volume remains constant. These two assumptions make the mass change of TOC in the reservoir per year equal to zero, which means the reservoir is in "steady state." The second assumption also makes the total inflow to the reservoir equal to the total outflow from the reservoir. The final assumption was that the reservoir behaves as a completely mixed system. This assumption makes the TOC concentration in the outflow equal to the TOC concentration in the lake. Thus, the mass balance equation simplifies to:

$$Q_{out}TOC_{lake} = Q_{in}TOC_{all} + Q_{in}TOC_{auto} \qquad \text{Equation 2-2}$$

and ultimately simplifies to:

$$TOC_{lake} = TOC_{all} + TOC_{auto} \qquad \text{Equation 2-3}$$

where TOC_{auto} = Concentration of TOC in the reservoir created by algae (mg/L)

TOC_{all} = Concentration of TOC contributed by tributary and runoff flow(mg/L)

TOC_{lake} = Concentration of TOC in the reservoir and in the outflow (mg/L)

Q_{out} = Total flow out of the reservoir (L/yr)

Q_{in} = Total flow into the reservoir from tributary and runoff flow (L/yr)

Equation 2-3 indicates that the concentration of TOC in the lake or TOC_{lake} is equal to the sum of the concentrations of TOC in the reservoir created by algae or TOC_{auto} and the concentration of TOC contributed by the inflow from the tributaries and indirect runoff or TOC_{all}. Thus, to compare the autochthonous and the allochthonous loads of TOC, TOC_{auto} and TOC_{all} were determined. To determine the TOC_{all} or average annual TOC concentration in the inflow from the tributaries and indirect runoff to the reservoir, historical TOC data from the US Geological Survey (USGS) was used along with additional data generated from a tributary sampling program conducted as part of this study. The TOC_{auto}, or the TOC which is produced in the reservoir by algae, was determined by using historical nitrogen and phosphorus data from the USGS and OWASA along with published nutrient and chlorophyll-a models from the literature.

2.3 ALLOCHTHONOUS TOC

The steps used in determining the concentration of TOC which was directly loaded to the reservoir from the tributaries and indirect runoff were as follows:

1. Historical USGS data over the period from October 1988 to September 1992 for the concentration of TOC in the two main tributaries, Morgan Creek and Cane Creek, was used to determine the average annual TOC concentrations in those two tributaries. Data was available on a monthly basis. Similar data were not available for the other tributaries.
2. A short-term tributary sampling program was undertaken to obtain TOC concentrations for all of the tributaries in the University Lake and the Cane

Creek Reservoir watersheds.

3. The data from the short-term tributary sampling program was used to compare the amount of TOC in the tributaries to the amount of TOC in Morgan and Cane Creek. The comparison was done in the form of a ratio of the concentration of TOC in each creek to the TOC concentration in Morgan or Cane Creek.
4. The TOC load was determined for each tributary by multiplying the historical annual average TOC concentration from Morgan or Cane Creek by the ratio of TOC in each creek to the TOC in Morgan or Cane Creek and by the annual volume of flow from each tributary.
5. The TOC load for the indirect runoff areas was determined by multiplying the TOC load per acre, calculated from the portion of the watershed that was drained by the tributaries, by the acreage of the indirect runoff area and by the annual volume of flow from the indirect runoff area.
6. The annual average TOC concentration in the inflow was determined by dividing the annual TOC load by the annual volume of flow from the tributaries and indirect runoff.

2.3.1 Historical USGS Data. Historical flow and TOC data were obtained from the USGS Water-Data Reports for North Carolina. The data used from the USGS Water-Data Reports were from the Morgan Creek near White Cross monitoring station and the Cane Creek near Orange Grove monitoring station (See figures 2-1 and 2-2). TOC concentrations were measured in the two creeks monthly from October 1988 to December 1993 by the USGS.

2.3.2 Tributary Sampling Program. No TOC data existed, prior to this study, for the other tributaries in the two watersheds. To obtain TOC data for the rest of the tributaries, a sampling program was undertaken from August to December 1993. Each month, the eleven tributaries were sampled for TOC at the locations shown on the watershed maps, Figures 2-1 and 2-2. All of the tributaries were sampled on the same day to make the comparisons more accurate. TOC was measured using an Oceanographics International Model 700 Carbon Analyzer.

2.3.3 TOC Ratios. The data from the tributary sampling program was used to compare the concentration of TOC in each of the tributaries to the TOC concentration in the two USGS-monitored tributaries, Morgan and Cane Creek. The ratios obtained from this comparison represent the concentration in each tributary divided by the concentration of TOC in Morgan or Cane Creek.

2.3.4 Tributary TOC Load. The TOC load for each tributary was determined by using the historical annual average TOC concentration from the USGS data for Morgan or Cane Creek along with the ratios from the sampling program and the annual volume of flow from each tributary. Historical flow data exists for each watershed at the two USGS monitoring stations, Morgan Creek at White Cross and

Cane Creek near Orange Grove, for a four-year period from October 1988 to September 1992. It was assumed that the flow per acre was uniform in each watershed. Thus, the historical flow data for Morgan or Cane Creek was used to calculate the flows for the other tributaries in each of the watersheds. The annual volume of flow per acre for the Morgan or Cane Creek portion of the watershed was multiplied by the acreage of each of the other tributary drainage basins to determine the annual volume of flow for each tributary. Thus, the annual TOC load (in kg/yr) from a tributary was determined by multiplying the annual volume of flow for each tributary by the ratio of TOC for each tributary and by the historical average TOC concentration for Morgan or Cane Creek. The annual TOC load per acre (in kg/acre) for the tributaries was calculated by dividing the total annual TOC load from the tributaries by the total acreage drained by the tributaries.

2.3.5 Indirect Runoff TOC Load. To quantify the load of TOC from the indirect runoff areas, it was assumed that the indirect runoff acreage is similar to the rest of the watershed. This allowed the TOC tributary loading data to be used for the indirect runoff areas of the watersheds. The TOC load per acre for the tributary portion of the watershed was determined as noted above. This TOC load per acre was then multiplied by the acreage of the indirect runoff portion of the watershed to determine the indirect runoff TOC load.

2.3.6 Total Allochthonous TOC Load. The total annual TOC load to the reservoir from the watershed is the sum of the annual tributary TOC load and the annual indirect runoff TOC load. This total annual TOC load was used in conjunction with the total annual volume of flow to the reservoir to determine the average annual TOC concentration in the inflow to the reservoir or TOC_{all}. This TOC_{all} is the allochthonous portion of the in-lake TOC concentration. Again, sedimentation was assumed to be minimal as most of the TOC was expected to be in dissolved form.

2.4 AUTOCHTHONOUS TOC

The steps which were used to determine the concentration of TOC produced by algae in the reservoir were as follows:

1. Phosphorus and nitrogen data from the USGS and OWASA were used to determine the phosphorus and nitrogen concentrations in the inflow to the reservoirs.
2. Nutrient models from the literature were used to convert the phosphorus and nitrogen concentrations in the inflow to their subsequent in-lake nutrient concentrations.
3. Chlorophyll-a models from the literature were used to convert the in-lake nutrient concentrations to the amount of algae that will grow in the lake due to those nutrient concentrations. The amount of algae was quantified in terms of the chlorophyll-a concentration in the reservoir.
4. Chlorophyll-a concentration was then correlated to the algal biomass concentra-

tion in the reservoir, using correlation factors from the literature.

5. Finally, the algal biomass concentration in the reservoir was correlated to the equivalent TOC concentration in the reservoir, again using correlation factors from the literature.

2.4.1 Nutrient Concentrations in the Inflow. The methods described in the allochthonous TOC load section above were also used to determine the inflow concentration of phosphorus and nitrogen to the reservoirs. The phosphorus and nitrogen loads to the reservoirs are a combination of the tributary-loaded phosphorus and nitrogen and the indirect-runoff loaded phosphorus and nitrogen.

The tributary-loaded phosphorus and nitrogen were determined by using the historical monthly USGS data record from October 1988 to September 1992 for Morgan Creek near White Cross and Cane Creek near Orange Grove. The historical USGS data yielded annual average phosphorus and nitrogen concentrations for Morgan Creek and Cane Creek.

Two short-term nutrient sampling programs carried out by OWASA were used to obtain phosphorus and nitrogen concentrations for each tributary in the University Lake and the Cane Creek Reservoir watersheds. The data for the University Lake tributaries was from a two-month study while the data for the Cane Creek Reservoir tributaries was from a year-long sampling program. The data from the OWASA sampling programs was used to compare the amount of phosphorus and nitrogen in the tributaries to the amount of phosphorus and nitrogen in Morgan and Cane Creek. The comparison was done in the form of a ratio of the concentration of phosphorus and nitrogen in each creek to the phosphorus and nitrogen in Morgan and Cane Creek.

The phosphorus and nitrogen load was determined for each tributary by using the historical annual average phosphorus and nitrogen concentration from Morgan and Cane Creek, the ratio of the phosphorus and nitrogen concentrations in each tributary to the concentration in Morgan and Cane Creek, and the annual volume of flow from each tributary. The indirect runoff phosphorus and nitrogen loads were determined by using the phosphorus and nitrogen loads per acre (calculated from the tributary nutrient loads and acreage of the tributary drainage areas), the volume of flow from the indirect runoff area, and the acreage of the indirect runoff area. The sum of the tributary and indirect runoff phosphorus and nitrogen loads is the total phosphorus and nitrogen load to the reservoirs.

The annual average concentration of phosphorus and nitrogen in the influent to the reservoirs was determined by dividing the total phosphorus and nitrogen loads to the reservoirs by the total annual flow to the reservoirs.

2.4.2 Nutrient Models. To convert the phosphorus and nitrogen concentrations in the inflow to their subsequent in-lake concentrations, a nutrient model was used. The nutrient model was a eutrophication model developed by Walker (1985) for watersheds of the southeastern United States. The model is based on the classic Vollenweider-type eutrophication model (1975) which relates the phosphorus and nitrogen loadings to the in-lake phosphorus and nitrogen concentrations through reservoir characteristics, assuming steady-state behavior and complete mixing throughout the photic zone:

$$C_L = C_I/(1+k_C*T_w) \qquad \text{Equation 2-4}$$

where C_L = average nutrient concentration in the lake or reservoir (mg/L)

C_I = average nutrient concentration in the inflow (mg/L)

k_C = nutrient trapping coefficient (1/yr)

T_w = average hydraulic residence time (yr)

The nutrient trapping coefficients were calculated for phosphorus and nitrogen using the equations provided by Walker (1985):

$$k_p = (3.0)(P_I)^{0.53}(T_w)^{-0.75}(Z)^{0.58} \qquad \text{Equation 2-5}$$

$$k_n = (0.67)(T_w)^{-0.75} \qquad \text{Equation 2-6}$$

where k_p = nutrient trapping coefficient for phosphorus (1/yr)

k_n = nutrient trapping coefficient for nitrogen (1/yr)

P_I = average phosphorus concentration in the inflow (mg/L)

Z = mean depth (m)

The average hydraulic residence time was determined using USGS flow data and the known volumes of the reservoirs as produced by OWASA. The average hydraulic residence time is equal to the volume of the reservoir divided by the total yearly flow to the reservoir.

