EFFECTS OF COPPER ON NITRIFICATION AND DENITRIFICATION OF LEACHATE FROM AN ABANDONED LANDFILL

by

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(ABSTRACT)

The purpose of this study was to investigate the effects of copper on the treatment of an abandoned landfill leachate by a Modified Ludzack Ettinger (MLE) single-sludge, activated sludge treatment system. MLE systems are designed to accomplish nitrification and denitrification, and at least two systems were used: one to which copper was added, and one maintained as a control. The system that did not receive copper additions gave an indication of the treatability of the leachate by an MLE system.

Copper was added at concentrations of 1.0, 2.0, 2.5, and 5.0 mgCu/L in the influent and the sludge age was varied from 8 to 30 day. It was determined that copper did inhibit nitrification and denitrification. A strong linear relationship was shown to exist between the specific copper loading on the system, that is the total copper entering the system within a day divided by the total biomass within the system, and the soluble copper concentration within the system. The adsorption of copper by the activated sludge, and the resulting soluble copper concentration in the mixed liquor, could be generally described by the Freundlich Isotherm.

Intermittent inhibition of nitrification unrelated to copper addition also occurred during treatment of the landfill leachate which was obtained from the abandoned Dixie Caverns Landfill near Roanoke, Virginia. The inhibiting substance was not identified during this study. It did not significantly inhibit denitrification,

but did cause elevated effluent suspended solids concentrations. An additional treatment step would be needed for reliable treatment of the leachate.

Copper additions caused inhibition of both nitrification and denitrification. The degree of nitrification and denitrification inhibition was a strong function of the soluble copper to MLVSS ratio in the reactors, i.e., the toxin-to-microorganism (T/M) ratio. Nitrification and denitrification appeared to be equally sensitive to copper. Both were severely inhibited at a soluble copper to MLVSS ratio of 0.001 in aerobic and anoxic reactors, respectively. *Nitrosomonas* species were more strongly inhibited by copper concentrations than were the *Nitrobacter* species. The denitrifiers appeared to be as sensitive to copper as the *Nitrosomonas* species.

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CHAPTER I. INTRODUCTION

Solid waste disposal and treatment issues have gained public attention in recent years because of environmental concerns. Incineration, ocean dumping, and sanitary landfills are the three major ways of disposing of solid wastes, and of these the most widely used method is sanitary landfills. In the recent past, and even in some places today, sanitary landfills were not so sanitary but were more like open dumps with no daily soil covering and no bottom liners. Soil covering helps control odors, spread of diseases, fires, and rodent populations. Bottom liners help protect ground water and surface water from contamination by landfill leachates. Proper disposal of solid wastes are important to help protect the environment and the public health.

Landfills fill up with water over time because of precipitation, the water leaches chemicals from the solid wastes, and the contaminated water (leachate) starts percolating from the bottom and sides of the landfill. Leachate from an operating landfill at first will have a high biological oxygen demand (BOD) associated with it because the initial extract from solid wastes typically contains readily biodegradable organics. As the landfill ages, however, the leachates become less biodegradable because of biodegradation in the landfill, and older leachates characteristically have high ammonia (NH3) concentrations (>35 mgNH3-N/L) and low BOD (10-30 mg/L). Ammonia is toxic to aquatic life. Also the nitrogen content of landfill leachates can accelerate the eutrophication process in surface waters and can contaminate ground water to such a degree that methemoglobinemia ("blue baby disease") may occur in infants if they drink it. Thus, landfill leachates have undesirable effects on both groundwaters and surface waters and usually need to be treated to protect water quality.

This investigation continued a treatability study of leachate from an abandoned municipal landfill that employed a Modified Ludzack Ettinger (MLE) process. The MLE process is a single-sludge, nitrification/denitrification, activated sludge process. The initial part of the study was conducted by Donald C. Marickovich who investigated mean cell residence times (MCRTs) of eight days and lower (1) and the toxicity of high copper doses (5 - 15 mgCu/L). For this part of the study, the experimental system was operated at high (30 days) and medium (8 - 15 days) sludge ages and investigated the toxicity of copper at lower doses (1 - 5 mgCu/L). Details of past research conducted on the treatability and organic characterization of this leachate are presented at the end of the literature review in Chapter 2.

The Dixie Caverns Landfill is located in Western Roanoke County, Virginia on 60 acres of land (2). The landfill was operated from 1965 to 1976 for both municipal and industrial wastes (2). There are two main sections of the landfill. The front section is an old municipal landfill, and the back section, which is separated from the front by a ridge, is an old hazardous waste landfill. From 1965 to 1968 the municipal waste was burned, compacted and then covered. In 1968, the disposal of the municipal garbage was modified to include compaction and covering with soil (2).

In 1969 the section of the municipal landfill that generated the leachate used in this study was started (2). A small stream which flowed west to east became the center line in the disposal site (2). No underdrains or redirection of the natural drainage was incorporated in the design which led to high levels of leachate production

(2). In 1971, at the prompting of the Virginia Health Department, Roanoke County built a cut-off ditch and an undersized holding pond to help deal with the leachate production (2). This did not solve the poor drainage problem and a valid permit, as required by the 1971 State Health Department Regulations, was never issued. In 1976 the landfill eventually closed down (2).

Today it can be observed that leachate from the front section of the landfill drains down the ridge, into the retention pond and then into a small stream. The cut-off ditch, which was filled with stones and covered with dirt (2), looks like a spring at the point where the leachate comes out. Between the pond and stream, a steel storage tank (approximately 25,000 gal in volume) has been built to store overflow leachate until it can be transported by truck to a sewage plant for treatment. At the start of this study the leachate pond was unlined, but during the summer of 1990 a liner was installed to prevent seepage into the ground.

The leachate exhibits traits typical of an old landfill leachate, namely high ammonia content and low BOD. Details of the leachate characteristics during this study are given in Chapter 4, Tables 7 and 8.

The back section of the Dixie Caverns Landfill was used to dispose of industrial wastes. A steel dust (fly ash) pile, disposed of by Roanoke Electric Steel, has been measured to have 45,000 parts per million (ppm) lead and 18,000 ppm cadmium (2). General Electric Corporation has also reported the storage of drums of non-halogenated hydrocarbons solvents in the landfill (2). In 1972 the Roanoke county staff recommended that then existing paint ponds used by several local paint manufactures be stopped entirely (2). This author does not know how long they operated or if they were suspended at that time. The EPA put this landfill on the Federal Superfund National Priorities List in the late 1980's (1) and it was being cleaned up during this study.

The objectives of this study were;

(1) To investigate the treatability of an old landfill leachate, with high ammonia, by a single-sludge activated sludge treatment process in the MLE configuration. Treatment of the leachate was considered complete if efficient total nitrogen removal, i.e. complete nitrification and near complete denitrification, was accomplished.

(2) To determine the inhibitory/toxic effects of copper on the nitrification and denitrification processes during MLE treatment of leachate.

CHAPTER II. LITERATURE REVIEW

This chapter is a literature review of: (1) nitrogen and the biochemical processes that result in nitrification and denitrification; (2) copper; (3) and past research on the Dixie Caverns Leachate.

NITROGEN

Background:

Nitrogen in a variety of forms may cause environmental problems. Nitrogen in leachate from landfills is mostly in the forms of organic-N, ammonium-N (NH_4^+-N)(or ammonia-N (NH_3-N) depending on the pH), nitrate-N (NO_3-N), and nitrite-N (NO_2-N). At pH values less than 9.3 ammonia is mostly in its ionized form (NH_4^+-N) because the pK_a is 9.3 at 25° C for the ammonium ion (6,34). At pH values greater than 9.3 ammonia is mostly aqueous ammonia (a dissolved gas) and may be stripped from solution (34). Eckenfelder (6) recommends a pH of 12 and greater for complete ammonia stripping.

Leachates from abandoned landfills often contain high ammonia concentrations because the organic-N in the solid waste has been broken down into its mineralized form as it aged. Ammonia is toxic to aquatic life in low concentrations and may kill fish at concentrations greater than about 3 mg/L (3). It also exerts an oxygen demand in the waters when nitrification takes place. Nitrogen is an essential nutrient for growth, thus increased nitrogen levels can lead to eutrophication of the surface waters. Algal blooms and excessive aquatic growth may be stimulated in the eutrophic waters which is undesirable (3-4) and leads to oxygen depletion.

The Virginia Water Control Board (VWCB) has Water Quality Standards for ammonia in state waters that are based on stream temperature and pH (32). As of August 17, 1990 the VWCB has been using revised Water Quality Standards to set ammonia limits, these revised standards use the streams ninetieth percentile high temperature and ninetieth percentile high pH to set chronic and acute toxicity limits. The total ammonia that is allowed to be discharge from a point source is determined by a stream mix for ammonia toxicity and an oxygen sag model in which the nitrogenous oxygen demand is considered along with carbonaceous oxygen demand. The following is: "Formulas Used in the Calculation of Chronic Criteria Values Ammonia in Freshwater. The 4-day average concentration of ammonia (in mg/L as un-ionized NH_3) can be calculated by using the following formulas.

$$0.80/FT/FPH/Ratio = \text{chronic criteria concentration}$$

where:

FT = final temperature

$= 10^{0.03(20-TCAP)}$; $TCAP < T < 30^\circ$ C

$= 10^{0.03(20-T)}$; $0 < T < TCAP$

TCAP = 15° C; When trout and other sensitive cold water species are present.

TCAP = 20° C; When trout and other sensitive cold water species are absent.

FPH = final pH

$= 1$; $8.0 < pH < 9.0$

$= (1 + 10^{7.4-pH})/1.25$; $6.5 < pH < 8.0$

Ratio $= 13.5$; $7.7 < pH < 9$

$= 20.25 \times (10^{7.7-pH}) / (1 + 10^{7.4-pH})$; $6.5 < pH < 7.7$

Conversions from un-ionized to total ammonia should be performed using the following formulas:

Total ammonia criteria = calculated un-ionized ammonia criteria [divided by] fraction of un-ionized ammonia

Where:

Fraction of un-ionized ammonia $= 1/(10^{pKa-pH} + 1)$

Where:

$pK_a = 0.09018 + (2729.92/\ 273.2 + \text{temperature}\ ^{o}C)$.

Note: to convert the calculated values to mg/L-N, multiply by 0.822" (45). A similar formula exists for acute toxic criteria and tables exist for ammonia limits in saline waters.

In the soil ammonia is readily converted to nitrate and nitrite (4-7). High levels of nitrate contamination in ground waters used for drinking increases the risk of methemoglobinemia in infants. The nitrate is reduced to nitrite in the digestive tract of infants below the age of 6 months. "Nitrite absorbed into the blood stream can combine with hemoglobin, thereby reducing its capacity to carry oxygen" (16). The boiling of drinking water actually makes the problem worse because the nitrate level increases with the evaporation of water molecules. The EPA has set a nitrate Primary Drinking Water Standard of 10 mg/L as nitrogen to protect public health (35).

Biochemistry:

The literature has thoroughly described and documented the biochemical processes that take place in the nitrogen cycle (3-14,16). Following is a summary of the mineralization of nitrogen, nitrification, and denitrification processes.

Mineralization:

Bacterial decomposition ammonifies nitrogenous organic compounds by breaking high energy bonds which liberate ammonia (Eq. 1) (4). Ammonification of nitrogen occurs readily in both aerobic and anaerobic conditions.

$$\text{organic N} \xrightarrow[\text{decomposition}]{\text{bacteria}} NH_4^+ \qquad [\text{Eq.1}]$$

Nitrification:

"Nitrification involves a group of aerobic, chemoautotrophic bacteria, collectively known as nitrifiers, which oxidize ammonium nitrogen (NH_4^+-N) to nitrate nitrogen (NO_3-N) in a two-step sequential reaction. The first involves the oxidation of NH_4^+-N to nitrite nitrogen (NO_2-N) by the genus, *Nitrosomonas* (Equation 2). In the second step, *Nitrobacter* oxidizes NO_2-N to NO_3-N (Equation 3). Both autotrophs utilize inorganic carbon to include carbon dioxide (CO_2), bicarbonate (HCO_3^-), and carbonates ($CO_3^=$) for synthesis of biomass. Both reactions are thermodynamically favorable with estimates of free energy of release from 58-84 kcal/mole for ammonium oxidation and from 15.4-20.9 kcal/mole for nitrite oxidation" (8). Since equation 3 yields less energy than equation 2 and a build up of nitrite is rarely observed, it can be concluded that the rate of conversion to nitrite controls the rate of overall reaction (8,6). Each individual step and the overall nitrification equation follows:

$$2NH_4^+ + 3O_2 \xrightarrow{\text{Nitrosomonas}} 2NO_2^- + 4H^+ + 2H_2O \qquad [\text{Eq.2}]$$

$$2NO_2^- + O_2 \xrightarrow{\text{Nitrobacter}} 2NO_3^- \qquad [\text{Eq.3}]$$

$$NH_4^+ + 2O_2 \xrightarrow{\text{Nitrifiers}} NO_3^- + 2H^+ + H_2O \qquad [Eq.4]$$

A charge balance of the oxidation process of ammonium to nitrate, reveals that a total of eight electrons are transferred and accepted by oxygen (7,11). The nitrogen ion goes from a N^{3-} state to a N^{5+} state. This requires 4.57 mg of oxygen for each mg of ammonium oxidized (6,7,11).

Eckenfelder (6) stated, "the cell yield for *Nitrosomonas* has been reported as 0.05-0.29 and for *Nitrobacter* 0.02-0.08. A value of 0.15 mg VSS/mg NH3-N is usually used for design purposes." Argaman (46) reported that if an ammonia concentration of 2.0 mg/L or greater is acceptable, then the nitrification process can be assumed as zero-order and the specific nitrification rate is nearly 2.3 g NH_4^+-N/g NVSS*d. Chai (47) reported that the biomass-yield coefficient, Y,and the cell-decay coefficient, b, for the nitrification process were 0.36 mg VSS/mg-N and 0.119/day, respectively for the combined population. Chai (47) estimated that the total nitrifiers consisted of 77.5% *Nitrosomonas* and 22.5% *Nitrobacter*.

The nitrification process destroys alkalinity according to the following equations for the hydrogen ion and bicarbonate (19):

$$H^+ + H_2CO_3^- \longleftrightarrow H_2CO_3 \qquad [Eq.5]$$

$$H_2CO_3 \longleftrightarrow CO_2 + H_2O \qquad [Eq.6]$$

Stoichiometrically, 7.14 mg of alkalinity as $CaCO_3$ are destroyed when 1 mg of ammonia-nitrogen is oxidized to nitrate-nitrogen (6,11,19). Argaman (46) when operating a MLE system determined that the predicted stoichiometric values for the amount of alkalinity destroyed in nitrification and then created in denitrification were in agreement with what actually occurred. Argaman (46) suggested a possible use of alkalinity data for monitoring and control of the process.

Argaman (46) determined that the nitrification critical sludge age for the aerobic basin was 2.5 days at 20° C. Chai's (47) research agreed with Argaman in that he determined that nitrification's critical hydraulic-retention time, in a chemostat, was 2.7 days at 23 ± 2° C. Chai (47) determined that oxidation of nitrite in the absence of ammonia was very unstable and that a hydraulic-retention time of 10 days was required for almost complete oxidation.

Chai (48) observed that the oxidation of nitrite was found to be inhibited by the concentration of nitrite only in the presence of a high concentration of ammonia. He also observed that very high ammonia concentration inhibited the oxidation of ammonia (48). He modeled inhibition constants (K_i) for ammonia oxidation reaction and of the nitrite oxidation reaction of 9,000 mgNH_3-N/L and 173 mgNH_3-N/L respectively (48). He postulated that ammonia was bonding to the enzyme-nitrite complex and inactivating it (48). Anthonisen (49) demonstrated that high concentrations of ammonia and nitrate inhibited nitrification. The cause of the inhibition was due to the free ammonia, NH_3 (FA) and free nitrous acid, HNO_2 (FNA) (49). The range of FA concentrations that begin to inhibit nitrifying organisms are: FA inhibition to *Nitrosomonas*, 10 to 150 mg/L and FA inhibition to *Nitrobacter* 0.1 to 1.0 mg/L (49). Nitrifiers were inhibited at concentrations of FNA between 0.22 and 2.8 mg/L (49).

Denitrification:

Denitrification is a Heterotrophic reaction which occurs when facultative anaerobic bacteria use N oxides (NO_3^- & NO_2^-) as terminal electron acceptors in the absence of O_2 and in the presence of an adequate energy source (3,11). "Denitrification requires: (i) the oxidation of ammonium-N to nitrate-N, (ii) the presence of a subsequent anaerobic zone; and (iii) an adequate carbon source for the denitrifying bacteria in the anaerobic zone" (12). McCarty developed the following process equations used by Randall (11).

$$6NO_3^- + 2CH_3OH \text{------>} 6NO_2^- + 2CO_2 + 4H_2O \qquad [Eq.7]$$

$$6NO_2^- + 3CH_3OH \text{------>} 3N_2 + 3CO_2 + 3H_2O + 6OH^- \qquad [Eq.8]$$

$$\text{Overall: } 6NO_3^- + 5CH_3OH \text{----->} 3N_2 + 5CO_2 + 7H_2O + 6OH^- \qquad [Eq.9]$$

Methanol is shown in Equation 7-9 as the carbon source, it is illustrated that denitrifying bacteria can utilize nitrite and nitrate in the place of oxygen to degrade methanol (11). In this research methanol was used as the energy source. It has been shown that the conversion of nitrate to nitrogen follows zero order kinetics in respect to nitrate content and organic carbon as long as the carbon is not limiting (15,17). Also the denitrification rate can be considered independent of nitrite concentration and proportional to the active concentration of mixed liquor volatile suspended solids when organic carbon is in excess to bacterial growth and nitrate reduction requirements (17). Nitrate usually does not accumulate in the anoxic reactor, suggesting that denitrification can be treated as a single step reaction such as in Equation 9 (15,17,18). Equation 9 shows alkalinity being created in the form of hydroxyl ion, OH^-. Stoichiometrically 3.57 mg/L as CaCO3 alkalinity is produced in the denitrification of methanol for every 1 mg of nitrate-nitrogen denitrified (11,19).

Argaman (46) reported nitrite utilization coefficients were 0.144 gNO_3^--N/gCOD and 0.007 gNO_3^--N/gVSS*d for denitrification. For a single-sludge system with high recycle rates the rate coefficient for COD removal was reported to be 0.026 L/mg*d (46).

Denitrification in a system by use of an anoxic chamber not only converts nitrates to nitrogen gas but also is an economical alternative to oxygen respiration in the activated sludge process (11,18). Sixty-two percent of the oxygen used in nitrification theoretically can be 'recovered' through complete denitrification (7,11). Research by McClintock (18) has show that the maximum reduction in waste sludge can be 45% using 100% nitrate respiration to oxidize wastewater organic carbon whereas the stoichiometric analysis predicted a 25% reduction. By properly designing an activated sludge system to incorporate denitrification, four advantages are accomplished: substantial reduction in oxygen requirement, substantial sludge reduction, substantial total nitrogen removal, and the formation of alkalinity (11,18).

Denitrification may need a synthetic energy source if the natural wastewater is low in a carbon source, then researchers have often added an organic carbon to the anoxic zone to energize the denitrifiers. Methanol is one of the most commonly used energy sources (6) but its high costs makes it undesirable for large scale systems. Systems designed to denitrify without supplemental carbon addition markedly cut operating costs (20), but for laboratory purposes methanol has been found to work most satisfactory.

A requirement for denitrification to occur is an anoxic zone. Wastewaters with high oxygen contents or treatment systems with recycle from an aerobic zone to an anoxic zone require the oxygen to be depleted before favorable denitrification condition exists. If methanol is added as a carbon source for denitrification, then enough excess must be added to reduce the oxygen. The following equation gives the stoichiometry of the oxygen/methanol reaction.

$$2CH_3OH + 3O_2 \dashrightarrow 2CO_2 + 4H_2O \qquad [Eq.10]$$

Thus 2/3 mole of methanol are stoichiometrically needed to reduce one mole of molecular oxygen.

Copper:

This section presents a short discussion on: the physical and chemical characteristics of copper, copper in activated sludge, the effects of copper, copper in leachate, the pollution limits on copper, and a overview of the terms toxicity and inhibition.

Physical and Chemical Characteristics of Copper:

Copper is found in nature in its native state and also in many combined mineral forms including the sulfides; chalcopyrite, chalcocite, bornite, tetrahedrite, tennanite, covellite, and the oxides; cuprite, tenorite, malachite, azurite, brochantite, atacamite, chrysoclla and native copper (23,24). It occurs in the earth's crust at 70 ppm and in seawater at 0.001-0.02 ppm (23). Man has many uses for copper including tools, ornaments, pots for cooking, coinage, electrical uses, ship building alloys, medical, bactericide, molluscicide, and fungicide (24).

Copper is a heavy metal in that it has a specific gravity of 8.96 (24); a metal having a specific gravity of 5.0 or greater is considered a heavy metal (21). Copper has an atomic number of 29, an atomic weight of 63.54, an atomic volume of 7.11 cm^3/mole, a density of 8.96 g/ml, an elemental symbol of Cu, a melting point of 1083 ^oC, and a boiling point of 2595 ^oC (24).

The Periodic Table of Elements classifies copper as a Group I-B element along with gold and silver, these metals are known as the coinage metals (25). Copper is a transition metal in that it has valence electrons in two shells (25). Its electronic configuration of 2-8-18-1 implies a stable closed shell of 18 electrons, but this shell is not inert (24). The underlying *d* orbitals appear to supply at least one *d* electron into a higher energy orbital of the outermost principal quantum level in metallic bonding (24). The electron structure of the free copper atom is $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^1$ and this unique structure contributes to its high electrical and heat conductivity (24). The 4*s* electron in the outermost quantum principal level is given up to form the Cu(I) ion, and the release of an additional one or two electrons from the 3*d* subgroup forms the Cu(II) and Cu(III) ions (24). Copper exhibits four oxidation states: elemental copper (0), +1, +2, and +3. The most common oxidation state for copper is +2 (25). In aqueous solutions there is a very strong tendency for disproportionation of Cu(I) into Cu(II) and metallic copper (24).

The standard oxidation potentials of copper(I) and copper(II) at 25° C are (24):

$Cu^{+} + e^{-}$ <----> Cu$E = 0.520$ [Eq.11]

$Cu^{2+} + 2e^{-}$ <----> Cu$E = 0.337$ [Eq.12]

Cations of copper are subject to loss by adsorption on, or ion exchange with, the walls of glass bottles (5). "Elemental copper is resistant to aerated alkaline solutions except in the presence of ammonia. It does not displace hydrogen from acid but dissolves readily in oxidizing acids such as nitric acid or in acid solutions that contain an oxidizing agent, ie, sulfuric acid solution containing ferric sulfate" (24). In this research nitric acid was used preserve all metal samples.

The equilibrium of copper in aqueous solutions may be complicated because copper forms complex species involving both organic and inorganic ligands (36). Ligands formed with inorganic compounds keep copper soluble and allow it to stay longer in solution instead of precipitating (6,34,35,36). In **Water Chemistry** "Table 5-1 Equilibrium Constants for Mononuclear Hydroxo Complexes," the following equilibrium constants for Cu^{2+} are presented; log $B_1 = 8.0$, log $B_3 = 15.2$, log $B_4 = 16.1$, and log $K_{so} = -19.3$. Note that B_i is the equilibrium constant for the reaction, $M^{n+} + i\ OH^{-}$ ------> $M(OH_i)^{(n-i)+}$ (34). These formula describe copper distribution in a relative simplistic aqueous solution which is not totally descriptive of the complex nature of a leachate copper distribution. Copper not only forms ligands with hydroxides but it complexes with organics, and inorganics such as; ammonia (6), ethylenediamine tetraacetate (EDTA), nitrilotriacetate (NTA), oxalate, glycine (36), citric acid (35), and hardness (6,34,35). The presence of other metals also affects the solubility of copper in solution. It is reported that copper will cause iron to corrode while it is precipitated, and in water lines this is a major problem (35).

Eckenfelder, presented in his book, **Principles of Water Quality Management** (6), Figure 1(a) "Optimum pH Values for Metal Removal", and Figure 1(b) "Optimum pH Values for Metals Removals in the Presence of Ammonia". These figures demonstrate that copper complexes with ammonia and is not as readily chemically precipitated as when ammonia is absent.