2.4.3 Chlorophyll-a Models. Two empirical models were used to calculate the chlorophyll-a concentration in the reservoirs from the in-lake nutrient concentrations. The first empirical model used was developed by Walker (1985) for reservoirs of the southeastern United States:

$$Chla = (X_{pn}^{1.33}/4.31)/[(1+K(X_{pn}^{1.33}/4.31)G)(1+(G)(A))] \quad \text{Equation 2-7}$$

where Chla = mean chlorophyll-a concentration for growing season (ug/L)

X_{pn} = composite nutrient concentration (ug/L) = $P_L^{-2}+((N_L-150)/12)^{-2})^{0.5}$

P_L = in-lake phosphorus concentration (ug/L)

N_L = in-lake nitrogen concentration (ug/L)

K = empirical coefficient relating nonalgal turbidity to chlorophyll-a (m^2/mg)

G = kinetic factor = $(Z_{mix})(0.14+0.0039/T_s)$

Z_{mix} = mean depth of mixed layer (m)

T_s = summer hydraulic residence time (yr)

= volume of the Reservoir/Average Summer Flow to Reservoir

A = non-algal turbidity (1/m)

The composite nutrient concentration, X_{pn}, and the kinetic factor, G, were calculated using the above equations from Walker (1985). The values used for the parameters K and A were literature values from Walker (1985). The mean depth of the mixed layer, Zmix, was determined by using mid-summer temperature-depth and dissolved oxygen-depth profiles for the Cane Creek Reservoir. University Lake did not have mid-summer temperature and dissolved oxygen profiles available, so a figure from Walker (1985) which relates mean total depth to mixing depth was used to determine the University Lake mixing depth. The summer hydraulic residence time, T_s, was determined by dividing the total flow to the reservoirs for the months of June, July and August by 0.25 year. The values used for the X_{pn}, K, A, G, Zmix and T_s are shown in Table 2-1 for both reservoirs.

The second empirical model used to determine the chlorophyll-a concentration in the reservoir was an empirical equation developed by Reckhow (1993) using data from North Carolina reservoirs. The equation is as follows:

$$LOG(Chla) = 2.330+0.775*LOG(P_L)+0.317*LOG(N_L) \qquad \text{Equation 2-8}$$

Table 2-1
Variables for the Walker Chlorophyll-a Equation

	1	2	3	4	5	6
Reservoir	*Composite Nutrient Conc., Xpn (ug/L)*	*Nonalgal Turbidity to Chlorophyll-a, K (sq-m/mg)*	*Nonalgal Turbidity, A (1/m)*	*Kinetic Factor, G*	*Mean Depth of Mixed Layer, Zmix (m)*	*Summer Residence Time, Ts (yr)*
Unversity Lake	49.18	0.025	0.8	0.16	1.0	0.252
Cane Creek Reservoir	36.67	0.03	0.8	0.427	3.00	1.598

2.4.4 Algal Biomass Concentration. Chlorophyll-a concentrations were converted to algal biomass concentrations using a correlation between chlorophyll-a and algal biomass. A literature search was done to determine the chlorophyll-a content of algae.

Three different literature values that were found for the average chlorophyll-a content of algae were from Oliver and Shindler (1980), Sakshaug (1977), and Patten et al. (1975). The average chlorophyll-a contents were, respectively, 1.15 percent, 0.886 percent, and 0.74 percent. For this study, the highest and lowest literature values were chosen to give a range of values for the algal biomass concentration. Thus, the Oliver and Shindler value of 1.15 percent and the Patten et al. value of 0.74 percent were used to convert the chlorophyll-a values to biomass values.

2.4.5 TOC Concentration Resulting from Algal Biomass. The TOC concentration resulting from the algal biomass was determined by converting the algal biomass concentrations in the reservoir to their corresponding TOC concentrations using two correlations from the literature.

The two values selected for the average TOC content of algae were from Oliver and Shindler (1980) and Redfield (1934). The average TOC contents were 36 percent and 40 percent, respectively. The Redfield value comes from the widely-used Redfield Ratios which quantify the amount of nutrients and carbon that are in living cells, such as algae.

2.5 COMPARISON OF ALLOCHTHONOUS AND AUTOCHTHONOUS

The simplified mass-balance equation, Equation 2-3, set the in-lake TOC concentration equal to the sum of the autochthonous and the allochthonous TOC concentrations in the reservoir. Thus, the TOC concentration in the reservoirs due to the two different sources could be directly compared. Using Equation 2-3, the prediction of the total amount of TOC in the reservoirs was calculated by summing the autochthonous and allochthonous TOC concentrations in the reservoirs. This value was subsequently compared to measured TOC concentrations by USGS and OWASA to verify the approach used.

CHAPTER 3 - RESULTS AND DISCUSSION

3.1 ALLOCHTHONOUS TOC

The TOC and nutrient concentrations in the inflow to the reservoir from the watershed, were determined using the methods described in Section 2.3.

3.1.1 Historical USGS Data. Historical data was obtained from the records of the United States Geological Survey (USGS) monitoring stations on Morgan Creek near White Cross and Cane Creek near Orange Grove. TOC concentrations were measured in the two creeks monthly from October 1988 to December 1993 by the USGS. The data are shown in Appendix A. The annual average TOC concentrations obtained from the USGS data for Morgan and Cane Creeks for this time period are shown in Table 3-1.

3.1.2 TOC Tributary Sampling Program. The TOC concentrations from the tributary sampling program undertaken from August to December 1993, are shown in Tables 3-2 and 3-3. Morgan Creek had the highest average TOC concentration of the University Lake tributaries with 5.4 mg/L and Pritchard Mill Creek had the lowest at 2.5 mg/L. The TOC concentration results for the Cane Creek Reservoir showed Dairy Creek with the highest average TOC concentration at 16.3 mg/L and Caterpillar Creek with the lowest at 3.5 mg/L. The unusually high average TOC concentration in Dairy

Table 3-1
Average TOC and Nutrient Concentrations for Morgan and Cane Creeks*

Station Name	1 *TOC Concentration (mg/L)*	2 *Phosphorus Concentration (mg/L as P)*	3 *Nitrogen Concentration (mg/L as N)*
Morgan Creek, White Cross	5.2	0.30	1.5
Cane Creek, Orange Grove	5.0	0.10	1.2

*from USGS data, Oct. 1988 - Dec. 1993.

Table 3-2
University Lake Tributary TOC Data

Date	1 *Morgan Creek (mg/L)*	2 *Phils Creek (mg/L)*	3 *Nevilles Creek (mg/L)*	4 *Pritchard Mill Creek (mg/L)*	5 *Price Creek (mg/L)*
8/24/93	4.5	4.8	4.5	2.0	
9/20/93	6.5	2.8	3.6	2.3	4.4
10/20/93	5.0	4.8	*	3.1	4.2
11/22/93	5.1	3.6	4.8	2.4	5.6
12/19/93	5.8	4.1	5.8	2.7	3.5
Average	5.4	4.0	4.7	2.5	4.4

Table 3-3
Cane Creek Reservoir Tributary TOC Data

Date	1 *Cane Creek (mg/L)*	2 *Bear Creek (mg/L)*	3 *Turkey Creek (mg/L)*	4 *Tom's Creek (mg/L)*	5 *Caterpillar Creek (mg/L)*	6 *Dairy Creek (mg/L)*
8/24/93	4.7	4.6	3.8	7.7	3.0	*
9/20/93	9.7	5.0	8.2	9.5	3.2	16.9
10/20/93	7.1	7.2	5.2	6.3	4.6	*
11/22/93	8.5	6.7	4.0	7.3	2.7	10.8
12/19/93	8.6	6.8	11.0	10.4	3.8	21.3
Average	7.7	6.1	6.4	8.2	3.5	16.3

*Creek was dry.

Creek was probably due to runoff from the dairy located on the creek.

3.1.3 Ratios. The data from the TOC tributary sampling program was used to compare the concentration of TOC in each of the tributaries to the TOC concentration in the two USGS-monitored tributaries, Morgan and Cane Creek. This was done to determine the annual average TOC loads from the tributaries. The comparison was done through the use of ratios which represent the measured concentration of TOC in each tributary for the five-month sampling period divided by the measured concentration of TOC in Morgan or Cane Creek for the same sampling period. The TOC ratio was calculated for each tributary, each month. Tables 3-4 and 3-5 show the TOC ratios for the tributaries. An average TOC ratio was then calculated for each creek for the five-month period, which is also shown in Tables 3-4 and 3-5.

3.1.4 Tributary Loads. The TOC load for each tributary was determined by using the historical annual average TOC concentration from the USGS data for Morgan and Cane Creek from Table 3-1 along with the ratios from the TOC sampling program in Tables 3-4 and 3-5 and the total annual volume of flow from each tributary.

The annual volume of flow from each tributary and indirect runoff area were determined using historical flow data from the two USGS monitoring stations, Morgan Creek at White Cross and Cane Creek near Orange Grove. The data are shown in Appendix B. The annual volume of flow to each reservoir from Morgan and Cane

Table 3-4
TOC Ratios for University Lake Tributaries*

Date	1 *Morgan Creek*	2 *Phils Creek*	3 *Nevilles Creek*	4 *Pritchard Mill Creek*	5 *Price Creek*
8/24/93	1.0	1.1	1.0	0.4	
9/20/93	1.0	0.4	0.6	0.3	0.7
10/20/93	1.0	1.0		0.6	0.8
11/22/93	1.0	0.7	0.9	0.5	1.1
12/19/93	1.0	0.7	1.0	0.5	0.6
Average	1.0	0.77	0.88	0.47	0.80

*Ratios are equal to the concentration of TOC in the named tributary divided by the concentration of TOC in Morgan Creek

Table 3-5
TOC Ratios for Cane Creek Reservoir Tributaries*

Date	1 *Cane Creek*	2 *Bear Creek*	3 *Turkey Creek*	4 *Tom's Creek*	5 *Caterpillar Creek*	6 *Dairy Creek*
8/24/93	1.0	1.0	0.8	1.6	0.6	
9/20/93	1.0	0.5	0.8	1.0	0.3	1.7
10/20/93	1.0	1.0	0.7	0.9	0.6	
11/22/93	1.0	0.8	0.5	0.9	0.3	1.3
12/19/93	1.0	0.8	1.3	1.2	0.4	2.5
Average	1.0	0.82	0.83	1.1	0.47	1.8

*Ratios are equal to the concentration of TOC in the named tributary divided by the concentration of TOC in Cane Creek

Creek was determined using the flow data. Using the acreage of the drainage area of Morgan and Cane Creek, the annual volume of flow for the two creeks was converted to an annual volume of flow per acre. It was assumed that the flow per acre in each watershed was uniform; thus, the annual volume of flow for the other tributaries was determined by multiplying the annual volume of flow per acre for the Morgan or Cane Creek portion of the watershed by the drainage areas of the other tributaries. The annual volume of flow for each tributary is shown along with the acreage of each of the drainage areas in Tables 3-6 and 3-7.

The annual TOC load from each tributary was next determined by multiplying the total annual volume of flow for each tributary by the ratio of TOC for each tributary and by the historical average TOC concentration for Morgan and Cane Creek. The results of this calculation are shown in Tables 3-8 and 3-9.

3.1.5 Indirect Runoff Loads. It was assumed that the indirect runoff portion of each watershed was similar to the rest of the watershed in terms of its TOC contribution; thus, the TOC load from indirect runoff was determined using the tributary TOC data. The TOC load per acre for the tributary portion of the watershed was determined using the annual tributary TOC load for each watershed in Tables 3-8 and 3-9, and the respective total tributary drainage area for each reservoir. The TOC load per acre was then multiplied by the acreage of the indirect runoff area to determine the indirect runoff TOC load. The indirect runoff TOC load is shown in

Table 3-6
Estimated Flows for the University Lake Tributaries

Tributary	1 *Drainage Area** *(acres)*	2 *Average Annual Flow From USGS Data* *(cfs)*	3 *Average Annual Flow Per Acre* *(cfs/acre)*	4 *Estimated Average Annual Flow* *(cfs)*
Morgan Creek	5,200	8.6	1.7E-03	8.59
Phils Creek	3,825			6.32
Nevilles Creek	2,550			4.21
Pritchard Mill Cr.	1,475			2.44
Price Creek	2,500			4.13
Total	15,550			25.7

*Data supplied by Edward Holland of OWASA.

Table 3-7
Estimated Flows for the Cane Creek Reservoir Tributaries

Tributary	1 *Drainage Area** *(acres)*	2 *Average Annual Flow from USGS Data* *(cfs)*	3 *Average AnnualFlow per Acre* *(cfs/acre)*	4 *Estimated Average Annual Flow* *(cfs)*
Cane Creek	4860	7.3	1.5E-03	7.29
Bear Creek	1330			2.00
Turkey Creek	3570			5.36
Tom's Creek	4940			7.41
Caterpillar Cr.	1790			2.69
Dairy	140			0.21
Total	16630			25.0

*Data supplied by Edward Holland of OWASA.

Table 3-8
TOC Load to University Lake from Tributaries

Tributary	1 *Average Annual Flow (cfs)*	2 *Ratio of Tributary TOC to Morgan Creek TOC*	3 *Morgan Creek TOC (mg/L)*	4 *Annual TOC Load (kg/yr)*
Morgan Creek	8.59	1.0	5.2	39,339
Phils Creek	6.32	0.77		22,369
Nevilles Creek	4.21	0.88		16,906
Pritchard Mill Creek	2.44	0.47		5,218
Price Creek	4.13	0.80		15,223
Total	25.7			99,055

Table 3-9
TOC Load to the Cane Creek Reservoir from Tributaries

Tributary	1 *Average Annual Flow (cfs)*	2 *Ratio of Tributary TOC to Cane Creek TOC*	3 *Cane Creek TOC (mg/L)*	4 *Annual TOC Load (kg/yr)*
Cane Creek	7.29	1.0	5.0	32,355
Bear Creek	2.00	0.82		7,268
Turkey Creek	5.36	0.83		19,650
Tom's Creek	7.41	1.1		36,727
Caterpillar Cr.	2.69	0.47		5,660
Dairy	0.21	1.8		1,708
Total	25.0			103,369

Tables 3-10 and 3-11.

3.1.6 Overall Allochthonous TOC Load. The overall annual TOC load to the reservoir is the sum of the annual tributary TOC load and the annual indirect runoff TOC load. This overall annual TOC load is shown in Table 3-12. The overall allochthonous TOC load was used in conjunction with the total annual volume of flow to the reservoir to determine the average annual TOC concentration in the inflow to the reservoir. The TOC concentration in the inflow to the reservoirs, or allochthonous TOC, is shown in Table 3-12.

3.2 AUTOCHTHONOUS TOC

The TOC concentration in the reservoirs produced by the algae in the reservoirs, was determined using the methods described in Section 2.4.

3.2.1 Nutrient Concentrations in the Inflow. The concentrations of phosphorus and nitrogen in the influent to the reservoirs were determined using the same methods as were used to determine the influent TOC concentrations to the reservoirs in Section 3.1.

Historical USGS Data. Historical data was obtained from the records of the USGS monitoring stations on Morgan Creek near White Cross and Cane Creek near Orange Grove. Phosphorus and nitrogen concentrations were measured in the two creeks

Table 3-10
TOC Load to University Lake from Indirect Runoff

Section of Watershed	1 *Annual Tributary TOC Load (kg/yr)*	2 *Drainage Area (acre)*	3 *Annual TOC Load per Acre (kg/acre-yr)*	4 *Annual Indirect Runoff TOC Load (kg/yr)*
Tributaries	99,055	15,550	6.37	-
Indirect Runoff	-	2,700	-	17,199

Table 3-11
TOC Load to the Cane Creek Reservoir from Indirect Runoff

Section of Watershed	1 *Annual Tributary TOC Load (kg/yr)*	2 *Drainage Area (acre)*	3 *Annual TOC Load per Acre (kg/acre-yr)*	4 *Annual Indirect Runoff TOC Load (kg/yr)*
Tributaries	103,369	16,630	6.22	-
Indirect Runoff	-	3,100	-	19,269

Table 3-12
Overall TOC Load to the Reservoirs

Reservoir	1 *Annual Tributary TOC Load (kg/yr)*	2 *Annual Indirect Runoff TOC Load (kg/yr)*	3 *Overall Annual TOC Load (kg/yr)*	4 *Total Annual Volume of Flow to Reservoir (L/yr)*	5 *Mean Inflow TOC conc. (mg/L)*
University Lake	99,055	17,199	116,254	2.69E+10	4.32
Cane Creek Reservoir	103,369	19,269	122,638	2.64E+10	4.64

monthly from October 1988 to December 1993 by the USGS. The data are shown in Appendix A. The annual average phosphorus and nitrogen concentrations obtained from the USGS data for Morgan and Cane Creeks for this time period are shown in Table 3-1.

OWASA Data. Two separate tributary sampling programs were undertaken by OWASA for the tributaries of University Lake and the Cane Creek Reservoir. The University Lake sampling program consisted of weekly phosphorus and nitrate sampling from September to October 1991. The average phosphorus and nitrate concentrations resulting from the two-month program are shown in Table 3-13. The Cane Creek Reservoir sampling program consisted of monthly phosphorus and nitrogen sampling from September 1992 to December 1993. The nitrogen measured for the Cane Creek Reservoir program was total nitrogen or the sum of nitrate, nitrite, and ammonia, while the nitrogen measured for the University Lake sampling program was only nitrate. The average concentrations of phosphorus and nitrogen resulting from the year-long period are shown in Table 3-14. The raw data from the OWASA sampling programs are shown in Appendix C. The University Lake sampling program only measured nitrate, while the Cane Creek Reservoir sampling program measure total nitrogen.

Ratios. The ratio method used in Section 3.1.3 to determine the TOC concentrations for each tributary was also used to determine phosphorus and nitrogen concentrations

Table 3-13
University Lake Tributary Phosphorus and Nitrate Data*

Tributary	1 *Average Phosphorus Concentration (mg/L)*	2 *Average Nitrate Concentration (mg/L)*
Morgan Creek	0.33	1.34
Phils Creek	0.04	1.02
Nevilles Creek	0.06	1.12
Pritchard Mill Creek	0.02	0.91
Price Creek	0.13	0.93

*from OWASA data, Sept. 1991 - Oct. 1991.

Table 3-14
Cane Creek Reservoir Tributary Phosphorus and Nitrogen Data*

Tributary	1 *Average Phosphorus Concentration (mg/L)*	2 *Average Nitrogen Concentration (mg/L)*
Cane Creek	0.12	1.25
Bear Creek	0.12	2.17
Turkey Creek	0.06	0.69
Tom's Creek	0.14	1.29
Caterpillar Cr.	0.17	3.99
Dairy	0.82	4.84

*from OWASA data, Sept. 1992 - Dec. 1993.

for each tributary. The nutrient data from the OWASA tributary sampling programs, Tables 3-13 and 3-14, was used to calculate the ratio of phosphorus and nitrogen ineach tributary to the phosphorus and nitrogèn in Morgan Creek and Cane Creek. The ratios obtained for phosphorus are shown in Tables C-5 and C-7 in Appendix C, and are summarized in Tables 3-15 and 3-16 for the two reservoirs. The ratios obtained for nitrogen are shown in Tables C-6 and C-8 in Appendix C, and are summarized in Tables 3-17 and 3-18.

The tributary sampling program for the tributaries of University Lake measured nitrate. Since the data from the sampling program was used for comparison purposes only, the nitrate ratio was used to represent the total nitrogen ratio, i.e. the nitrate ratio calculated from comparing the nitrate concentration in a tributary to the nitrate concentration in Morgan Creek was assumed to be similar to the total nitrogen ratio.

Tributary Loads. The phosphorus and nitrogen loads for each tributary were determined by using the historical annual average phosphorus and nitrogen concentration from the USGS data for Morgan and Cane Creek from Table 3-1, along with the ratios from the OWASA sampling program summarized in Tables 3-15 thru 3-18, and the total annual volume of flow from each tributary presented in Tables 3-6 and 3-7. The annual average phosphorus load from each tributary is shown in Tables 3-15 and 3-16, and the annual average nitrogen load from each tributary is shown in Tables 3-17 and 3-18.

Table 3-15
Phosphorus Load to University Lake from Tributaries

Tributary	1 *Ratio of Tributary Phosphorus to Morgan Creek Phosphorus*	2 *Average Annual Flow (cfs)*	3 *Morgan Creek Phosphorus (mg/L)*	4 *Annual Phosphorus Load (kg/yr)*
Morgan Creek	1.0	8.59	0.30	2,282
Phils Creek	0.14	6.32		227
Nevilles Creek	0.19	4.21		217
Pritchard Mill Creek	0.07	2.44		45
Price Creek	0.43	4.13		467
Total		25.7		3,238

Table 3-16
Phosphorus Load to the Cane Creek Reservoir from Tributaries

Tributary	1 *Ratio of Tributary Phosphorus to Cane Creek Phosphorus*	2 *Average Annual Flow (cfs)*	3 *Cane Creek Phosphorus (mg/L)*	4 *Annual Phosphorus Load (kg/yr)*
Cane Creek	1.0	7.29	0.10	651
Bear Creek	1.6	2.00		278
Turkey Creek	0.91	5.36		436
Tom's Creek	1.5	7.41		991
Caterpillar Cr.	2.5	2.69		597
Dairy	13.2	0.21		247
Total		25.0		3,201

Table 3-17
Nitrogen Load to University Lake from Tributaries

Tributary	1 *Ratio of Tributary Nitrogen to Creek Nitrogen*	2 *Average Annual Flow (cfs)*	3 *Morgan Creek Nitrogen (mg/L)*	4 *Annual Nitrogen Load (kg/yr)*
Morgan Creek	1.0	8.59	1.5	11,614
Phils Creek	0.80	6.32		6,875
Nevilles Creek	0.94	4.21		5,335
Pritchard Mill Creek	0.67	2.44		2,223
Price Creek	0.72	4.13		4,033
Total		25.7		30,080

Table 3-18
Nitrogen Load to the Cane Creek Reservoir from Tributaries

Tributary	1 *Ratio of Tributary Nitrogen to Creek Nitrogen*	2 *Average Annual Flow (cfs)*	3 *Cane Creek Nitrogen (mg/L)*	4 *Annual Nitrogen Load (kg/yr)*
Cane Creek	1.0	7.29	1.2	7,503
Bear Creek	1.7	2.00		3,479
Turkey Creek	0.64	5.36		3,537
Tom's Creek	1.2	7.41		8,953
Caterpillar Cr.	3.7	2.69		10,221
Dairy	4.3	0.21		936
Total		25.0		34,629

Indirect Runoff Loads. It was assumed that the indirect runoff portion of each watershed was similar to the rest of the watershed in terms of its phosphorus and nitrogen contributions. Thus, the phosphorus and nitrogen load from indirect runoff were determined using the tributary phosphorus and nitrogen data. The phosphorus and nitrogen loads per acre for the tributary portion of the watershed were determined using the annual tributary phosphorus and nitrogen loads for each watershed from Tables 3-15 thru 3-18, and the respective total tributary drainage area for each reservoir. The phosphorus and nitrogen loads per acre were then multiplied by the acreage of the indirect runoff area to determine the indirect runoff phosphorus and nitrogen loads. The indirect runoff phosphorus loads are shown in Tables 3-19 and 3-20, while the indirect runoff nitrogen loads are shown in Tables 3-21 and 3-22.