Copper in Activated Sludge:

Cheng (36) reported that copper complexes (with EDTA, NTA, oxalate and glycine) in strong soluble ligands allowed copper uptake in activated sludge of between 5% and 20%, depending on the ligand. Thus, the copper was kept soluble by the chelating agents. He also determined in 120 minute activated sludge batch tests that had a pH of 5.80, and non-complexed copper concentrations of 2.1, 10.3, and 25.2 mg/L, that in 10 minutes 81-84% and in 120 minutes 85-91% of the copper was taken up by the activated sludge or precipitated (36). Cheng (36) showed also that copper rapidly complexed with the biomass, as long the copper was not already bound by strong chelating agents.

Nelson researched the effects of copper in activated sludge and reviewed the literature and developed Figure 2 "Speciation-Distribution Diagram for Copper as Function of pH." Table 1 summarizes all species considered in the calculations of Figure 2 and their corresponding equilibrium (overall formation) constants.

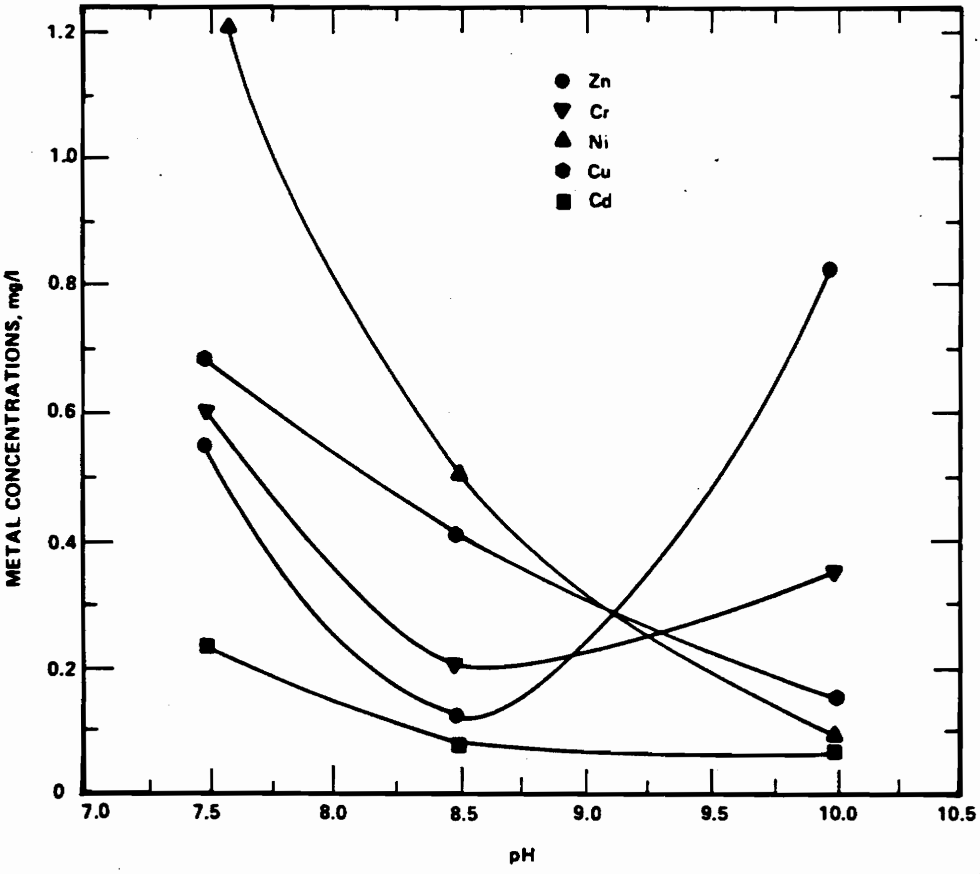

Figure 1(a). Optimum pH Values for Metal Removal.
*Source of figure is reference 6, Figure 10.13(b) on page 482.

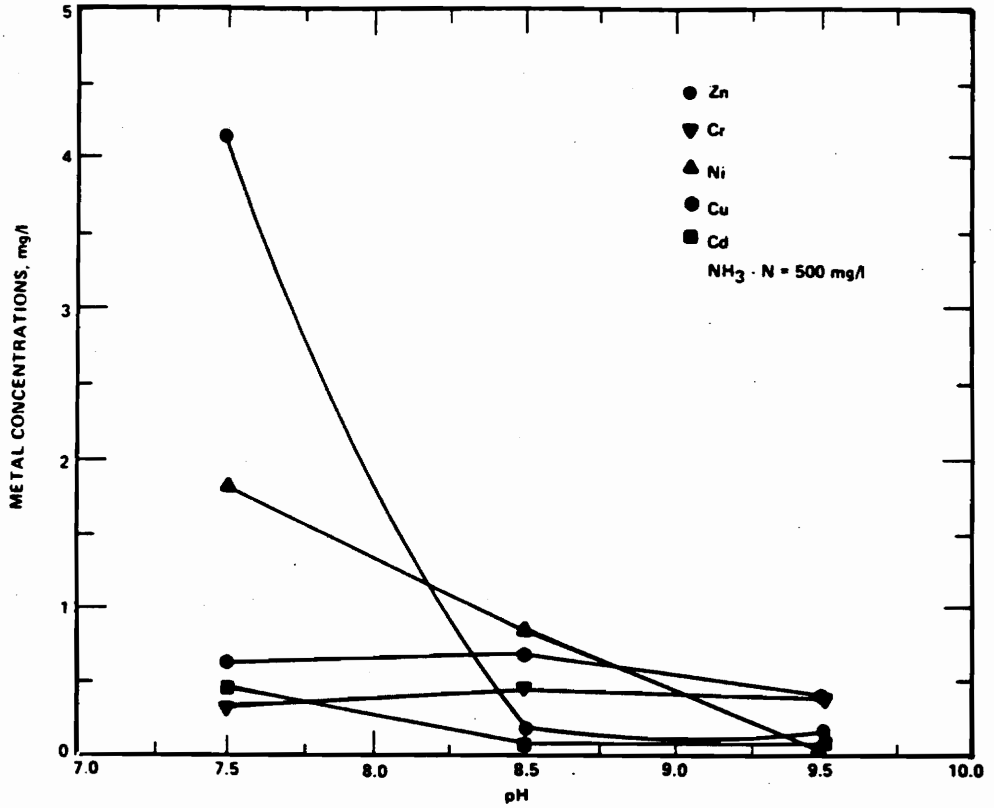

Figure 1(b). Optimum pH Values for Metal Removal in the Presence of Ammonia.

*Source of figure is reference 6, Figure 10.13(a) on page 481.

Table 1. Overall Formation Constants for Metal Species.[a] (I= O M, 25° C)

Meatal	Species (ML (i)$_n$)	log(B(i)) OH$^-$	Cl$^-$	NH$_3$	SO$_4^=$	CO$_3^=$	HPO$_4^=$	Organic[b]
Cu	ML	6.3	0.40	4.04	2.36	6.75	3.2[d]	5.4
	ML$_2$	14.3[c]	0.3[c]	7.47		9.92		
	ML$_3$	13.5		10.27				
	ML$_4$	16.4		11.75				

[a] Values from Martell and Smith unless otherwise noted.

[b] Typical values for Polypeptides.

[c] Vuceta.

[d] I = 0.1 M.

*Source of table is reference 37, Table 5 on page 1332.

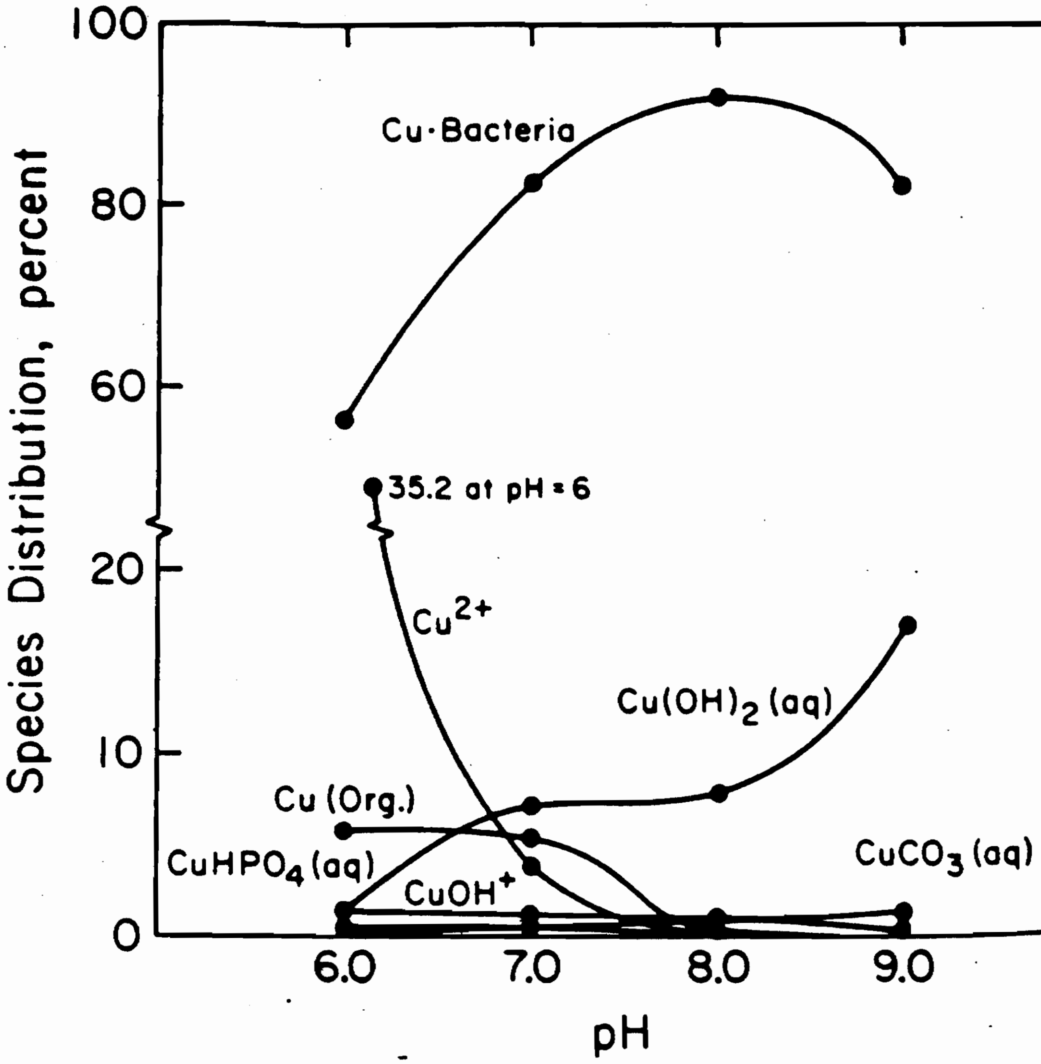

Figure 2. Speciation-Distribution Diagram for Copper as Function of pH.
*Source of figure is reference 37, Figure 12 on page 1330.

The literature contains little information on the toxic limits of copper in an activated sludge process. A full scale aerobic toxicity study on the effects of copper on COD removal was conducted in 1965 (38). It was concluded that 1 mg Cu/L was the maximum concentration of copper that could be received continuously in a domestic sewage without having a detectable effect on BOD or COD removal (38,39). This study did not investigate the effects of copper on the nitrification process directly but copper dosages of 0.4, 1.2, 2.5, 5.0, and 10 mg/L were investigated. As the concentration of copper increased, suspended matter and turbidity in the effluent increased (38). Nitrifiers are some of the most sensitive bacteria in the activated sludge process and this researcher believes that the nitrification process was probably greatly effected by the increasing copper doses.

Effects of Copper:

In trace amounts copper is required for all forms of aerobic and most forms of anaerobic life (24). Copper is often an essential constituent of cofactors or co-enzymes, which are organic compounds which cooperate with enzymes (26). Co-enzymes contain or is a vitamin (26).

Build up of copper in soils can be toxic to plants (5).

Copper ions have a catalytic effect on the oxidation of iron and manganese (5,33). The presence of about 0.1 mg/L of copper increases the rate of iron oxidation 5-6 times (5). Beds of scrap iron are used at copper mines to precipitate metallic copper from overburden waste leachate (24). The iron is dissolved and metallic copper is precipitated in a operation called cementation (24).

Growth of iron bacteria in water mains can be controlled by chlorine and copper sulfate (5). A copper sulfate dosage of 0.3-0.5 mg/L applied continuously for several weeks can be effective (5). Copper sulfate ($CuSO_4$) is the main algicide of choice to control algal in water-supply reservoirs and algal blooms may be suppressed by regular application (5).