Overall Phosphorus and Nitrogen Loads. The overall annual phosphorus and nitrogen loads to the reservoirs are the sum of the annual tributary loads and the annual indirect loads. These overall annual phosphorus and nitrogen loads are shown in Tables 3-23 and 3-24. The overall phosphorus and nitrogen loads were used in conjunction with the total annual volume of flow to the reservoirs to determine the average annual phosphorus and nitrogen concentrations in the inflow to the reservoir. The phosphorus and nitrogen concentrations in the inflow to the reservoirs are shown in Tables 3-23 and 3-24.

Table 3-19
Phosphorus Load to University Lake from Indirect Runoff

Section of Watershed	1 *Annual Tributary Phosphorus Load (kg/yr)*	2 *Drainage Area (acre)*	3 *Annual Phosphorus Load per Acre (kg/acre-yr)*	4 *Annual Indirect Runoff Phosphorus Load (kg/yr)*
Tributaries	3,238	15,550	0.21	-
Indirect Runoff	-	2,700	-	562

Table 3-20
Phosphorus Load to the Cane Creek Reservoir from Indirect Runoff

Section of Watershed	1 *Annual Tributary Phosphorus Load (kg/yr)*	2 *Drainage Area (acre)*	3 *Annual Phosphorus Load per Acre (kg/acre-yr)*	4 *Annual Indirect Runoff Phosphorus Load (kg/yr)*
Tributaries	3,201	16,630	0.19	-
Indirect Runoff	-	3,100	-	597

Table 3-21
Nitrogen Load to University Lake from Indirect Runoff

Section of Watershed	1 *Annual Tributary Nitrogen Load (kg/yr)*	2 *Drainage Area (acre)*	3 *Annual Nitrogen Load per Acre (kg/acre-yr)*	4 *Annual Indirect Runoff Nitrogen Load (kg/yr)*
Tributaries	30,080	15,550	1.93	-
Indirect Runoff	-	2,700	-	5,223

Table 3-22
Nitrogen Load to the Cane Creek Reservoir from Indirect Runoff

Section of Watershed	1 *Annual Tributary Nitrogen Load (kg/yr)*	2 *Drainage Area (acre)*	3 *Annual Nitrogen Load per Acre (kg/acre-yr)*	4 *Annual Indirect Runoff Nitrogen Load (kg/yr)*
Tributaries	34,629	16,630	2.08	-
Indirect Runoff	-	3,100	-	6,455

Table 3-23
Overall Phosphorus Load to the Reservoirs

Reservoir	1 *Annual Tributary Phosphorus Load (kg/yr)*	2 *Annual Indirect Runoff Phosphorus Load (kg/yr)*	3 *Overall Annual Phosphorus Load (kg/yr)*	4 *Total Annual Volume of Flow to Reservoir (L/yr)*	5 *Mean Inflow Phosphorus conc. (mg/L)*
University Lake	3,238	562	3,800	2.69E+10	0.14
Cane Creek Reservoir	3,201	597	3,798	2.64E+10	0.14

Table 3-24
Overall Nitrogen Load to the Reservoirs

Reservoir	1 *Annual Tributary Nitrogen Load (kg/yr)*	2 *Annual Indirect Runoff Nitrogen Load (kg/yr)*	3 *Overall Annual Nitrogen Load (kg/yr)*	4 *Total Annual Volume of Flow to Reservoir (L/yr)*	5 *Mean Inflow Nitrogen conc. (mg/L)*
University Lake	30,080	5,223	35,303	2.69E+10	1.31
Cane Creek Reservoir	34,629	6,455	41,084	2.64E+10	1.55

3.2.2 Nutrient Models. Using the influent phosphorus and nitrogen concentrations from Tables 3-23 and 3-24, the in-lake concentrations of phosphorus and nitrogen were determined from the Walker (1985) eutrophication model, previously discussed in Section 2.4.2.

$$C_L = C_I/(1+k_C*T_w) \qquad \text{Equation 2-4}$$

C_L represents the average nutrient concentration in the lake or reservoir and C_I represents the average nutrient concentration in the inflow and k_C is the nutrient trapping coefficient. The nutrient trapping coefficients for phosphorus and nitrogen, $k_{C,P}$ and $k_{C,N}$ respectively, were calculated in accordance with Equations 2-5 and 2-6, and are shown in Table 3-25. Also shown in Table 3-25 is the average hydraulic residence time, T_w, used for the equation. The average nutrient concentrations in the reservoirs as calculated from the Walker eutrophication model are shown in Table 3-25. The calculated reservoir nutrient concentrations are compared to measured reservoir nutrient concentrations in Section 3.5.

3.2.3 Chlorophyll-a Models. Two empirical models were used to calculate the chlorophyll-a concentration in the reservoirs from the in-lake nutrient concentrations. The first empirical model used was developed by Walker (1985). The empirical model was introduced in Section 2.4.3 as Equation 2-7 and is as follows:

Table 3-25
In-Lake Nutrient Concentrations

Reservoir	1 *Phosphorus Trapping Coefficient, Kc,p (1/yr)*	2 *Nitrogen Trapping Coefficient, Kc,n (1/yr)*	3 *Hydraulic Residence Time, Tw (yr)*	4 *In-lake Phosphorus Conc. (mg/l)*	5 *In-Lake Nitrogen Conc. (mg/l)*
University Lake	12.3	4.44	0.080	0.071	0.97
Cane Creek Reservoir	5.49	1.26	0.430	0.043	1.01

Table 3-26
Variables for the Walker Chlorophyll-a Equation

Reservoir	1 *Composite Nutrient Conc., Xpn (ug/L)*	2 *Nonalgal Turbidity to Chlorophyll-a, K (sq-m/mg)*	3 *Nonalgal Turbidity, A (1/m)*	4 *Kinetic Factor, G*	5 *Mean Depth of Mixed Layer, Zmix (m)*	6 *Summer Residence Time, Ts (yr)*
Unversity Lake	49.2	0.025	0.8	0.16	1.0	0.252
Cane Creek Reservoir	36.7	0.03	0.8	0.427	3.00	1.60

Table 3-27
Predictions of Chlorophyll-a Concentration

Reservoir	1 *Walker Chlorophyll-a Prediction (ug/L)*	2 *Reckhow Chlorophyll-a Prediction (ug/L)*
University Lake	31.6	27.3
Cane Creek Reservoir	16.0	18.6

$$Chla = (X_{pn}^{1.33}/4.31)/[(1+K(X_{pn}^{1.33}/4.31)G)(1+(G)(A))] \qquad \text{Equation 2-7}$$

where Chla is the mean chlorophyll-a concentration for the growing season. The values used for the variables of the Walker chlorophyll-a equation are shown in Table 3-26 for each reservoir. The composite nutrient concentration, X_{pn}, was determined using the equation given in Section 2.4.3. The values used for K, the empirical coefficient relating nonalgal turbidity to chlorophyll-a, and A, nonalgal turbidity, were values from the literature (Walker, 1985). The kinetic factor, G, and the summer hydraulic residence time, T_s, were determined using the equations given in Section 2.4.3. The mean depth of the mixed layer, Zmix, was determined through an examination of temperature depth profiles for the summer months for the Cane Creek Reservoir, while Zmix for University Lake was determined from a figure relating mean total depth and Zmix from Walker (1985). The chlorophyll-a concentration calculated with the Walker equation for each reservoir is shown in Table 3-27.

The second empirical model used to determine the chlorophyll-a concentration in the reservoirs was an empirical equation developed by Reckhow (1993). The equation was introduced in Section 2.4.3 and is as follows:

$$LOG(Chla) = 2.330+0.775*LOG(P_L)+0.317*LOG(N_L) \qquad \text{Equation 2-8}$$

The chlorophyll-a concentrations resulting from the Reckhow equation are shown in Table 3-27. The chlorophyll-a concentrations predicted by the two models are relatively close to each other with a relative difference of approximately 13 percent. The calculated chlorophyll-a concentrations are compared to measured reservoir chlorophyll-a concentrations in Section 3.5.

3.2.4 Algal Biomass Concentration. The chlorophyll-a concentrations were converted to algal biomass concentrations using the average chlorophyll-a content of algae from Oliver and Shindler (1980) and Patten et al. (1975) as discussed in Section 2.4.4. The average chlorophyll-a contents were, respectively, 1.15% and 0.74%. The results of this conversion are shown in Table 3-28. The ranges indicated are for the two percentages applied to both the Walker and Reckhow predictions.

3.2.5 TOC Concentration Resulting from Algal Biomass. The TOC concentration resulting from the algal biomass was determined by using the average TOC content of algae from Oliver and Shindler (1980) and Redfield (1934). The average TOC contents were 36% and 40%, respectively, as discussed in Section 2.4.5. The results of this conversion are shown Table 3-28. Again, the ranges indicated are for the two percentages applied to both the Walker and Reckhow predictions.

Table 3-28
Concentration of TOC Resulting from Algal Production

Reservoir	1 *Algal Biomass Concentration (mg/l)*	2 *TOC From Algae (mg/l)*
University Lake	2.37 to 4.22	0.85 to 1.69
Cane Creek Reservoir	1.39 to 2.48	0.50 to 0.99

Table 3-29
TOC Concentrations in the Reservoirs

Reservoir	1 *TOC From Algae (mg/l)*	2 *TOC Directly Loaded from the Watershed (mg/l)*	3 *Overall TOC Conc. (mg/l)*
University Lake	0.85 to 1.69	4.32	5.16 to 6.01
Cane Creek Reservoir	0.50 to 0.99	4.64	5.14 to 5.63

3.3 OVERALL TOC

The overall TOC concentration in the reservoirs is equal to the sum of the TOC concentration resulting from the direct load from the watershed (the allochthonous TOC) and the TOC concentration resulting from the algae in the reservoir (the autochthonous TOC). The overall TOC concentration in the reservoirs is shown in Table 3-29.

3.4 RESULTS

The overall concentration of TOC in the University Lake and Cane Creek Reservoirs is shown in Table 3-29 along with the autochthonous and allochthonous TOC contributions. The allochthonous TOC load is the major source of TOC in the reservoir. The results of this study indicate that the majority of the TOC in University Lake, 72 to 84 percent, results from the allochthonous TOC load. The same is true for the Cane Creek Reservoir, where 82 to 90 percent of the TOC results from the allochthonous TOC load. The algae in the reservoirs contribute minimally to the TOC in the reservoirs producing only 10 to 28 percent of the TOC.

The model neglects biodegradation of TOC and release of TOC from sediments. However, references indicate TOC release from sediments is minimal (Martin, 1993).

3.5 VALIDATION OF RESULTS

To validate the results of the study, a comparison of the predicted TOC, phosphorus, nitrogen and chlorophyll-a concentrations to average measured concentrations in the two reservoirs are shown in Tables 3-30 through 3-33.

3.5.1 TOC Comparison. A comparison of the predicted TOC concentrations using the approach presented in this study to average measured concentrations of TOC in the two reservoirs is shown in Table 3-30. The reported measured concentrations of TOC were obtained from the USGS data base, and from an OWASA data base. The USGS data consists of a four-year data set for University Lake and a three-year data set for the Cane Creek Reservoir. The OWASA data consists of a seven-month sampling program for one location in University Lake and a year-long sampling program for three locations in the Cane Creek Reservoir. The raw data from these two sources is presented in Appendix D. Table 3-30 shows that the predicted TOC concentrations from this modeling study are in good agreement with the OWASA in-lake data for University Lake but not with the USGS in-lake data. The table also shows that the predicted TOC concentration in the Cane Creek Reservoir is relatively consistent with the OWASA data, within 20 percent for the three different locations in the reservoir. The USGS in-lake data for the Cane Creek Reservoir is again not in agreement with the predictions from this study, nor with the measured data from OWASA. This may be a result of a number of high TOC values by the USGS which may be attributable to high particulate TOC concentrations.