"The literature on fish toxicity contains references to the effects of water hardness on the toxicity of heavy metals. The general observation made is that heavy metals are much less toxic to fish in hard water than they are in soft water" (34).

Copper in Leachates

The copper composition of a typical landfill leachate has a concentration range of 0.10 to 9.0 mg/L (28). The EPA has reported copper concentrations from contaminated ground and surface waters in the vicinity of uncontrolled hazardous waste sites of 0.001 to 16 mg/L (29).

Pollution Limits on Copper:

The State of California has set soluble threshold limit concentration (STLC) values for 18 toxic metal constituents of waste (30). The STLC for copper is 25.0 mg/L, thus wastewaters with concentrations higher than 25.0 mg/L are considered hazardous wastes (30).

The National Technical Advisory Committee Report (in a report to the U.S. Secretary of the Interior, issued by the Federal Water Pollution Control Administration, April 1, 1968) recommended that raw-surface-water criteria for public water supplies have a permissive copper criteria of 1.0 mg/L and a desirable copper criteria of virtually absent (5). The U.S. EPA in 1980 regulations set a drinking water recommended limit for copper of 1 mg/L (35). WHO, International in 1971 regulations set a drinking water recommended limit for copper of 0.05 mg/L and a maximum permissible level limit of 1.5 mg/L (35). The European Community regulations set a copper guide level of 0.1 mg/L (35).

The Environmental Protection Agency has stated water quality criteria for total recoverable copper (31). The criteria for copper states that "freshwater aquatic organisms and their uses should not be affected if the four-day average concentration (ug/L) of copper does not exceed the numerical value given by (the formula), $e^{(0.8545[\ln(\text{hardness})]-1.465)}$ more than once every 3 years on the average and if the one-hour average concentration (in ug/L) does not exceed the numerical value given by $e^{(0.9422[\ln(\text{hardness}]-1.464)}$ more than once every three years." (31). The criteria for saltwater proposed by the EPA states that the one-hour average concentration of 2.9 ug/L not to be exceeded more the once every three years on average (31). The Commonwealth of Virginia's criterion for total recoverable copper for the protection of freshwater aquatic life is given by the formula, $e^{(0.8545[\ln(\text{hardness})]-1.465)}$ and the saltwater criterion is 2.9 ug/L (32).

Toxicity and Inhibition:

The inhibitor/toxic effects of copper on the nitrification and denitrification process was investigated in this research. Inhibitory toxicity causes microorganisms to stop growing or slows their growth rate to such an extent that they wash out of the system. A system that slowly loses one of its operations, such as nitrification or denitrification, over a period of time would be suspected of inhibition or chronic toxicity. Acute toxicity (toxic) causes the immediate death of the microorganisms. Acute toxicity of a system would be suspected if it loses a treatment operation over a short period of time accompanied by cell lysing. Acute and inhibitory toxicity can occur together and in varying degrees of severity. In this paper the terms toxicity and inhibition are used interchangeably.

Measuring Responses to Toxic Conditions:

Researchers in the past have presented chemical and metal toxicity in terms of a threshold concentration level of the chemical or metal after which toxicity would occur. Randall (50) in a paper called "The Responses of Activated Sludge Systems to Toxic Conditions" argued the point that a concentration of toxic chemical at which toxicity occurred was too simplistic an approach to the investigation of toxicity. Randall presented research and discussed others research which supported the thesis that the chemical-to-microorganism (T/M) ratio was a more exact way to express responses to toxic conditions. Randall (50) "proposed that researchers express their results in terms of the T/M ratio so that results may be more comparable between researchers, and so that other factors that affect toxicity can be more readily identified."

Past Research on the Dixie Caverns Landfill:

Partial analyses of Dixie Cavern's leachate organics revealed that it contained the following priority pollutants (1):

1,4-Dichlorobenzene	1.60 ppb
Naphthalene	0.71 ppb
N-Nitroso-Diphenylamine	3.60 ppb
Chlorobenzene	10.0 ppb.

Marickovich (1), of VPI & SU, conducted research into the treatability of the Dixie Cavern Landfill's leachate. He used the same MLE systems as used in the experimentation presented in this paper. His investigation into the treatment of the leachate looked into nitrogen, metals, and COD removal. The treatment system was operated at sludge ages ranging from 1.5 to 15 days. He determined that at sludge ages between 8 to 15 days that total nitrogen removal reached up to 84% and even at the lowest sludge age nitrogen was removed as much as 56%. The MLE process removed influent average iron concentrations of 18.6 mg/L to less than 1 mg/L in the effluent. Influent COD was not removed to any significant extent until activated carbon was used and activated carbon removed about 100% of the COD. The average influent leachate COD was 90.2 mg/L with a range from 71.4 to 107 mg/L and the average leachate BOD_5 was 4.8 mg/L with a range from 0.9 to 9.4 mg/L. Towards the end of his 584 day study two severe incidents of leachate inhibition occurred. These periods of inhibition seem to be due to unknown toxins in the leachate. These upsets of the treatment process led Marickovich to wonder if ammonia and metal removal by a MLE system was a viable option for this landfill leachate (1).

Marickovich (27) also conducted two copper toxicity experiments in his research which are of particular interest to this paper. Additions of 15 and 5 mgCu/L to the influent leachate feed were investigated at a 8 day sludge age (27). Both experiments were found to severely inhibit nitrification and caused the MLE system to fail (27). The following Table 2 gives the average characterization of the experiments in the MLE system (27). Relevant information in Table 2 is used in the discussion chapter of this paper to supply data points in the appropriate figures.

Table 2. Characterization of Copper Experiments, Research by Marickovich (27)

System	**MLE**	**MLE**
Sludge Age (days)	**8**	**8**
Copper Dose (mg/L)	**15**	**5**
Days of Study	467-483	514-553
Total Days	16	39
Days Used	474	534, 538, & 546
Average MLVSS (mg/L)	475	941
Average MLSS (mg/L)	623	1219
Avg. Effluent VSS (mg/L)	74.0	47.8
Avg. Effluent TSS (mg/L)	88.0	59.1
Influent TKN (mg/L)	57.9	58.7
Influent NH_3 (mg/L)	50.5	55.8
Influent NO_3 (mg/L)	0.00	0.68
Avg. Effluent TKN (mg/L)	32.3	29.6
Avg. Effluent NH_3 (mg/L)	24.9	23.3
Avg. Effluent NO_3 (mg/L)	4.2	1.78
Avg. Effluent NO_2 (mg/L)	9.4	13.2
Measured Influent Cu (mg/L)	11.2	4.12
System Loading**	314.4	58.4
System Avg. Soluble Cu (mg/L)	1.37	0.93
System Avg. Total Cu (mg/L)	?	25.8
System Avg. Sol. Cu/MLVSS*	28.8	9.88
System Avg. Sol. Cu/MLSS*	22.0	7.63
System Avg. Total Cu/MLVSS*	?	274
System Avg. Total Cu/MLSS*	?	212

? No data available.
* All the above ratios are multiplied by 10,000.
** Units are Cumg/day/MLVSSmg/system multiplied by 10,000.

CHAPTER III.

MATERIALS & METHODS

In this chapter, details to be discussed include: the sampling, storage and testing of the Dixie Caverns Landfill Leachate; the setup, operation, and testing of the Modified Ludzack Ettinger (MLE) treatment processes used to treat the leachate; and the methods used to analyze the information gained from the experiments.

Research Overview:

This research continued an earlier study of the treatability of old municipal leachate from the Dixie Caverns Landfill by a MLE process operated at high (30 days) and medium (8-15 days) sludge ages, and conducted an activated sludge toxicity study of copper. The MLE process is a single-sludge, nitrification/denitrification process (44). Two similar treatment systems, which had already been designed and constructed for evaluation in laboratory scale were initially used to conduct the research, and on day 159 of the study, a third similar system was set up. The system used to treat leachate without copper addition was considered to be the control. The control system was also used to study the potential of the MLE process for treatment of the landfill leachate, while the systems were used for the copper toxicity study. The systems will be referred to numerically with the first control as #1, the original toxicity system as #2 and the second control as #3. Thus, at least one system was always operated as a control.

Three sludge ages, 8, 15, and 30 days, were investigated in this study. Four different copper doses were added to the influent leachate, 1.0, 2.0, 2.5, and 5.0 mgCu/L. Table 3 summarizes the sludge ages and copper doses investigated, and the values used for each of the systems.

Table 3. Operating Sludge Ages and Copper Additions

Day of Study (day)	System (Number)	Sludge Age (days)	Copper Addition (mgCu/L)
0 to 115	1	8	0.0
115 to 176	1	15	0.0
176 to 245	1	30	0.0
245 to 253	1	30	2.0
253 to 319	1	30	5.0
0 to 29	2	8	0.0
29 to 57	2	8	2.5
57 to 115	2	8	0.0
115 to 141	2	15	0.0
141 to 160	2	15	1.0
160 to 173	2	15	0.0
173 to 225	2	15	1.0
225 to 253	2	15	2.0
253 to 319	2	15	5.0
153 to 319	3	15	0.0

The #1 System operated as a control for the 8, 15, and 30 day sludge age experiments. Towards the end of the study, System #1, while operating at a 30 day sludge age, was spiked with 2.0 and 5.0 mgCu/L doses.

The #2 System was initially operated at an eight day sludge age and was allowed to reach steady state before it was spiked with a 2.5 mgCu/L dose. Steady state was determined by steady volatile solids production, nearly complete nitrification and denitrification, and system operation for at least three sludge ages. The #2 System failed following the 2.5 mgCu/L spike. Failure was determined by loss of nitrification, denitrification, and solids washout. The system was then allowed to recover without copper addition, after which it was increased to a 15 day sludge age because the #1 (control) and #2 systems were both being disrupted by possible organic toxins in the leachate. The #2 system was operated with 1.0, 2.0 and 5.0 mgCu/L doses after reaching steady state, at the 15 day sludge age.

The #3 System was started on day 159 of this study. It was operated as a 15 day sludge age control to the end of operation.

Site Location and Collection:

The exact location of the Dixie Caverns Landfill was discussed in Chapter 1. During the course of this study, leachate was at first taken from the steel leachate retention tank and then directly from the leachate pond. The storage tank was suspected of possibly concentrating toxins in the leachate, and thereby causing the unexplained nitrification upsets in the two systems being operated, so from the 3/27/90 leachate run to the end of the study, leachate was collected directly from the pond. The sloping nature of the terrain at the site allowed for siphoning from either the tank or the pond. The siphoning was accomplished by means of a series of garden hoses connected together with taped, air tight, connections. One end of the hose, taped to a six foot long wooden handle, was placed about two feet below the surface of the leachate and the other end was connected to the influent end of a portable hand pump. The pump handle was pumped to create a vacuum pressure within the hose to induce flow to start. Once a water column was formed within the hose, the elevation difference between the leachate pond or tank surface and the end of the hose where the carboys were being filled was sufficient to induce gravity flow. Thirteen plastic (Nalgene) carboys (three with 50 liters (L), four with 30 L, and six with 20 L volumes) with a total volume of 390 L were gravity filled in a period from thirty to sixty minutes. These carboys were transported, using the Civil Engineering half ton truck, back to the VPI & SU Environmental Engineering Laboratories. The leachate was stored in the carboys in the constant temperature room at a temperature of 20 °C. The 390 L of leachate would feed the treatment systems for three weeks.

On the same day as the field trip to the landfill for leachate, a sample was taken from one of the 50 L carboys after thorough mixing. The pH and alkalinity of the sample were measured, and a portion of the sample was stored for subsequent metals analysis. Because the TKN, ammonia, nitrate, nitrite, and COD concentrations of the raw leachate influent were determined every 3 or 4 days, no special efforts were made to analyze for them on the day of the field trip.