Table 3-30
Comparison of TOC Results

Reservoir	1 *Prediction (mg/L)*	2 *OWASA Data (mg/L)*	3 *USGS Data (mg/L)*
University Lake	5.16 to 6.01	5.26*	7.48***
Cane Creek Reservoir	5.14 to 5.63	6.5 to 6.7**	7.56****

* from OWASA data, Aug. 1993 - Feb. 1994.

** from OWASA data, Sept. 1992 - Dec. 1993.

*** from USGS data, Nov. 1988 - Aug. 1993.

****from USGS data, Apr. 1989 - Aug. 1993.

Table 3-31
Comparison of Phosphorus Results

Reservoir	1 *Prediction (mg/L)*	2 *OWASA (mg/L)*	3 *USGS Data (mg/L)*
University Lake	0.07	0.05 to 0.15*	0.04***
Cane Creek Reservoir	0.04	0.05 to 0.06**	0.04****

* from OWASA 1989 study by CDM (1989), range is a prediction, not a measured value.

** from OWASA data, Dec. 1992 - July 1993.

*** from USGS data, Nov. 1988 - Aug. 1993.

****from USGS data, Apr. 1989 - Aug. 1993.

Despite the many assumptions made in the modeling approach in this study, in the interest of simplification, the predictions give a reasonable estimate of the TOC concentrations in both reservoirs, at least when compared to OWASA's TOC data.

3.5.2 Phosphorus Comparison. A comparison of results for phosphorus obtained in this study to measured concentrations of phosphorus in the two reservoirs is shown in Table 3-31. Data from OWASA and the USGS were used for the measured concentrations of phosphorus in the reservoirs. The OWASA data consists of actual phosphorus concentrations for the Cane Creek Reservoir, and predicted concentrations for University Lake. The predicted University Lake phosphorus concentrations are from a 1989 University Lake watershed study by Camp Dresser & McKee (CDM, 1989). The University Lake phosphorus concentration predicted by the CDM study, is in agreement with the modeling results of this study. The USGS data, however, is 40 percent lower than the phosphorus concentration predicted by this study.

The Cane Creek Reservoir phosphorus concentration predicted by this study is in agreement with the USGS data. The OWASA data is relatively close, 25 to 50 percent higher than the phosphorus concentration predicted from this study. The raw data from OWASA and the USGS can be found in Appendix D, along with the predictions from the 1989 University Lake study by Camp Dresser & McKee (CDM, 1989).

3.5.3 Nitrogen Comparison. The comparison of the nitrogen results are shown in Table 3-32. The University Lake nitrogen concentration predicted by this study is in good agreement with the USGS nitrogen data and the OWASA nitrogen concentration predicted by the 1989 CDM study (CDM, 1989). The Cane Creek Reservoir nitrogen concentration prediction is also in good agreement with the USGS nitrogen data. The OWASA measured nitrogen concentration, however is 30 to 50 percent higher than the predicted nitrogen concentration for the Cane Creek Reservoir. The raw data from OWASA and the USGS can be found in Appendix D, along with the OWASA University Lake nitrogen predictions by CDM.

3.5.4 Chlorophyll-a Comparison. A comparison of the results obtained in this study for chlorophyll-a concentrations to corresponding measured concentrations for the two reservoirs is shown in Table 3-33. The University Lake chlorophyll-a concentration prediction is in agreement with the OWASA chlorophyll-a prediction by CDM (CDM, 1989). However, the USGS chlorophyll-a concentration is 64 percent lower than the lowest predicted chlorophyll-a concentration from this study. The Cane Creek Reservoir chlorophyll-a concentration is also in reasonable agreement with the measured chlorophyll-a data by OWASA. However, the USGS chlorophyll-a concentration is again appreciably lower than the predicted chlorophyll-a concentration, i.e. 40 percent lower, and also appreciably lower than OWASA measured values. The raw data from these two sources can be found in Appendix D, along with the OWASA 1989 chlorophyll-a predictions by CDM.

Table 3-32
Comparison of Nitrogen Results

Reservoir	1 *Prediction (mg/L)*	2 *OWASA (mg/L)*	3 *USGS Data (mg/L)*
University Lake	0.97	0.85 to 2.6*	0.91***
Cane Creek Reservoir	1.0	1.3 to 1.5**	0.96****

* from OWASA 1989 study by CDM (1989), range is a prediction, not a measured value.

** from OWASA data, Sept. 1992 - Dec. 1993.

*** from USGS data, Nov. 1988 - Aug. 1993.

****from USGS data, Apr. 1989 - Aug. 1993.

Table 3-33
Comparison of Chlorophyll-a Results

Reservoir	1 *Prediction (ug/L)*	2 *OWASA (ug/L)*	3 *USGS Data (ug/L)*
University Lake	27 to 32	16 to 40*	8.1***
Cane Creek Reservoir	16 to 19	11 to 18**	10.4****

* from OWASA 1989 study by CDM (1989), range is a prediction, not a measured value.

** from OWASA data, Sept. 1992 - Dec. 1993.

*** from USGS data, Nov. 1988 - Aug. 1993.

****from USGS data, Apr. 1989 - Aug. 1993.

3.6 SENSITIVITY ANALYSIS

The sensitivity of the autochthonous TOC modeling to different parameters was studied in order to determine which parameters have the greatest effect on the TOC concentration in the reservoirs. The parameters of interest were the phosphorus and nitrogen concentrations in the inflow to the reservoirs and the depth of the mixed layer in the reservoirs.

3.6.1 Sensitivity to Phosphorus and Nitrogen

The sensitivity of the model to phosphorus or nitrogen was determined by inputting phosphorus or nitrogen inflow concentrations at a level 50 percent higher and 50 percent lower than the actual phosphorus or nitrogen influent value calculated in this analysis. Tables 3-34 and 3-35 show the predicted influent phosphorus concentrations along with the ranges of values examined, while Tables 3-36 and 3-37 shows the same for nitrogen. The tables also show the predicted in-lake phosphorus, chlorophyll-a, autochthonous TOC, and overall TOC concentrations resulting from the variation in the nutrient inflow concentrations.

The percent change resulting from raising or lowering the phosphorus or nitrogen inflow concentrations are shown in Tables 3-34 through 3-37. For the reservoirs, lowering the phosphorus inflow concentration by 50 percent resulted in an autochthonous TOC decrease of only 5 to 8 percent, while increasing the phosphorus inflow concentration by 50 percent resulted in an autochthonous TOC increase of only

Table 3-34
Sensitivity of Results to Phosphorus Loading for University Lake

	1	2	3	4	5	6
Phosphorus	*Inflow Phosphorus Conc. (mg/L)*	*Resulting In-lake Phosphorus Conc. (mg/L)*	*Chlorophyll-a Conc. (ug/L)*	*TOC Conc. from Algae (mg/L)*	*Overall TOC Conc. (mg/L)*	*Percent Change from Average Overall TOC Conc. (mg/L)*
50 % Lower	0.07	0.04	20.0	0.86	5.2	-8%
Average	0.14	0.07	29.5	1.27	5.6	0%
50 % Higher	0.21	0.10	35.2	1.50	5.8	4%

Table 3-35
Sensitivity of Results to Phosphorus Loading for the Cane Creek Reservoir

	1	2	3	4	5	6
Phosphorus	*Inflow Phosphorus Conc. (mg/L)*	*Resulting In-lake Phosphorus Conc. (mg/L)*	*Chlorophyll-a Conc. (ug/L)*	*TOC Conc. from Algae (mg/L)*	*Overall TOC Conc. (mg/L)*	*Percent Change from Average Overall TOC Conc. (mg/L)*
50 % Lower	0.07	0.03	11.8	0.51	5.2	-5%
Average	0.14	0.04	17.3	0.75	5.4	0%
50 % Higher	0.21	0.05	20.6	0.89	5.5	2%

Table 3-36
Sensitivity of Results to Nitrogen Loading for University Lake

	1	2	3	4	5	6
Nitrogen	*Inflow Nitrogen Conc. (mg/L)*	*Resulting In-lake Nitrogen Conc. (mg/L)*	*Chlorophyll-a Conc. (ug/L)*	*TOC conc. from Algae (mg/L)*	*Overall TOC Conc. (mg/L)*	*Percent Change from Average Overall TOC Conc. (mg/L)*
50 % Lower	0.66	0.48	18.2	0.81	5.1	-9%
Average	1.31	0.97	29.5	1.27	5.6	0%
50 % Higher	1.97	1.45	35.1	1.52	5.8	4%

Table 3-37
Sensitivity of Results to Nitrogen Loading for the Cane Creek Reservoir

	1	2	3	4	5	6
Nitrogen	*Inflow Nitrogen Conc. (mg/L)*	*Resulting In-lake Nitrogen Conc. (mg/L)*	*Chlorophyll-a Conc. (ug/L)*	*TOC conc. from Algae (mg/L)*	*Overall TOC Conc. (mg/L)*	*Percent Change from Average Overall TOC Conc. (mg/L)*
50 % Lower	0.78	0.51	12.6	0.56	5.2	-4%
Average	1.55	1.01	17.3	0.75	5.4	0%
50 % Higher	2.33	1.51	19.3	0.84	5.5	2%

2 to 4 percent. Lowering the nitrogen inflow concentration by 50 percent in the reservoirs, resulted in an autochthonous TOC decrease of about 4 to 9 percent, while increasing the nitrogen inflow concentration by 50 percent resulted in an autochthonous TOC increase of about 2 to 4 percent. Therefore, the TOC concentration in the two reservoirs appears to be relatively insensitive to influent phosphorus and nitrogen.

3.6.2 Walker Chlorophyll-a Model Sensitivity to Mixing Depth

The sensitivity of the Walker Chlorophyll-a model to the mixing depth of the reservoirs, Zmix, was examined. The sensitivity was determined by inputting the Zmix value at a level 50 percent higher and 50 percent lower than the estimated Zmix value. Tables 3-38 and 3-39 shows the estimated Zmix value along with the ranges of Zmix values examined. The predicted chlorophyll-a concentrations resulting from the variation in Zmix values are also shown in Table 3-38 and 3-39, along with the autochthonous TOC and overall TOC concentrations.

Decreasing the mixing depth by 50 percent resulted in an increase of the chlorophyll-a concentration of 14 percent for University Lake and 20 percent for the Cane Creek Reservoir. Increasing the mixing depth by 50 percent resulted in a decrease of the chlorophyll-a concentration of 11 percent for University Lake and 26 percent for the Cane Creek Reservoir. However, the 50 percent reduction in the mixing depth increased the average overall TOC concentration by only 2 to 3 percent in the

Table 3-38
Walker Chlorophyll-a Model Sensitivity to Zmix for University Lake

	1	2	3	4	5
Zmix	*Zmix (m)*	*Chlorophyll-a Conc. (ug/L)*	*TOC conc. from Algae (mg/L)*	*Overall TOC Conc. (mg/L)*	*Percent Change from Average Overall TOC Conc. (mg/L)*
50 % Lower	0.5	36.0	1.50	5.8	3%
Average	1.0	31.6	1.34	5.7	0%
50 % Higher	1.5	28.0	1.18	5.5	-4%

Table 3-39
Walker Chlorophyll-a Model Sensitivity to Zmix for the Cane Creek Reservoir

	1	2	3	4	5
Zmix	*Zmix (m)*	*Chlorophyll-a Conc. (ug/L)*	*TOC conc. from Algae (mg/L)*	*Overall TOC Conc. (mg/L)*	*Percent Change from Average Overall TOC Conc. (mg/L)*
50 % Lower	1.5	20.8	0.88	5.5	2%
Average	3.0	17.3	0.75	5.4	0%
50 % Higher	4.5	12.8	0.54	5.2	-4%

reservoirs. The identical increase in mixing depth yielded only a 4 percent reduction in TOC concentration in the reservoirs. Therefore, the TOC concentration in the two reservoirs appears to be relatively insensitive to mixing depth.