System Design and Operation:

The three Modified Ludzack Ettinger (MLE) Process treatment systems used during this study were single-sludge, nitrification/denitrification systems approximately identical in size and operating parameters. Table 4 lists the operating parameters used for the treatment systems. The systems consisted of an anoxic reactor followed by an aerobic reactor, and a clarifier for sludge settling and return (Figure 3). There were two recycles, from both the aerobic reactor and the clarifier to the

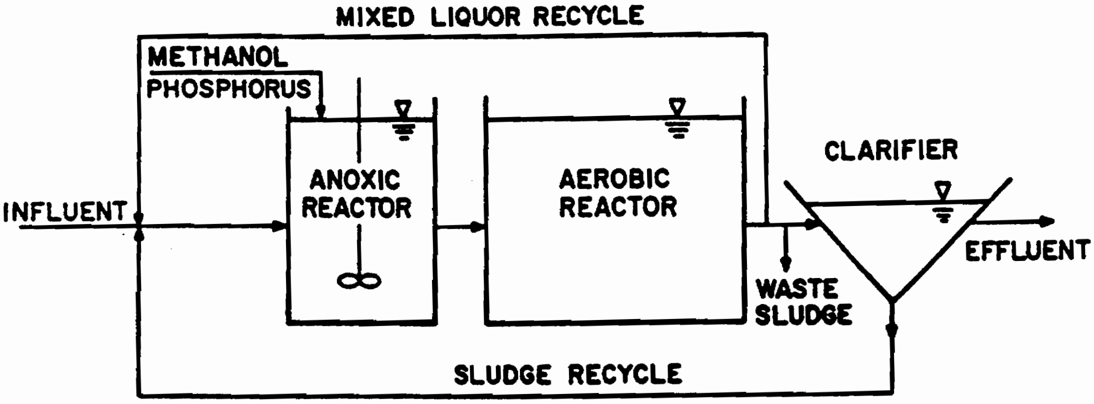

Figure 3. Diagram of Experimental MLE System (1).

Table 4. Description and Operating Parameters of Treatment Systems

Parameter	Size
Flow Rate	6 L/d
Aerated Volume	3 L
Anoxic Volume	1.5 L
Clarifier Volume	1.0 L
Reactor Hydraulic Retention Time	18 hr
Sludge Recycle Ratio	1:1
Aerobic Recycle Ratio	2:1
Methanol Addition	170 to 280 mg/L
Phosphorus Addition	8.8 to 15 mg/L

anoxic reactor. The purpose of the recycle from the aerobic reactor was to return nitrate to the anoxic zone. In the aerobic zone, organic and ammonia nitrogen were oxidized by nitrifiers to nitrite and then nitrate. The recycled nitrates from the aerobic zone and the clarifier were reduced in the anoxic zone by denitrifiers to nitrite and then nitrogen gas. The nitrate and nitrite were used as terminal electron exceptors by the denitrifiers during food uptake.

Influent leachate entered the anoxic chamber and flowed by gravity into the aerobic chamber through a tube. The tube was about two inches from the bottom of each chamber. The mixed liquor flowed out of the aerobic chamber through another tube at the water surface level of the chamber. It then proceeded into a clarifier which had a surface level exit to a waste carboy.

The 1.5 L anoxic chamber was completely mixed by a stirring paddle driven by an electric motor. The paddle was operated at the lowest setting possible that kept the solids suspended and prevented oxygen from being mixed into the chamber. The 3.0 L aerobic chamber was completely mixed by compressed air entering through a fine bubble diffuser stone. The total reactor volume of 4.5 L was divided into a 1.5 L anoxic zone and a 3 L aerobic zone. The clarifier which followed the aerobic chamber was one L in volume and was assumed not to be part of the reactor volume for sludge age calculations and analysis purposes. An electric motor driven scraper operated at one revolution per minute assisted the clarifier in solids collection, compaction and recycle.

The leachate was deficient in both an energy source for denitrification and phosphorous for bacterial growth. To remedy this condition, a methanol (CH_3OH) and potassium phosphate monobasic (KH_2PO_4) solution was added continuously by a pump.

Enough methanol to reduce any molecular oxygen in the recycled flows to the anoxic chamber and to energize complete denitrification of the recycled nitrates was needed. Equation 10 in Chapter 2 shows that 2/3 mole of methanol are stoichiometrically needed to reduce one mole of molecular oxygen. If the recycle flow of 3Q contained 7.0 mgO_2/L, then 14 mg of methanol per L of leachate would be needed to reduce the oxygen so that the chamber would be anoxic. Equation 7 in Chapter 2 shows that 5/6 moles of methanol are stoichiometrically needed to denitrify one mole of nitrate-N. For a TKN value of 60 mg/L in the influent leachate, about 137 mg of methanol per liter of leachate would be required assuming that all the nitrogen would first be nitrified, and then denitrified. This assumption is conservative when determining methanol requirements in a MLE designed system, because it is impossible to recycles all nitrates to obtain complete denitrification. The total methanol required for both oxygen reduction and denitrification would be 14 + 137 = 151 mg methanol per liter of influent leachate. In this study a minimum of 170 and a maximum of 280 mg of methanol per liter of leachate was added to ensure that methanol would not limit denitrification.

Potassium phosphate monobasic (KH_2PO_4) was added to the anoxic chamber. Precipitation of phosphorous with the metals in the leachate was expected to occur in the reactors, so excess phosphorous was added to insure that it would not be limiting (1). One gram of phosphorous per 140 grams of COD removed by activated sludge is considered to be a minimum value for bacterial growth (41). The 170 to 280 mg of methanol per liter being added had a theoretic oxygen demand (THOD) of 250 to 420 mg/L (using Equation 10). This translates to a minimum phosphorous concentration of 1.8 to 3.2 mgP/L. The actual phosphorous added was 8.8 to 15 mgP/L, which is 4.9 times the recommended value. This ratio was also used by Marickovich (1). Analyses of the anoxic chamber and effluent for phosphate-phosphorous showed that phosphorous never limited bacterial growth.

The stock feed solution of methanol and potassium phosphate was made up adding 7.2 gm of methanol and 1.655 gm of potassium phosphate to 1 L of deionized/distilled water. The stock feed solution was made up weekly, stored in a refrigerator, and fed at a rate of between 140 to 250 ml/day. The THOD for the stock feed rate of 140 ml/day is 250 mg/L and for 250 ml/day is 450 mg/L. A sample THOD calculation is in Appendix A.

When copper addition experiments were conducted, using the #2 System, and later in the #1 Reactor, the copper stock solution of 1000 mgCu/L was mixed into the influent leachates. The copper stock solution was made up with Cupric Chloride ($CuCl_2*2H_2O$) and controlled for quality by comparing with a standardized copper solution. The copper stock solution was made up by adding 2.683 gm of Cupric Chloride to 1 L of distilled/deionized water. See Table 3, Operating Sludge Ages and Copper Additions, for the time line of the experiments. The 20 L Nalgene plastic carboys used had previously contained the 5.0 and 15.0 mg copper per liter of leachate influent feed for Marickovich's experiments (27). The carboy was only washed out before using for this experiment, so retained copper may have desorbed from the walls during this experiment. A three days supply of 2.5 mgCu/L influent was mixed up at a time. The influent samples for total copper analysis were taken from the leachate that was left in the carboy. Usually the sample was taken after nearly three days in the carboy. Since the influent was not continuously mixed by a stirrer, copper precipitated out in the carboy over time. As the leachate level decreased, the total copper would concentrate in the remaining volume due to the precipitate. The total copper concentration varied with how long the leachate set in the carboy, and it was suspected that soluble copper was precipitating out, adsorbing, and desorbing from the containers wall. Acid washing the container after the experiment was over with 10% HCL did solubilize copper from the wall. On the whole, however, the 2.5 mgCu/L experiment went well because soluble and total copper were monitored in each chamber of the treatment system.

The next experiment involved addition of 1.0 mg copper per liter of leachate fed to the #2 System which was operating at a fifteen day sludge age. Analysis of high influent total copper in the feed caused concern. The dosing of copper was discontinued and started again once the reactor recovered to almost 100% nitrification. The 20 L Nalgene plastic carboy used for this experiment was different from the 2.5 mgCu/L experiment carboy, but in an effort to condition this carboy to minimize adsorption of copper from the influent leachate/copper mix, a series of seven 1.0 mgCu/L tap water solutions were added to the carboy and allowed to sit for various time periods. Once the experiment started the influent leachate was continuously stirred by a magnetic stirring bar to help ensure a more even distribution of copper in the influent leachate. A two day supply of influent leachate was made up at a time and samples were taken directly from the carboy. When the total influent copper samples were analyzed after seventeen days of operating with the 1.0 mgCu/L concentration, their average concentration was 2.2 mgCu/L. This was deemed too high and it appeared that copper adsorbed to the side walls had desorbed back into the leachate/copper mixture. So the first 1.0 mgCu/L addition experiment was discontinued and the second one was started up fourteen days later.

An acid-washed, 20 L glass carboy contained leachate that was continuously stirred by a magnetically driven stirring bar during the second 1.0 mgCu/L experiment. The influent leachate was prepared daily, and the carboy was rinsed out daily. The first two total copper samples averaged 5.7 mgCu/L and were taken directly from the carboy when little leachate was left in the carboy. The high measured total copper led to a change in sampling procedure. The rest of the influent total copper samples were taken from the end of the Tygon tubing influent lines. After changing the sampling method, the average influent total copper concentration was found to be 0.83 mgCu/L for the rest of the second 1.0 mgCu/L experiment. It is interesting to note that the soluble copper concentrations in the reactor chambers during both 1.0 mgCu/L experiments were relatively constant. It was concluded that the influent sampling methods used during the first tests caused the high readings. See Appendix C, Tables C-1, C-2, and C-14, for more details.

The copper dose added to the #2 System, operated at a fifteen day sludge age, was stepped up to 2.0 and then to 5.0 mgCu/L. The #1 System, while operated at a thirty day sludge age, was spiked with a 2.0 mgCu/L dose for eight days and then stepped up to a 5.0 mgCu/L dose when the dosage to the #2 system was increased. Both systems were fed from the same 20 L glass carboy, which daily was rinsed out and had spiked leachate made up in it. All total copper influent samples were taken from the end of the Tygon tubing influent lines. The 5.0 mg copper per L addition was the last dosage investigated in this study.

System Startup:

The #1 and #2 Systems were started on 11/17/89 (day 0 of the study) with 4.5 L of mixed liquor wasted from a pilot scale nutrient removal treatment system being operated by Sam McClintock and Vikram Pattarkine at Blacksburg, Virginia. The #3 System was started on 4/19/90 (day 153 of study) with mixed liquor wasted from the #1 System (the control).

Daily Protocol:

Leachate influent was checked to see if the influent carboy should be changed. The effluent waste carboy was emptied into the sink. Solids were wasted from the aerobic chamber to maintain the desired mean cell residence time (MCRT). The Methanol and Phosphate feed container was filled. Tubing was squeezed to help cut down on growth on the tubing walls. Walls of the chambers were scrapped to prevent attached growth.

Sampling:

Samples for laboratory analyses were usually taken every three or four days during steady-state periods. Tables 5 and 6 show all the parameters measured. On a typical sampling day all the following parameters were analyzed; Volatile and Suspended Solids, Chemical Oxygen Demand (COD), Ammonia Nitrogen (NH_3-N), Total Kjeldahl Nitrogen (TKN), Nitrate Nitrogen (NO_3), Nitrite Nitrogen (NO_2), Phosphate Phosphorus (PO_4-P), and Total and Soluble Copper. Copper samples were taken only from the reactors with spiked influent, and were preserved with concentrated Nitric Acid and stored at 4 °C.

Effluent samples were collected from the clarifier overflows over a few hours period. A 100 ml aliquot of each effluent sample was taken for total copper concentration analysis. For volatile and suspended solids analysis, samples were filtered through glass filters with a pore size of 1.5 um, until clogging became a problem. The glass filtered samples were again filtered, this time through membrane filters with a 0.45 um pore size. Analysis for COD, Ammonia, TKN, Nitrate, Nitrite, Phosphate, and soluble copper were conducted on the twice filtered effluent samples.

Influent samples filtered through a 0.45 um pore size membrane filter were analyzed for COD, Ammonia, TKN, Nitrate, Nitrite, and Phosphate. Samples of influent leachate for total copper analysis were taken either directly from the influent carboy or from the influent lines. For more details of total copper influent leachate sampling, see the Section, "System Design and Operation", in this chapter.