3.7 IMPLICATIONS TO WATERSHED MANAGEMENT

The results of this study indicate that the majority of the TOC in the two reservoirs, 72 to 90 percent of it, results from allochthonous TOC. Autochthonous TOC only accounts for 10 to 28 percent of the TOC concentration in the reservoirs. This suggests that measures to reduce TOC concentrations by only controlling algal growth, such as through copper sulfate applications, could achieve an in-lake TOC reduction of only 10 to 28 percent. This would be expected to lower disinfection by-product formation by only 10 to 28 percent. Where additional TOC reduction is required, measures would need to be taken to reduce the allochthonous TOC load to the reservoir.

To reduce the allochthonous load, the major TOC sources in the watershed would need to be identified and either eliminated or minimized. The relative TOC contributions by the different tributaries can be analyzed to pinpoint high loads of TOC. Table 3-2 shows the average TOC concentrations for the tributaries of University Lake. Morgan Creek had by far the largest average TOC concentration at 5.4 mg/L. The relative TOC loads from the tributaries should also be examined. Table 3-8 shows that 34 percent of the allochthonous TOC load was from Morgan Creek.

Table 3-3 shows the average TOC concentrations for the tributaries of the Cane Creek Reservoir. Dairy Creek had the highest average TOC concentration at 16.3 mg/L, and Tom's Creek had the next highest average TOC concentration at 8.2 mg/L. The relatively high Dairy Creek TOC concentration is probably the result of runoff from dairy operations. The TOC load from Dairy Creek is shown in Table 3-9 along with the TOC loads from the other tributaries. Despite the high TOC concentration, the Dairy Creek TOC load was relatively low compared to the other tributaries, only 1.4 percent of the total allochthonous load. Tom's Creek had the highest tributary TOC load, contributing 30 percent of the total allochthonous TOC.

Control strategies to reduce the allochthonous TOC load should target Morgan Creek for University Lake and Tom's Creek for the Cane Creek Reservoir.

CHAPTER 4 - CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

To effectively control TOC concentrations in the two reservoirs serving the Orange Water and Sewer Authority, the sources of TOC must be known. This study used a simplified steady-state mass balance approach to compare the main sources of TOC in the University Lake and the Cane Creek Reservoir. The main TOC sources were the TOC which is directly loaded to the reservoirs from the watershed (allochthonous TOC) and the TOC which is produced in the reservoirs by algae generated as a result of nutrient influxes to the reservoirs (autochthonous TOC).

The results of this study indicate that allochthonous TOC is the primary source of TOC in the reservoirs. The TOC load from the watershed accounts for 72 to 90 percent of the total TOC concentration in the reservoirs. The autochthonous TOC load accounts for only 10 to 28 percent of the in-lake TOC concentration.

The estimates of the allochthonous and autochthonous loads are based on a simple modeling approach, but the results are in reasonable agreement with the observed TOC concentrations in the reservoirs. The sum of the allochthonous and autochthonous TOC predictions in the reservoirs are approximately 5.0 mg/L. This predicted TOC concentration is relatively close to the actual measured TOC concentrations in the reservoirs which are around 5.3 to 6.7 mg/L according to OWASA data.

4.2 RECOMMENDATIONS

The watershed management strategy adopted to reduce TOC concentrations in the reservoirs in order to control disinfection by-product precursors should be one which effectively minimizes TOC concentrations at the source. The results indicate that the major portion of TOC, 72 to 90 percent, is directly loaded to both the University Lake and Cane Creek reservoirs from the watershed (allochthonous TOC). Thus, the allochthonous TOC load would need to be targeted to reduce the TOC concentrations in the reservoirs substantially. To effectively minimize the allochthonous TOC load, the sources of TOC in the watershed should be identified.

To identify the major watershed sources of TOC, extensive TOC sampling of the tributaries is recommended. Sampling locations should include points upstream and downstream of dairies, farms and any other suspected TOC sources. Once identified, the major sources of TOC in the watershed can be studied to determine if they can be reduced.

The model used to obtain the estimates of the TOC loads in this study is relatively crude. A more comprehensive model could be developed and applied as more data becomes available.

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APPENDICES

APPENDIX A

USGS DATA

Table A-1
TOC, Nitrogen, and Phosphorus Data
for USGS Sample Location Morgan Creek at White Cross

	1	2	3
Date	TOC (mg/L as C)	Total Phosphorus (mg/L as P)	Total Nitrogen (mg/L as N)
10/25/88	6.5	0.24	0.9
11/21/88	5.6	0.16	1.1
12/16/88	3.5	0.09	1.1
1/11/89	4.8	0.19	1.6
2/16/89	3.6	0.11	0.8
2/28/89	12*	0.29	1.4
4/26/89	4.1	0.13	2.6
5/23/89	3.7	0.16	1.2
6/28/89	4.8	0.43	1.6
7/24/89	4.1	0.33	2.1
8/23/89	4.6	0.44	1.4
9/13/89	8.6	0.56	2.7
10/12/89	7.1	0.04	0.9
11/28/89	3.2	0.14	1.2
12/12/89	7.7	0.27	1.7
1/10/90	4.1	0.13	1.4
2/21/90	4.5	0.09	1.1
3/22/90	2.5	0.07	0.8
4/30/90	11*	0.69	2.5
5/29/90	13*	0.42	2.5
6/12/90	2.4	0.16	1.5
7/26/90	4	0.27	1.6
8/6/90	4	0.23	1.7
9/4/90	5.9	0.30	2.3
10/26/90	11		
11/19/90	4.3	0.13	1.1
12/19/90	3.9	0.16	0.9
1/15/91	4.5	0.09	1.2
2/26/91	2.9	0.06	1.1
3/27/91	3.3	0.12	0.7
4/23/91	4.6	0.12	0.9
5/29/91	6.7	0.14	1.8
6/24/91	5.2	0.45	2.6
7/29/91	7.8	0.49	1.9
8/15/91	11	0.59	2.3
9/23/91	15	0.52	4.4
11/25/91	6	0.39	0.7
12/4/91	5.8	0.37	0.8
1/3/92	25*	1.20	3.1
1/13/92	4.3	0.17	1.7
2/6/92	3.3	0.10	0.8
3/12/92	6.3	0.12	0.8
4/20/92	5.7	0.18	1.2
5/6/92	3.6	0.14	0.8

Table A-1
TOC, Nitrogen, and Phosphorus Data
for USGS Sample Location Morgan Creek at White Cross

	1	2	3
Date	*TOC (mg/L as C)*	*Total Phosphorus (mg/L as P)*	*Total Nitrogen (mg/L as N)*
6/3/92	4.2	0.20	1.0
7/14/92	5.2	0.34	1.8
8/4/92	4.5	0.23	1.4
9/2/92	4.5	0.32	1.0
10/8/92	7.4	0.29	1.3
11/19/92	4.4	0.21	1.4
12/2/92	4.2	0.21	1.3
1/5/93	58*	2.80	3.3
2/3/93	2.6	0.07	
3/30/93	4.1	0.08	1.0
4/22/93	8.3	0.06	
5/13/93	9.1	0.16	1.6
6/23/93	3.5	0.24	1.5
7/13/93	4.8	0.28	1.5
8/2/93	4.2	0.26	1.3
9/27/93	3.9	0.41	1.1
10/6/93	3.1	0.32	1.1
11/18/93	5	0.29	
12/15/93	4.1	0.20	1.4
Average	5.2	0.30	1.5
Standard Deviation	2.3	0.37	0.7

*Atypically high TOC data points were not included in the TOC average
These values assumed to be associated with high turbidity loads,
with particles that were assumed to settle out of the water column

Table A-2
TOC, Nitrogen, and Phosphorus Data
for USGS Sample Location Cane Creek near Orange Grove

Date	1 *TOC (mg/L as C)*	2 *Total Phosphorus (mg/L as P)*	3 *Total Nitrogen (mg/L as N)*
10/25/88	9.1	0.13	1.1
11/1/88			
11/21/88	6.2	0.06	1.2
12/16/88	4.1	0.04	1.0
1/11/89			
2/16/89	3.5	0.03	0.5
2/21/89			
2/28/89	12*	0.14	1.2
3/20/89			
3/24/89			
4/26/89	3.5	0.02	0.9
5/2/89			
5/23/89	2.9	0.04	1.0
6/9/89			
6/28/89	5.8	0.11	1.5
7/24/89	4.4	0.05	1.5
8/8/89			
8/23/89	4.9	0.15	1.3
9/12/89	3.5	0.08	1.1
10/12/89	4.1	0.06	1.4
11/16/89	5.0	0.06	0.6
12/12/89	8.7*	0.21	1.5
1/10/90	6.2	0.04	1.0
2/21/90	5.3	0.03	0.8
3/22/90	3.0	0.03	0.9
4/30/90	3.3	0.05	1.0
5/29/90	12*	0.32	2.7
6/14/90	2.5	0.04	1.5
7/17/90	3.1	0.06	0.9
8/6/90	3.2	0.06	0.7
9/4/90	4.0	0.05	0.6
10/25/90	13*	0.12	1.8
11/19/90	5.6	0.05	0.9
12/19/90	4.1	0.06	1.1
1/15/91	4.7	0.03	1.2
2/26/91	2.9	0.02	1.0
3/27/91	3.1	0.04	0.7
4/16/91	5.1	0.06	0.9
5/29/91	9.3*	0.27	2.4
6/19/91	12*		
7/29/91	7.5	0.14	1.9
8/28/91	3.9	0.13	1.1
9/19/91	4.2	0.10	0.5

Table A-2
TOC, Nitrogen, and Phosphorus Data
for USGS Sample Location Cane Creek near Orange Grove

	1	2	3
Date	*TOC (mg/L as C)*	*Total Phosphorus (mg/L as P)*	*Total Nitrogen (mg/L as N)*
11/19/91	5.0	0.09	1.0
12/4/91	5.1	0.05	0.4
1/3/92	20*	0.79	2.5
1/13/92	4.1	0.05	1.3
2/6/92	2.9	0.03	0.9
3/12/92	7.4	0.04	0.7
4/21/92	13*	0.16	1.4
5/6/92	3.8	0.06	1.1
6/3/92	4.7	0.10	1.2
7/14/92	4.8	0.09	1.3
8/4/92	7.8	0.32	1.2
9/2/92	7.4	0.29	1.8
10/8/92	10.0	0.14	1.1
11/19/92	5.8	0.05	1.4
12/2/92	6.3	0.08	1.7
1/11/93	6.7	0.04	0.9
2/3/93	2.8	0.03	2.3
3/30/93	4.6	0.02	0.8
4/5/93	3.3	0.02	0.8
5/13/93	8.4	0.08	1.4
6/23/93	3.0	0.06	1.2
7/13/93	5.5	0.14	1.0
8/2/93	4.5	0.12	0.9
9/27/93	6.5	0.10	0.8
10/6/93	5.0	0.07	0.5
11/18/93	8.5	0.13	0.5
12/15/93	5.0	0.03	1.2
Average	5.0	0.10	1.2
Standard Deviation	1.8	0.11	0.5

*Atypically high TOC data points were not included in the TOC average
These values assumed to be associated with high turbidity loads,
with particles that were assumed to settle out of the water column

APPENDIX B

FLOW DATA

Table B-1
USGS Average Monthly Flow Data
Sample Location: Morgan Creek at White Cross

	1	2	3	4	5	6	7
Month	*1988 Average monthly flow (cfs)*	*1989 Average monthly flow (cfs)*	*1990 Average monthly flow (cfs)*	*1991 Average monthly flow (cfs)*	*1992 Average monthly flow (cfs)*	*1993 Average monthly flow (cfs)*	*Overall Average Monthly Flow (cfs)*
January		2.54	13.20	20.60	8.39	16.30	12.21
February		22.00	22.70	4.15	11.00	6.84	13.34
March		27.90	15.90	15.30	11.70	46.10	23.38
April		17.20	14.90	9.01	6.61	19.70	13.48
May		30.10	19.20	7.31	2.77	4.29	12.73
June		3.93	4.69	3.26	13.30	0.96	5.23
July		5.29	1.09	7.37	2.61	0.67	3.41
August		2.61	1.08	2.79	3.01	2.97	2.49
September		2.25	0.08	3.47	1.26	4.54	2.32
October		13.10	4.10	1.27	1.29		4.94
November	3.47	7.61	2.48	1.56	5.71		4.17
December .	1.56	13.20	5.14	1.44	5.52		5.37
Average year flow (cfs)		12.31	8.71	6.46	6.10		8.59
Average Summer Flow* (cfs)		3.38	0.75	4.54	2.29		2.74

*Summer months were considered to be July, August, and September.

Table B-2
Average Monthly Flow Data
USGS Sample Location: Cane Creek at Orange Grove

Month	1 *1988 Average Monthly Flow (cfs)*	2 *1989 Average Monthly Flow (cfs)*	3 *1990 Average Monthly Flow (cfs)*	4 *1991 Average Monthly Flow (cfs)*	5 *1992 Average Monthly Flow (cfs)*	6 *1993 Average Monthly Flow (cfs)*	7 *Overall Average Monthly Flow (cfs)*
January		3.89	11.80	26.00	15.70	15.30	14.54
February		23.90	18.10	4.66	7.03	6.82	12.10
March		28.60	10.40	18.50	11.20	34.10	20.56
April		10.80	11.40	7.98	7.03	16.20	10.68
May		18.70	13.90	7.59	2.72	1.84	8.95
June		3.76	1.62	1.93	12.70	0.20	4.04
July		10.20	0.49	3.47	1.48	0.30	3.19
August		1.41	0.20	0.68	1.05	0.80	0.83
September		0.93	0.02	7.84	0.16	0.38	1.87
October		5.24	3.23	0.85	0.71		2.51
November	3.15	3.34	1.19	0.62	5.56		2.77
December	1.95	10.20	8.97	0.75	5.59		5.49
Average Year Flow (cfs)		10.08	6.78	6.74	5.91		7.29
Average Summer Flow* (cfs)		4.18	0.24	4.00	0.90		1.96

*Summer months were considered to be July, August, and September.

APPENDIX C

OWASA NUTRIENT DATA

Table C-1
Total Phosphorus Tributary Data for University Lake*

Date	1 Morgan Creek (mg/L P)	2 Phils Creek (mg/L P)	3 Neville Creek (mg/L P)	4 Pritchard's Mill Creek (mg/L P)	5 Price Creek (mg/L P)
9/9/91	0.31	0.03	0.02	0.01	0.06
9/16/91	0.29	0.07	0.07	0.04	0.08
9/23/91	0.49	0.05	0.03	0.05	0.1
9/30/91	0.3	0.04	0.06	0.01	0.07
10/7/91	0.33	0.01	0.07	0.01	0.11
10/14/91	0.26	0.02	0.03	0.02	0.07
10/21/91	0.29	0.07	0.13		0.48
10/28/91	0.38	0.06	0.08		0.09
Mean	0.33	0.04	0.06	0.02	0.13
Standard Deviation	0.07	0.02	0.04	0.02	0.14

*From OWASA Feeder Creek Monitoring Data

Table C-2
Nitrate Tributary Data for University Lake*

Date	1 Morgan Creek (mg/L as N)	2 Phils Creek (mg/L as N)	3 Neville Creek (mg/L as N)	4 Pritchard's Mill Creek (mg/L as N)	5 Price Creek (mg/L as N)
9/9/91	1.19	1.03	1.00	1.06	1.04
9/16/91	1.11	0.88	0.83	0.78	0.88
9/23/91	2.06	1.02	0.92	1.02	1.09
9/30/91	1.63	1.03	0.90	0.81	0.85
10/7/91	1.16	0.91	0.87	0.88	0.74
10/14/91	1.29	0.89	0.93	0.91	0.93
10/21/91	1.23	0.81	0.78		0.78
10/28/91	1.02	1.55	2.76		1.09
Mean	1.34	1.02	1.12	0.91	0.93
Standard Deviation	0.34	0.23	0.66	0.11	0.14

*From OWASA Feeder Creek Monitoring Data

Table C-3
Total Phosphorus Tributary Data for the Cane Creek Reservoir*

	1	2	3	4	5	6
Date	*Cane Creek (mg/L P)*	*Bear Creek (mg/L P)*	*Turkey Creek (mg/L P)*	*Tom's Creek (mg/L P)*	*Caterpillar Creek (mg/L P)*	*Dairy Creek (mg/L P)*
9/14/92	0.16	0.24	0.20	0.45	0.08	
10/5/92	0.71	0.16	0.08	0.22	0.41	
10/26/92	0.11	0.04	0.01	0.14	0.05	
11/16/92	0.07	0.13	0.03	0.10	0.08	0.63
12/7/92	0.11	0.17	0.03	0.05	0.06	0.47
12/28/92	0.04	0.13	0.25	0.07	0.82	1.49
1/18/93	0.04	0.11	0.02	0.05	0.08	0.47
2/9/93	0.06	0.09	0.01	0.07	0.27	0.62
3/2/93	0.02	0.03	0.02	0.02	0.03	0.54
3/23/93	0.04	0.09	0.07	0.09	0.10	0.52
4/20/93	0.04	0.11	0.05	0.05	0.09	0.62
5/4/93	0.04	0.03	0.04	0.06	0.06	0.47
5/25/93	0.07	0.17	0.04	0.14	0.13	
6/15/93	0.08	0.13	0.05	0.17	0.20	0.53
7/7/93	0.24	0.19	0.09	0.43	0.22	2.31
7/27/93	0.09	0.12	0.03	0.24	0.16	
8/17/93	0.12	0.14	0.04	0.18	0.19	1.24
10/27/93	0.15	0.04	0.02	0.08	0.07	
11/30/93	0.09	0.15	0.10	0.14	0.14	0.88
12/13/93	0.08	0.14	0.05	0.09	0.09	0.63
Mean	0.12	0.12	0.06	0.14	0.17	0.82
Standard Deviation	0.15	0.06	0.06	0.12	0.18	0.53

*From OWASA Feeder Creek Monitoring Data

Table C-4
Total Nitrogen Tributary Data for the Cane Creek Reservoir*

	1	2	3	4	5	6
Date	Cane Creek (mg/L as N)	Bear Creek (mg/L as N)	Turkey Creek (mg/L as N)	Tom's Creek (mg/L as N)	Caterpillar Creek (mg/L as N)	Dairy Creek (mg/L as N)
9/14/92		3.91		1.20		
10/5/92	2.10	2.62	1.18		9.18	
10/26/92				1.20		
11/16/92	1.60	2.81	0.68	1.46	3.26	5.40
12/7/92	1.93	3.18	0.57	1.34	3.67	4.95
12/28/92	1.41	2.43	0.46	1.58	6.95	7.52
1/18/93	1.21	2.27	0.36	1.20	3.27	4.64
2/9/93	0.63	0.79	0.57	0.74	3.47	2.75
3/2/93	0.54	0.73	0.55	0.68	2.34	4.29
3/23/93	0.39	0.53	0.41	0.48	1.97	3.06
4/20/93	0.83	2.22	0.60	0.68	3.25	3.43
5/4/93	0.85	1.70	0.73	1.83	3.13	2.89
5/25/93	1.48	3.22	0.83	1.32	3.47	
6/15/93	1.80	3.06	0.96	1.89	3.35	2.27
7/7/93	1.46	0.73	0.63	1.29	4.42	6.62
7/27/93	0.92	2.32	0.65	1.62	3.73	
8/17/93	2.14	3.15	0.98	2.60	4.28	11.35
10/27/93	0.38	0.69	0.39	0.63	3.03	
11/30/93	1.57	2.77	1.15	1.54	5.12	3.78
12/13/93						
Mean	1.25	2.17	0.69	1.29	3.99	4.84
Standard Deviation	0.58	1.06	0.25	0.53	1.74	2.49

*From OWASA Feeder Creek Monitoring Data

Table C-5
University Lake Total Phosphorus Ratios*

Date	1 Morgan Creek	2 Phils Creek	3 Neville Creek	4 Pritchard's Mill Creek	5 Price Creek
9/9/91	1.00	0.10	0.06	0.03	0.19
9/16/91	1.00	0.24	0.24	0.14	0.28
9/23/91	1.00	0.10	0.06	0.10	0.20
9/30/91	1.00	0.13	0.20	0.03	0.23
10/7/91	1.00	0.03	0.21	0.03	0.33
10/14/91	1.00	0.08	0.12	0.08	0.27
10/21/91	1.00	0.24	0.45		1.66
10/28/91	1.00	0.16	0.21		0.24
Mean	1.00	0.14	0.19	0.07	0.43
Standard Deviation	0.00	0.08	0.12	0.04	0.50

*Ratios of Conc. of Phosphorus in Tributary to Conc. of Phosphorus in Morgan Creek

Table C-6
University Lake Nitrate Ratios*

Date	1 Morgan Creek	2 Phils Creek	3 Neville Creek	4 Pritchard's Mill Creek	5 Price Creek
9/9/91	1.00	0.87	0.84	0.89	0.87
9/16/91	1.00	0.79	0.75	0.70	0.79
9/23/91	1.00	0.50	0.45	0.50	0.53
9/30/91	1.00	0.63	0.55	0.50	0.52
10/7/91	1.00	0.78	0.75	0.76	0.64
10/14/91	1.00	0.69	0.72	0.71	0.72
10/21/91	1.00	0.66	0.63		0.63
10/28/91	1.00	1.52	2.71		1.07
Mean	1.00	0.80	0.94	0.67	0.72
Standard Deviation	0.00	0.31	0.79	0.15	0.19

*Ratios of Conc. of Nitrate in Tributary to Conc. of Nitrate in Morgan Creek

Table C-7
Cane Creek Reservoir Total Phosphorus Ratios*

Date	1 Cane Creek	2 Bear Creek	3 Turkey Creek	4 Tom's Creek	5 Caterpillar Creek	6 Dairy Creek
9/14/92	1.00	1.50	1.25	2.81	0.50	
10/5/92	1.00	0.23	0.11	0.31	0.58	
10/26/92	1.00	0.36	0.09	1.27	0.45	
11/16/92	1.00	1.86	0.43	1.43	1.14	9.00
12/7/92	1.00	1.55	0.27	0.45	0.55	4.27
12/28/92	1.00	3.25	6.25	1.75	20.50	37.25
1/18/93	1.00	2.75	0.50	1.25	2.00	11.75
2/9/93	1.00	1.50	0.17	1.17	4.50	10.33
3/2/93	1.00	1.50	1.00	1.00	1.50	27.00
3/23/93	1.00	2.25	1.75	2.25	2.50	13.00
4/20/93	1.00	2.75	1.25	1.25	2.25	15.50
5/4/93	1.00	0.70	1.00	1.50	1.50	11.75
5/25/93	1.00	2.43	0.57	2.00	1.86	
6/15/93	1.00	1.63	0.63	2.13	2.50	6.63
7/7/93	1.00	0.79	0.38	1.79	0.92	9.63
7/27/93	1.00	1.35	0.39	2.86	1.82	
8/17/93	1.00	1.17	0.33	1.50	1.58	10.33
10/27/93	1.00	0.27	0.13	0.53	0.47	
11/30/93	1.00	1.67	1.11	1.56	1.56	9.78
12/13/93	1.00	1.75	0.63	1.13	1.13	7.88
Mean	1.00	1.56	0.91	1.50	2.49	13.15
Standard Deviation	0.00	0.84	1.34	0.69	4.35	8.72