Ten or twenty milliliter samples of mixed liquor solids were pipetted directly from the anoxic and aerobic chambers and filtered through glass microfilters for

Table 5. Monitored Influent and Effluent Parameters

Parameter	Influent Leachate	Effluent Leachate
Suspended and Volatile Solids		X
Soluble Kjeldahl Nitrogen	X	X
Ammonia Nitrogen	X	X
Nitrate and Nitrite Nitrogen	X	X
Chemical Oxygen Demand	X	X
Total Copper (after addition)	X	X
Soluble Copper (0.45 um filtered)		X
Total Metals (Fe, Mn, Zn, Ni, Cu, Cd, Cr, & Pd)	X**	
Alkalinity	X**	X*
Phosphate Phosphorous	X	X
pH	X**	X*

* Measured less than 10 times.

** Measured when new leachate was collected from the landfill.

Table 6. Monitored System Parameters

Parameter	Anoxic Reactor	Aerobic Reactor
Mixed Liquor Suspended Solids	X	X
Mixed Liquor Volatile Suspended Solids	X	X
Soluble Chemical Oxygen Demand	X	
Nitrate & Nitrite Nitrogen	X	
Phosphate Phosphorous	X	
Soluble Copper (0.45 um filtered)	X	X
Total Copper (unfiltered)	X	X
pH	X*	X*
Dissolved Oxygen	X*	X*

* Measured less than 10 times.

Primary filtration by 10 um glass fiber filter.

mixed liquor total and volatile suspended solids (MLSS & MLVSS) analysis. Small beakers were dipped directly into the anoxic and aerobic chambers to collect mixed liquor. The samples were filtered through 0.45 um membrane filters, and then analyzed for soluble copper for both chambers, and COD, nitrate, nitrite and phosphate for the anoxic chamber. Ten or twenty-five milliliter (ml) mixed liquor total copper samples (depending on the expected copper concentrations) were taken directly from the anoxic and aerobic chambers for analysis.

Measurements of pH and dissolved oxygen (D.O.) were taken very infrequently and were measured directly in the reacting chambers and clarifiers. Alkalinity of effluent samples were only checked twice because the influent alkalinity was high, averaging 540 mg/L as $CaCO_3$, and was not likely to limit nitrification.

Laboratory Tests:

Total Kjeldahl Nitrogen (TKN):

Leachate and effluent TKN concentrations were determined in accordance with the Semi-Micro-Kjeldahl Method as described in Test 420B, pages 411 to 412, of the 16th Edition of Standard Methods for the Examination of Water and Wastewater (40). Each sample was first filtered through a membrane filter with a 0.45 um pore size. Usually a 50 ml aliquot of each sample was used but sometimes a 25 ml aliquot was used. These were digested in 100 ml Kjeldahl flasks. Each digested sample was then distilled into 20 ml of indicating boric acid solution. This solution was finally titrated with 0.02 N standardized sulfuric acid solution in accordance with Test 420 B. This test measures organic and ammonia nitrogen together.

Ammonia Nitrogen (NH_3-N):

Leachate and effluent ammonia-N concentrations were determined using the

Titrimetric Method as described in Tests 417 A & D (40). Samples of 25 or 50 ml aliquot were analyzed.

Nitrate and Nitrite Nitrogen (NO_3-N & NO_2-N):

The nitrate and nitrite nitrogen concentrations in the leachate, effluent and anoxic chamber were determined using a Dionex 2010 Ion Chromatograph (IC) in accordance with Test 429 (40).

pH:

Leachate, effluent and anoxic chamber pH's were determined with the use of a Fisher Accumet pH Meter Model 610A.

Chemical Oxygen Demand (COD):

Leachate, effluent and anoxic chamber COD concentrations were determined using the Closed Reflex Titrimetric Method, Test 508 B (40).

Alkalinity:

The leachate and effluent alkalinity concentrations were determined using the Potentiometric Titration to Preselected pH Method, Test 403 Alkalinity (40).

Metals:

Spiked influent leachate, aerobic chamber, anoxic chamber and effluent samples were analyzed for total and soluble copper concentrations, and leachate samples were also characterized for the following total metal concentrations; iron, manganese, zinc, nickel, cadmium, chromium and lead. Total metal samples were preserved with concentrated Nitric Acid. These samples were stored and digested in accordance with the procedure for total and soluble recoverable methods, pages Metal 4 to 6, Sections 3 & 4, contained in EPA's Methods of Chemical Analysis of Water and Wastes (42). Soluble copper samples were filtered through a membrane filter with a 0.45 um pore size and preserved with concentrated nitric Acid. The digested total metal and acidified soluble copper samples were analyzed with either a Perkin-Elmer

703 Atomic Absorption Spectrophotometer or a Perkin-Elmer 5100 PC Atomic Absorption Spectrophotometer. Copper, iron, manganese, and zinc were analyzed with a Perkin-Elmer 703 Atomic Absorption Spectrophotometer and the detection limits were 0.02, 0.03, 0.01 and 0.005 (rounded to 0.01) respectively. Nickel, cadmium, chromium and lead were analyzed with a Perkin-Elmer 5100 PC Atomic Absorption Spectrophotometer by Marilyn Grender, a Chemist, and the data set reflects the correct detection limits.

Phosphate Phosphorous (PO_4-P):

Leachate, effluent and anoxic chamber phosphate phosphorous concentrations were determined using a Dionex 2010 Ion Chromatograph (IC) in accordance with Test 429 (40).

Suspended and Volatile Solids:

The mixed liquor and effluent total and volatile suspended solids in the aerobic and anoxic chambers were determined in accordance with Test 209 C & D(40).

Analysis:

Mean Cell Residence Time (MCRT) or Sludge Age:

The MCRT's of all three systems were maintained by wasting solids directly from the aerobic chamber and monitoring the effluent solids. The amount of mixed liquor volume wasted to maintain the desired sludge age was determined from the following equations:

$$MCRT = (X * V)/[(Q_w * X) + (Q - Q_w) * X_{eff}] \qquad [Eq.13]$$

$$(Q_w * X * MCRT) + [(Q - Q_w) * X_{eff} * MCRT] = X * V$$

$$(Q_w * X * MCRT) + (Q * X_{eff} * MCRT) - (Q_w * X_{eff} * MCRT) = X * V$$

$$Q_w * [(X * MCRT) - (X_{eff} * MCRT)] = [(X * V) - (Q * X_{eff} * MCRT)]$$

$$Q_w = (X * V - Q * X_{eff} * MCRT)/[MCRT * (X - X_{eff})] \qquad [Eq.14]$$

Where:

Q_w = Volume of mixed liquor wasted each day (L/day).

X = Average MLVSS concentration (mg/L).

V = Reactor Volume (aerobic & anoxic chambers), 4.5 L.

Q = Influent flow rate, 6.0 L/day.

X_{eff}=Effluent VSS concentration from the clarifier (mg/L).

X = Average MLVSS concentration (mg/L) = $1/3 * X_{anx} + 2/3 * X_{aer}$.

Where:

X_{anx} = anoxic chamber MLVSS

X_{aer} = aerobic chamber MLVSS

Since wasting occurred only from the aerobic tank, the Q_w was weighted by the MLVSS in the chamber. Once Q_w was calculated using the average MLVSS, then the actual volume wasted was calculated by the ratio, X_{aer} / X.

If the desired MCRT could not be maintained because of loss of solids in the effluent (X_{eff}), then wasting was discontinued except wasting associated with sampling. The MCRT was then calculated by the following form of the above formula.

$$\text{MCRT} = (X * V)/[(Q_w * X) + (Q - Q_w) * X_{eff}] \qquad \text{[Eq.15]}$$

Nitrogen Wasted per liter of flow (N_w):

N_w = Nitrogen wasted per liter of flow (mg/L).

$$N_w = \{ N_s * [Q_w * X + (Q - Q_w) * X_{eff}] / Q \} \qquad \text{[Eq.16]}$$

N_s = Nitrogen in Volatile Solids (10.4%) (ref. 1).

Total Influent Nitrogen (TN_{in}):

TN_{in} = Total Influent Nitrogen (mg/L).

$$TN_{in} = (TKN_{in} + NO_{2in} + NO_{3in}) \qquad \text{[Eq.17]}$$

Where:

TKN_{in} = Influent Total Kjeldahl Nitrogen (mg/L).

NO_{2in} = Influent Nitrite Nitrogen (mg/L).

NO_{3in} = Influent Nitrate Nitrogen (mg/L).

Total Effluent Nitrogen (TN_{eff}):

TN_{eff} = Total Effluent Nitrogen.

$$TN_{eff} = TKN_{eff} + NO_{2eff} + NO_{3eff} + N_w \qquad [Eq.18]$$

Where:

TKN_{eff} = Effluent Total Kjeldahl Nitrogen (mg/L).

NO_{2eff} = Effluent Nitrite Nitrogen (mg/L).

NO_{3eff} = Effluent Nitrate Nitrogen (mg/L).

Nitrogen Available for Nitrification per liter of Q (N_aN):

N_aN = Nitrogen available for nitrification per liter of flow (mg/L).

$$N_aN = TKN_{in} - N_w - (TKN_{eff} - NH_{3eff}) \qquad [Eq.19]$$

Where:

NH_{3eff} = Effluent Ammonia Nitrogen (mg/L).

Total Nitrogen Nitrified per liter of flow (TNN):

TNN = Total Nitrogen Nitrified per liter of flow (mg/L).

$$TNN = TKN_{in} - N_w - TKN_{eff} - (0.25 * NO_{2eff}) \qquad [Eq.20]$$

Percent Nitrification (%N):

%N = Percent Nitrification.

$$\%N = TNN * 100/ N_aN \qquad [Eq.21]$$

Nitrogen Available for Denitrification per liter of Q (N_aDeN):

N_aDeN = Nitrogen Available for Denitrification per liter of flow (mg/L).

$$N_aDeN = TNN + (0.60 * NO_{2in}) + NO_{3in} \qquad [Eq.22]$$

Note, raw leachate is pumped into the anoxic zone first, so any nitrate and nitrite in the leachate is denitrified before flowing into the aerobic zone.

Total Nitrogen Denitrified per liter of flow (TNDeN):

TNDeN = Total Nitrogen Denitrified per liter of flow (mg/L).

$$TNDeN = TKN_{in} + 0.60 * NO_{2in} + NO_{3in} - N_w - TKN_{eff} - NO_{3EFF} - 0.60 * NO_{2eff} \qquad [Eq.23]$$

Percent Denitrification (%DeN):

%DeN = Percent Denitrification.

$$\%DeN = TNDeN * 100/ N_aDeN \qquad [Eq.24]$$

NO_x-N Entering the Anoxic Chamber ($NO_x\text{-}N_{in\ Anx}$):

$$NO_x\text{-}N_{in\ Anx} = [3/4 * (0.6 * NO_{2eff} + NO_{3eff}) + 1/4 * (0.6 * NO_{2in} + NO_{3in})] \qquad [Eq25]$$

NO_x-N Leaving the Anoxic Chamber ($NO_x\text{-}N_{out\ Anx}$):

$$NO_x\text{-}N_{out\ Anx} = 0.6 * NO_{2anx} + NO_{3anx} \qquad [Eq26]$$

NO_{2anx} = Nitrite Nitrogen measured in the Anoxic Chamber (mg/L).

NO_{3anx} = Nitrate Nitrogen measured in the Anoxic Chamber (mg/L).

Percent Denitrification in the Anoxic Chamber ($\%DeN_{in\ Anx}$):

$$\%DeN_{in\ Anx} = NO_x\text{-}N_{in\ Anx} * 100/ NO_x\text{-}N_{out\ Anx} \qquad [Eq27]$$

CHAPTER IV. RESULTS

In this chapter the results of the MLE experiments will be given. The characterization of the Dixie Caverns Landfill Leachate will be presented first, followed by the data regarding the distribution of solids within the systems. Next, the N concentration balances and reactions in each of the systems will be presented, and finally, copper test data will be presented.

LEACHATE CHARACTERIZATION

Table 7 presents the range and average concentrations of all the leachate constituents measured during the entire period of study. Table 8 gives the range and average of the various N constituents for each field trip sample. The average leachate TKN was 51.1 mg/L with a range of 44.7 to 59.4 mg/L. The ammonia-N average concentration was 46.2 and ranged from 40.3 to 54.6 mg/L. Note that the leachate BOD_5 was not directly measured during this experiment due to the fact that previous data showed that leachate had a low BOD_5, always less than 10 mg/L and about 5% of the COD (1). Thus, a biodegradable carbon source was needed for denitrification to occur. The results also show that the leachate was clearly phosphorus deficient after COD was added for denitrification. Appendixes B and C contain all the measurements used to make Tables 7 and 8.