*Ratios of Conc. of Phosphorus in Tributary to Conc. of Phosphorus in Cane Creek

Table C-8
Cane Creek Reservoir Total Nitrogen Ratios*

Date	1 Cane Creek	2 Bear Creek	3 Turkey Creek	4 Tom's Creek	5 Caterpillar Creek	6 Dairy Creek
9/14/92						
10/5/92	1.00	1.25	0.56		4.37	
10/26/92						
11/16/92	1.00	1.76	0.43	0.91	2.04	3.38
12/7/92	1.00	1.65	0.30	0.69	1.90	2.56
12/28/92	1.00	1.72	0.33	1.12	4.93	5.33
1/18/93	1.00	1.88	0.30	0.99	2.70	3.83
2/9/93	1.00	1.25	0.90	1.17	5.50	4.37
3/2/93	1.00	1.35	1.02	1.26	4.33	7.94
3/23/93	1.00	1.36	1.05	1.23	5.05	7.85
4/20/93	1.00	2.67	0.72	0.82	3.92	4.13
5/4/93	1.00	2.00	0.86	2.15	3.68	3.40
5/25/93	1.00	2.18	0.56	0.89	2.34	
6/15/93	1.00	1.70	0.53	1.05	1.86	1.26
7/7/93	1.00	0.50	0.43	0.88	3.02	4.52
7/27/93	1.00	2.52	0.71	1.76	4.05	
8/17/93	1.00	1.47	0.46	1.21	2.00	5.30
10/27/93	1.00	1.79	1.03	1.65	7.91	
11/30/93	1.00	1.76	0.73	0.98	3.26	2.41
12/13/93						
Mean	1.00	1.69	0.64	1.17	3.70	4.33
Standard Deviation	0.00	0.51	0.26	0.38	1.60	1.95

*Ratios of Conc. of Nitrogen in Tributary to Conc. of Nitrogen in Cane Creek

APPENDIX D

RESERVOIR DATA

Table D-1
USGS TOC Data for University Lake Reservoir

Date	*TOC (mg/L)*
11/21/88	9.10
4/26/89	5.70
6/28/89	6.00
8/23/89	8.10
9/13/89	5.20
10/12/89	6.90
4/30/90	4.80
6/12/90	6.20
8/6/90	6.70
9/4/90	6.30
10/26/90	8.60
4/23/91	5.70
6/24/91	6.40
7/31/91	9.10
8/15/91	15.00
9/23/91	8.50
11/25/91	8.9
4/30/92	6.80
6/4/92	8.10
8/10/92	9.80
10/14/92	6.60
5/3/93	7.20
6/3/93	6.80
8/5/93	6.90
Average	7.48
Standard Deviation	2.09

Table D-2
USGS Data for University Lake Reservoir

Date	1 *Total Phosphorus (mg/L)*	2 *Total Nitrogen (mg/L)*	3 *Chlorophyll-a (ug/L)*
11/21/88	0.06	0.90	9.50
4/26/89	0.05	1.60	4.60
6/28/89	0.08	0.90	3.80
8/23/89	0.03	0.70	5.70
9/13/89	0.04	0.60	1.30
10/12/89	0.04	1.20	7.50
4/30/90	0.03	0.50	
6/12/90	0.03	0.60	9.20
8/6/90	0.02	0.60	3.50
9/4/90	0.03	0.60	
10/26/90	0.06	1.00	
4/23/91	0.03	0.59	
6/24/91	0.04	1.00	
7/31/91	0.05	0.80	8.50
8/15/91	0.07	3.20	6.00
9/23/91	0.08	2.60	6.80
11/25/91	0.05	0.96	13.0
4/30/92	0.02	0.40	9.10
6/4/92	0.05	0.40	1.10
8/10/92	0.03	0.60	6.90
10/14/92	0.05	0.97	10.00
5/3/93	0.04	0.40	12.00
6/3/93	0.03	0.30	6.80
8/5/93	0.02	0.40	28.00
Average	0.04	0.91	8.07
Standard Deviation	0.02	0.69	5.80
Growing Season Average*			7.69

*Growing Season Average includes April to October.

Table D-3
OWASA TOC data for University Lake

Date	TOC (mg/L)
8/18/93	4.90
9/9/93	6.56
9/15/93	5.80
10/4/93	5.37
10/11/93	5.01
10/26/93	4.61
11/10/93	4.82
12/10/93	6.29
12/27/93	6.03
1/19/94	4.28
2/1/94	4.19
Average	5.26
Standard Deviation	0.81

Table D-4
University Lake Predictions*

	1 *Total Phosphorus (mg/L)*	2 *Total Nitrogen (mg/L)*	3 *Chlorophyll-a (ug/L)*
Low	0.05	0.85	16.1
Medium	0.09	1.49	28.2
High	0.15	2.59	40.3

*from 1989 University Lake Watershed Study by CDM (1989).

Table D-5
USGS TOC Data
for Cane Creek Reservoir

Date	*TOC (mg/L)*
4/26/89	9.50
6/28/89	8.40
8/23/89	5.20
9/13/89	7.90
10/12/89	2.90
4/30/90	5.80
6/12/90	8.10
8/6/90	5.40
9/4/90	6.40
10/26/90	6.60
4/16/91	8.80
6/24/91	6.40
7/29/91	7.80
8/28/91	9.90
9/19/91	7.50
9/19/91	8.10
11/19/91	9.40
4/30/92	8.90
6/4/92	3.50
8/10/92	49*
10/14/92	7.40
4/22/93	16.00
6/3/93	7.40
8/5/93	6.60
Average	7.56
Standard Deviation	2.57

*Atypically high TOC Value was not used for the TOC Average.

Table D-6
USGS Data for Cane Creek Reservoir

	1	2	3
Date	*Total Phosphorus (mg/L)*	*Total Nitrogen (mg/L)*	*Chlorophyll-a (ug/L)*
4/26/89	0.06	2.00	2.10
6/28/89	0.04	0.70	8.10
8/23/89	0.04	0.70	5.00
9/13/89	0.06	0.90	64.00
10/12/89	0.23	2.10	7.50
4/30/90	0.02	0.80	3.20
6/12/90	0.03	1.30	5.10
8/6/90	0.03	0.50	8.10
9/4/90	0.04	0.80	9.40
10/26/90	0.04	0.80	7.50
4/16/91	0.03	1.00	2.50
6/24/91	0.03	0.90	9.90
7/29/91	0.03	0.80	7.40
8/28/91	0.03	1.10	3.60
9/19/91	0.04	1.20	6.10
9/19/91	0.03	1.10	7.50
11/19/91	0.02	1.30	0.00
4/30/92	0.03	1.20	19.00
6/4/92	0.04	0.74	8.10
8/10/92	0.02	0.50	2.20
10/14/92	0.04	0.70	22.00
4/22/93	0.08	0.98	7.20
6/3/93	0.02	0.50	22.00
8/5/93	0.01	0.40	12.00
Average	0.04	0.96	10.40
Standard Deviation	0.04	0.42	12.79
Growing Season Average*			10.85

*Growing Season Includes April to October.

Table D-7
OWASA TOC Data for the Cane Creek Reservoir

	1	2	3
Date	Sample Site #3 (mg/L)	Sample Site #5 (mg/L)	Sample Site #7 (mg/L)
9/14/92			
10/5/92			
10/26/92	8.0	7.0	7.0
11/16/92	11.0	9.0	9.0
12/7/92	8.0	7.0	7.0
12/28/92	7.0	7.0	8.0
1/18/93	7.0	7.0	7.0
2/8/93			
3/1/93			
3/22/93	5.9	7.7	6.6
4/19/93			
5/3/93			
5/24/93	6.7	6.3	6.3
6/14/93	6.4	6.0	6.1
7/6/93	5.0	5.4	5.6
7/26/93	5.5	4.7	4.7
8/16/93	6.5	5.7	5.5
10/25/93	5.7	7.0	9.4
11/23/93	4.7	4.5	4.5
12/13/93			
Average	6.7	6.5	6.7
Standard Deviation	1.6	1.2	1.5

Table D-8
OWASA Total Phosphorus Data for the Cane Creek Reservoir

	1	2	3
Date	Sample Site #3 (mg/L)	Sample Site #5 (mg/L)	Sample Site #7 (mg/L)
9/14/92	0.04		0.18
10/5/92	<0.01	<0.01	<0.01
10/26/92	0.03	0.03	0.02
11/16/92	0.03	0.01	0.05
12/7/92	0.03	0.03	0.03
12/28/92	0.04	0.02	0.02
1/18/93	0.04	0.03	0.04
2/8/93	0.08	0.05	0.04
3/1/93	0.03	0.02	0.03
3/22/93	0.16	0.15	0.13
4/19/93	0.07	0.11	0.08
5/3/93	0.05	0.04	0.09
5/24/93	0.04	0.03	0.04
6/14/93	0.04	0.03	0.03
7/6/93	0.04	0.03	0.02
7/26/93	0.01	0.01	
8/16/93	0.04	0.04	0.04
10/25/93	0.05	0.14	0.07
11/23/93	0.04	0.04	0.03
12/13/93	0.07	0.05	0.06
Average	0.05	0.05	0.06
Standard Deviation	0.03	0.04	0.04

Table D-9
OWASA Total Nitrogen Data for the Cane Creek Reservoir

	1	2	3
Date	Sample Site #3 (mg/L)	Sample Site #5 (mg/L)	Sample Site #7 (mg/L)
9/14/92			
10/5/92			
10/26/92			
11/16/92			
12/7/92			1.32
12/28/92	1.12	1.16	1.18
1/18/93	1.22	1.20	1.20
2/8/93			
3/1/93	0.76	0.83	0.85
3/22/93		0.64	0.81
4/19/93	1.89	1.60	1.37
5/3/93	2.59	2.06	2.90
5/24/93			
6/14/93			1.09
7/6/93	1.27	1.44	0.86
7/26/93			
8/16/93			
10/25/93			
11/23/93			
12/13/93			
Average	1.47	1.28	1.29
Standard Deviation	0.66	0.48	0.64

Table D-10
OWASA Chlorophyll-a Data for the Cane Creek Reservoir

	1	2	3
Date	Sample Site #3 (mg/m^3)	Sample Site #5 (mg/m^3)	Sample Site #7 (mg/m^3)
9/14/92	59.29		12.36
10/5/92	21.34	10.18	8.23
10/26/92	29.22	29.88	19.53
11/16/92	4.57	3.87	3.68
12/7/92	2.35	2.35	2.82
12/28/92	9.91	5.26	4.66
1/18/93	4.20	6.22	5.03
2/8/93			
3/1/93			
3/22/93	12.11	8.15	4.95
4/19/93			
5/3/93			
5/24/93	29.80	24.70	24.90
6/14/93	20.76	18.95	14.83
7/6/93	19.40	17.76	26.68
7/26/93	16.03	15.25	14.20
8/16/93	23.39	17.51	13.69
10/25/93	11.23	7.99	7.88
11/23/93	7.40	7.52	6.72
12/13/93			
Average	18.07	12.54	11.34
Standard Deviation	14.39	8.28	7.62
Growing Season Average*	25.61	17.78	15.81

*Growing Season includes April to October.