Table 7. Characteristics of Dixie Caverns Leachate

Constituents	N*	Avg. Concentration**	Range**
COD	72	60.0	42.0-78.3
TKN	80	51.1	44.7-59.4
Ammonia-N	85	46.2	40.3-54.6
Nitrite-N	78	0.68	0.00-4.17
Nitrate-N	78	0.61	0.00-3.26
Chloride	78	200	146-261
Phosphate-P	78	0.07	0.00-0.26
Alkalinity	16	540	503-575
pH	16	6.54	6.36-6.80
Iron	16	20.6	5.0-48.3
Manganese	16	0.93	0.68-1.14
Zinc	16	0.095	0.045-0.230
Nickel	16	0.085	0.010-0.184
Copper	16	0.017	0.006-0.034
Cadmium	16	0.0077	0.0001-0.0925
Chromium	16	0.0017	0.0010-0.0034
Lead	16	0.003	0.001-0.006

* Number of observations.
** All values expressed as mg/L, except for pH.

Table 8. Dixie Caverns Leachate Nitrogen Characterization

Trip	Date	Nitrogen Sum*	TKN*	NH_3-N*	NO_2-N*	NO_3-N*
1	11/22/90	58.1-61.0 59.3	57.3-60.2 58.5	52.5-55.4 53.9	0.0	0.81
2	12/13/89	60.2	59.4	54.6	0.0	0.81
3	1/4/90	47.1-51.2 52.3	44.7-54.3 48.5	38.2-45.0 41.5	0.0-2.60 0.56	1.58-6.85 3.26
4	1/27/90	48.5-52.6 50.4	44.3-51.2 48.9	38.8-44.7 43.1	0.0-1.10 0.16	0.08-6.00 1.39
5	2/16/90	51.0-53.3 51.7	50.7-52.4 51.4	44.2-46.1 45.4	0.0	0.01-0.94 0.34
6	3/6/90	49.0-54.6 50.8	46.8-54.5 49.8	39.3-45.4 42.7	0.0-.38 0.12	0.01-3.59 0.84
7	3/27/90	49.9-51.3 50.8	47.6-51.2 49.7	42.8-47.2 45.8	0.0-3.02 0.50	0.10-1.04 0.55
8	4/14/90	48.1-49.9 49.1	41.8-48.9 44.7	37.0-44.5 40.3	0.81-7.78 4.17	0.10-0.24 0.20
9	4/30/90	47.6-51.5 50.5	46.1-48.0 47.5	42.2-44.2 43.1	1.20-3.87 2.64	0.28-0.60 0.40
10	5/21/90	47.2-55.0 49.7	46.8-49.1 47.8	45.0-41.7 43.5	0.0-6.24 1.50	0.02-0.71 0.33
11	6/6/90	48.0	47.9	44.6	0.0	0.10
12	6/25/90	50.1-52.5 51.3	49.7-51.6 50.7	45.5-47.7 46.9	0.0-1.35 0.42	0.01-0.71 0.18
13	7/16/90	52.2-57.8 53.7	52.3-53.1 52.7	46.3-49.0 47.7	0.0-4.62 0.81	0.0-0.70 0.17
14	8/6/90	52.6-54.4 53.6	52.5-54.4 53.6	46.7-49.8 48.6	0.0	0.0-0.12 0.04
15	8/27/90	51.9-52.2 52.0	51.9-52.2 52.0	46.7-47.6 47.3	0.0	0.01-0.05 0.03
16	9/17/90	54.4-55.2 54.7	54.0-54.9 54.4	48.3-49.8 49.1	0.0	0.18-0.37 0.25
Range Avg.		48.0-60.2 52.4	44.7-59.4 51.1	40.3-54.6 46.2	0.00-4.17 0.68	0.00-3.26 0.61

* mg/L

SOLIDS DISTRIBUTIONS

The mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS), effluent total suspended solids (Eff. TSS), and effluent volatile suspended solids (Eff. VSS) are presented in Figures 4, 5, and 6. The range and averages for each significant operational change within the systems are presented in Appendix B in Tables B-4 to B-7 along with a data base of all the solids in Tables B-24 to B-29.

The results from system #1 clearly show the effects of sludge age on the MLSS and MLVSS concentrations as shown in Figure 4. As expected, the SS concentrations increased substantially as the sludge age increased. The sludge age was increased from 8 to 15 day on day 115 of the study and then from 15 to 30 day on day 176 of the study. Also, as expected, the ratio of MLVSS to MLSS decreased as the sludge age increased and when copper was added the ratio decreased further. It is interesting to note that the SS concentrations in the aerobic zone were always substantially higher than those in the anoxic zone, except when the system was being operated at an 8 day sludge age. Refer to Table B-4 for more details.

The effluent SS concentrations in system #1 also increased as the sludge age and copper addition increased. The average effluent TSS and VSS for the 8 day sludge age were 3.9 and 3.6 mg/L, respectively, while the average effluent TSS and VSS for the 15 day sludge age were 5.9 and 4.9 mg/L, respectively. The average effluent TSS and VSS for the 30 day sludge age, from day 176 to 245, were 13 and 10 mg/L, respectively. Figure 4 shows that effluent SS increased greatly during the 5.0 mgCu/L addition, from day 253 to 319, and the average effluent TSS and VSS were 75 and 45 mg/L, respectively. Also note that the high effluent TSS and VSS, of 137 and 80 mg/L, respectively, on day 264 were increased by partial aeration of the aerobic chamber on

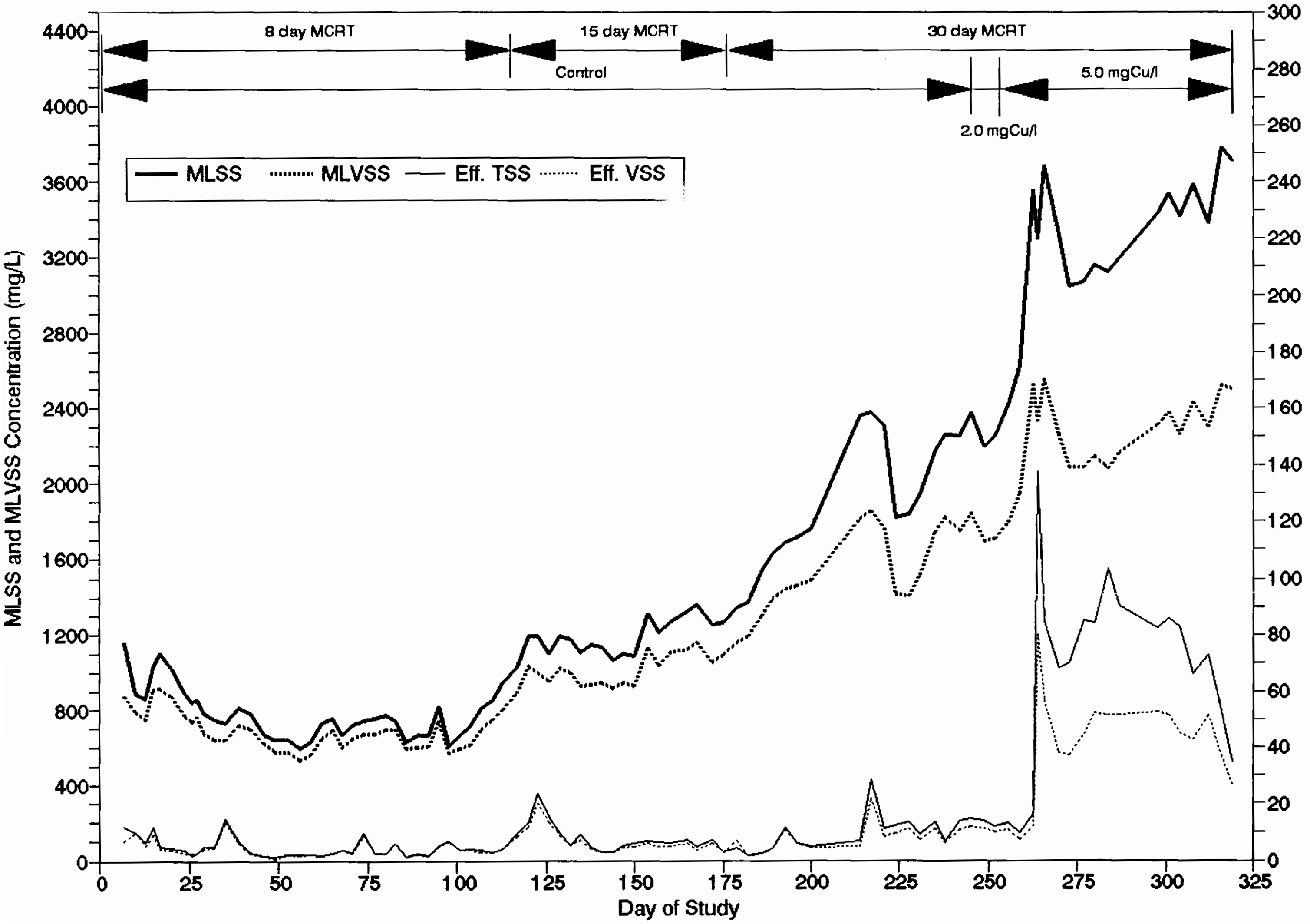

Figure 4. #1 System, MLSS, MLVSS, and Effluent VSS & TSS

day 263. The partial aeration was due to the fact that the diffuser stone came off the aeration hose which did not reach the bottom of the chamber and so the bottom half of the chamber was not aerated. This situation lasted for about 4 to 24 hours before being discovered and corrected. The remainder of the Results Chapter will refer to this event as the aeration incident. It is interesting to note that control system #3 also experienced elevated levels of effluent SS from day 245 to 300 as shown in Figure 6, page 54.

It is of even greater interest to note that the SS concentrations increased as the copper addition increased in system #1. There was a 3.7% increase when the copper addition was 2.0 mgCu/L and a 34% increase when the addition was increased to 5.0 mgCu/L. Of course, the results were not obtained at the same time and there may have been differences in the influent leachate which partially explain the increase, rather than it being attributed solely to copper accumulation in the activated sludge.

The results from system #2 also clearly show the effects of sludge age on the MLSS and MLVSS concentrations. As expected, the SS concentrations increased substantially as the sludge age increased from 8 to 15 day on day 115 of the study (Figure 5). Also as expected, the ratio of MLVSS to MLSS decreased as the sludge age increased. At the 8 day sludge age, from day 89 to 115 of the study, the average ratio was 89%, and at the 15 day sludge age, from day 132 to 141 of the study, the average ratio was 85%, a 4% decrease. It is interesting to note that the SS concentrations in the aerobic zone were always substantially higher than those in the anoxic zone, except during the 2.5 mgCu/L addition, from day 29 to 57, when the SS were about even in both zones.

The results also show the effects of copper on the MLSS and MLVSS concentrations in system #2. Note, that the SS decreased during the 2.5 mgCu/L addition at the 8 day sludge age but generally increased with the copper additions at

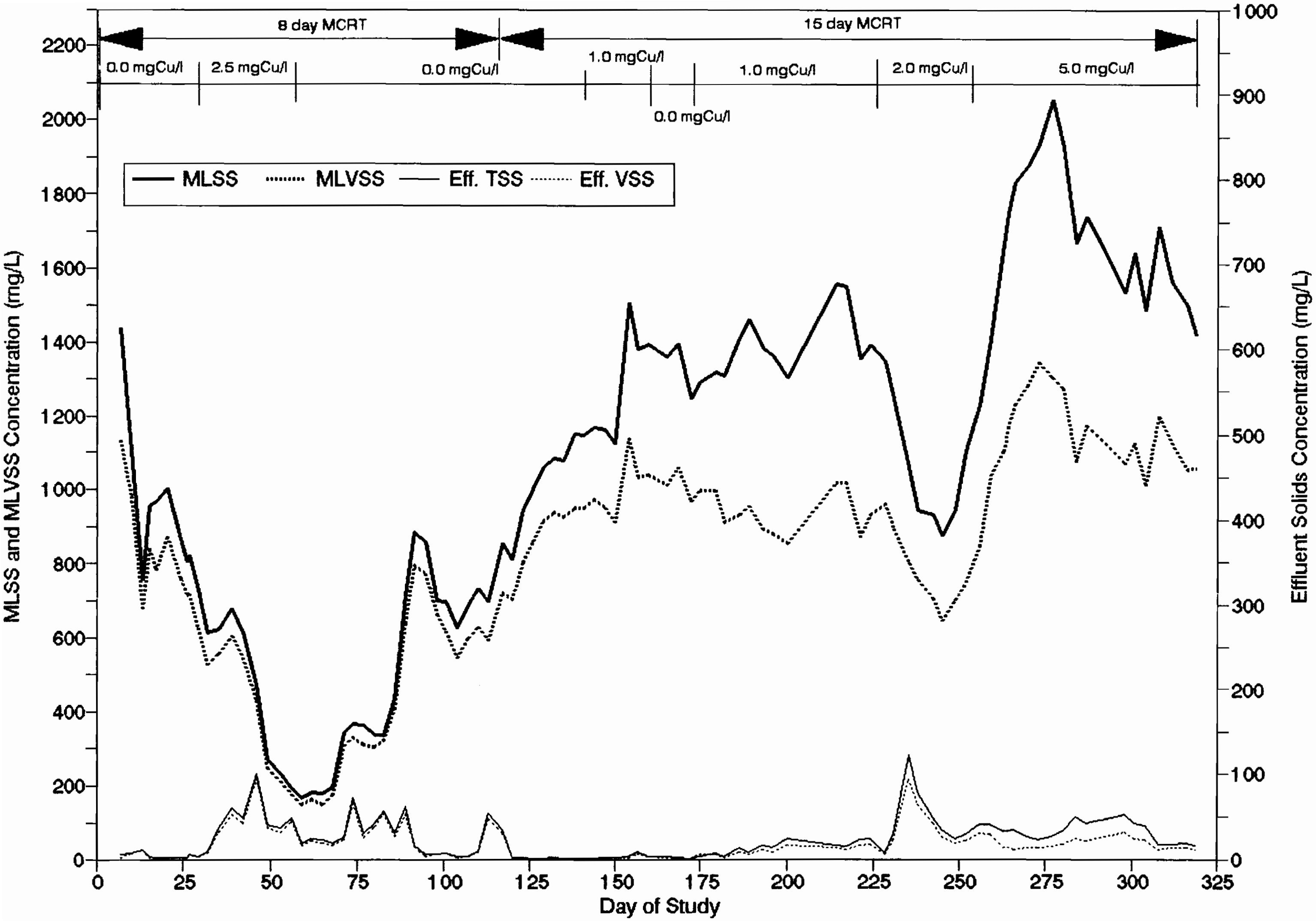

Figure 5. #2 System, MLSS, MLVSS, and Effluent VSS & TSS

the 15 day sludge age. On day 29 of the study the MLSS and MLVSS were 730 and 630 mg/L, respectively, and by day 59 of the study the MLSS and MLVSS were down to 150 and 170 mg/L, respectively. Thus, system #2 experienced solids failure during the 2.5 mgCu/L addition at an 8 day sludge age. At the 15 day sludge age there were four copper additions to the leachate, two additions at 1.0 mgCu/L, one at 2.0 mgCu/L and the last at 5.0 mgCu/L. The two 1.0 and 5.0 mgCu/L additions resulted in MLSS increases of 24%, 27%, and 52%, respectively, while the 2.0 mgCu/L addition resulted in a 5.2% decrease when compared with the MLSS before copper addition was started. The 2.0 mgCu/L addition started on day 225 and ended on day 253. On day 224 of the study the MLSS and MLVSS were 1390 and 930 mg/L, respectively, and on day 245 of the study the MLSS and MLVSS were at their lowest concentration of 880 and 650 mg/L, respectively. But on day 256 of the study the MLSS and MLVSS had rebounded to 1230 and 850 mg/L, respectively. These results, as shown in Figure 5, clearly show that the bacterial growth was inhibited during the 2.0 mgCu/L addition. As expected, the ratio of MLVSS to MLSS generally decreased as the copper addition increased except when the system was being inhibited. The 2.5, 1.0, 1.0, 2.0, and 5.0 mgCu/L additions had MLVSS/MLSS ratios of 89%, 75%, 65%, 74%, and 69%, respectively. Note that the ratio of MLVSS to MLSS actually increased by 3% during the 2.5 mgCu/L addition and by 9% during the 2.0 mgCu/L addition.

Figure 5 clearly shows that the effluent TSS and VSS increased significantly as the copper addition in system #2 increased. During the 2.5 and 2.0 mgCu/L additions the effluent TSS and VSS reached their highest levels. On day 46 of the study the effluent TSS and VSS were 100 and 95 mg/L, respectively, while on day 235 the effluent TSS and VSS were 123 and 94 mg/L, respectively. The increase in effluent solids could indicate that bacteria were being inhibited by death and lysing, and that settleability of the solids was being hindered.

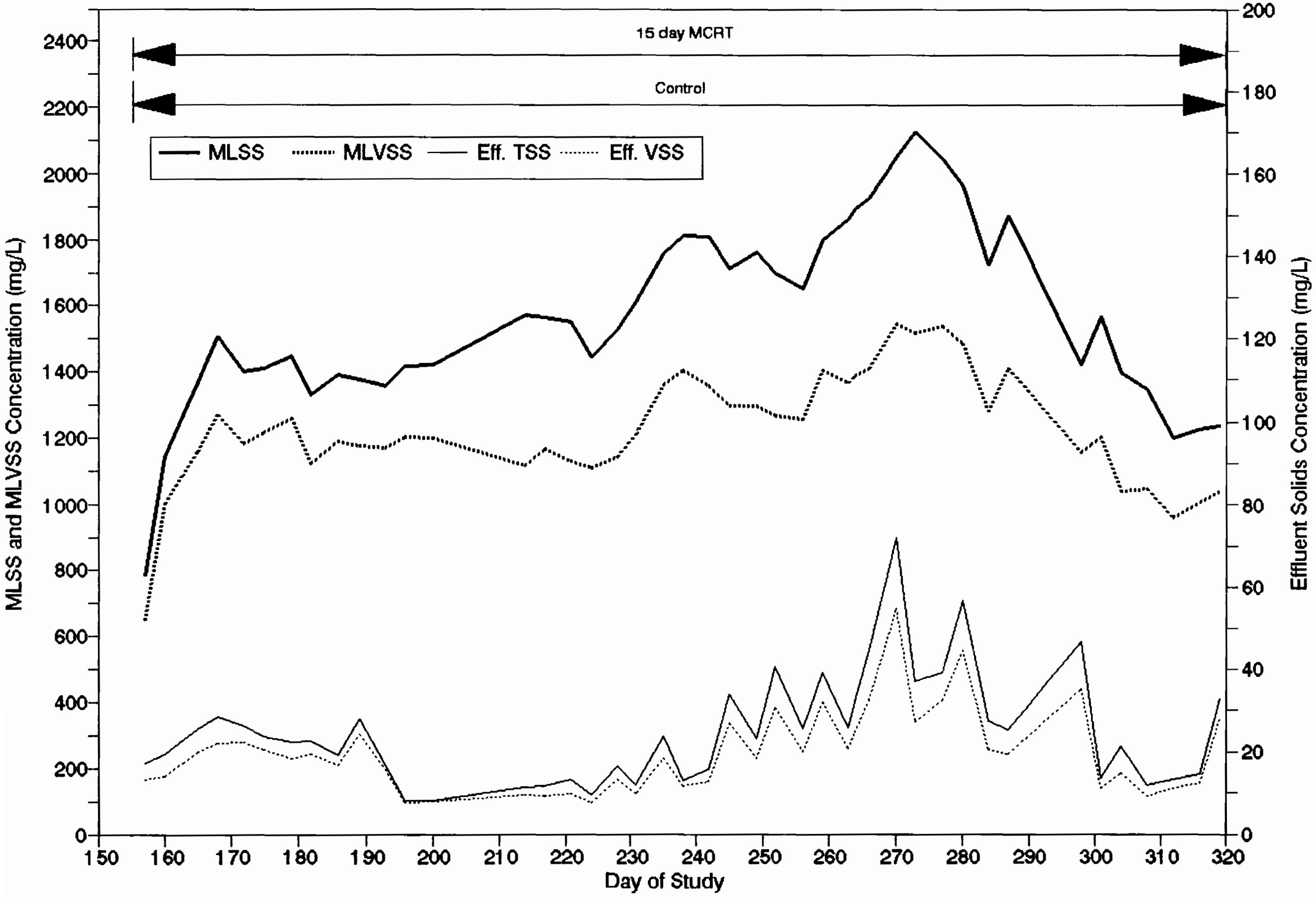

Figure 6. #3 System, MLSS, MLVSS, and Effluent TSS & VSS

Figure 6 shows that system #3 had no problem retaining MLSS and MLVSS over time. The high level of effluent TSS and VSS, which reached levels of 72 and 55 mg/L, respectively, on day 270 of the study, indicate that there were significant settling problems and that some bacteria were probably being inhibited at times.

NITROGEN PERFORMANCE DATA

Figures 7 through 15 present the performance of the systems in treating N in the leachate. Figures 7 to 9 deal with system #1 while Figures 10 to 12 refer to system #2 and Figures 13 to 15 refer to system #3. A nitrogen balance of the systems are shown in Figures 4, 8, and 12. Total influent nitrogen (Inf. TN), effluent ammonia-N (Eff. NH_3-N), effluent TKN, and total effluent nitrogen (Eff. TN) are plotted in the figures. The vertical arrows within the figures mark the day of the study when a new leachate batch was started. These N balances assume that the N difference between influent TN and effluent TN was denitrified and left the systems as N_2 gas. The influent TN is defined as the sum of influent leachate TKN, nitrite-N, and nitrate-N while the effluent TN is defined as the sum of the effluent TKN, nitrite-N, nitrate-N and the N in the mixed liquor which was wasted to maintain sludge age (refer to Equations 17 and 18). Effluent nitrite-N and nitrate-N are shown in Figures 8, 11, and 14. Anoxic chamber nitrite-N, nitrate-N, NO_x-$N_{in\ Anx}$, and NO_x-$N_{out\ Anx}$ are shown in Figures 9, 12, and 15. NO_x-$N_{in\ Anx}$ is defined in Equation 25, and NO_x-$N_{out\ Anx}$ is defined in equation 26, but in general NO_x-N = 0.6 NO_2-N + NO_3-N.

Flow into the anoxic zone comes from influent leachate, aerobic recycling, and sludge recycling. Equation 25 assumes that the aerobic chamber is completely mixed and no reactions are taking place in the clarifier, so that the effluent NO_2-N and NO_3-N is equal to the recycled NO_2-N and NO_3-N from the aerobic chamber and clarifier.

Equation 26 assumes that the anoxic chamber is completely mixed so that the NO_2-N and NO_3-N measured in the anoxic zone is equal to the NO_2-N and NO_3-N leaving the anoxic zone. Notice that in the equation NO_x-N = 0.6 NO_2-N + NO_3-N, that a 0.6 factor is applied to the NO_2-N term. This factor is present because this formula is evaluating the denitrification process in the anoxic zone. Since denitrification is a two part reaction in which nitrate-N is converted first to nitrite-N and then to N_2 gas, the denitrification process is partially complete when the nitrite is present and fully complete when neither nitrite nor nitrate is present. A charge balance of the reduction process of nitrate to nitrogen gas reveals that a total of five electrons are transferred and accepted by N. The 0.6 factor is used because the N in NO_3^- is at a $^+5$ state, the N in NO_2^- is at a $^+3$, and the N in N_2 is at a $^+0$ state, thus the N in NO_2^- can still receive 3 electrons or 60% of the total electrons in the denitrification process.

Tables B-12 to B-14 present a detailed summary of the range and average of the following constituents for each system's operating conditions: N available for nitrification and denitrification, total N nitrified and denitrified, percent nitrification and denitrification, effluent N wasted, effluent N sum, effluent TKN, effluent ammonia-N, effluent nitrate-N, effluent nitrite-N, and anoxic nitrite-N and nitrate-N. Appendix B also contains the complete data base for the nitrogen constituents in Tables B-15 to B-23.

The results indicate that system #1's nitrification and denitrification were at times inhibited by the leachate and copper additions as shown in Figures 7, 8, and 9. When the effluent had only nitrate, but lacked ammonia and nitrite, then **Nitrosomonas** and **Nitrobacter** were not being inhibited. When nitrite appeared in the effluent then the **Nitrobacters** were inhibited. When ammonia appeared in the effluent then the **Nitrosomonads** were inhibited.

On day 98 to 129 the **Nitrosomonas** species were inhibited and rebounded while

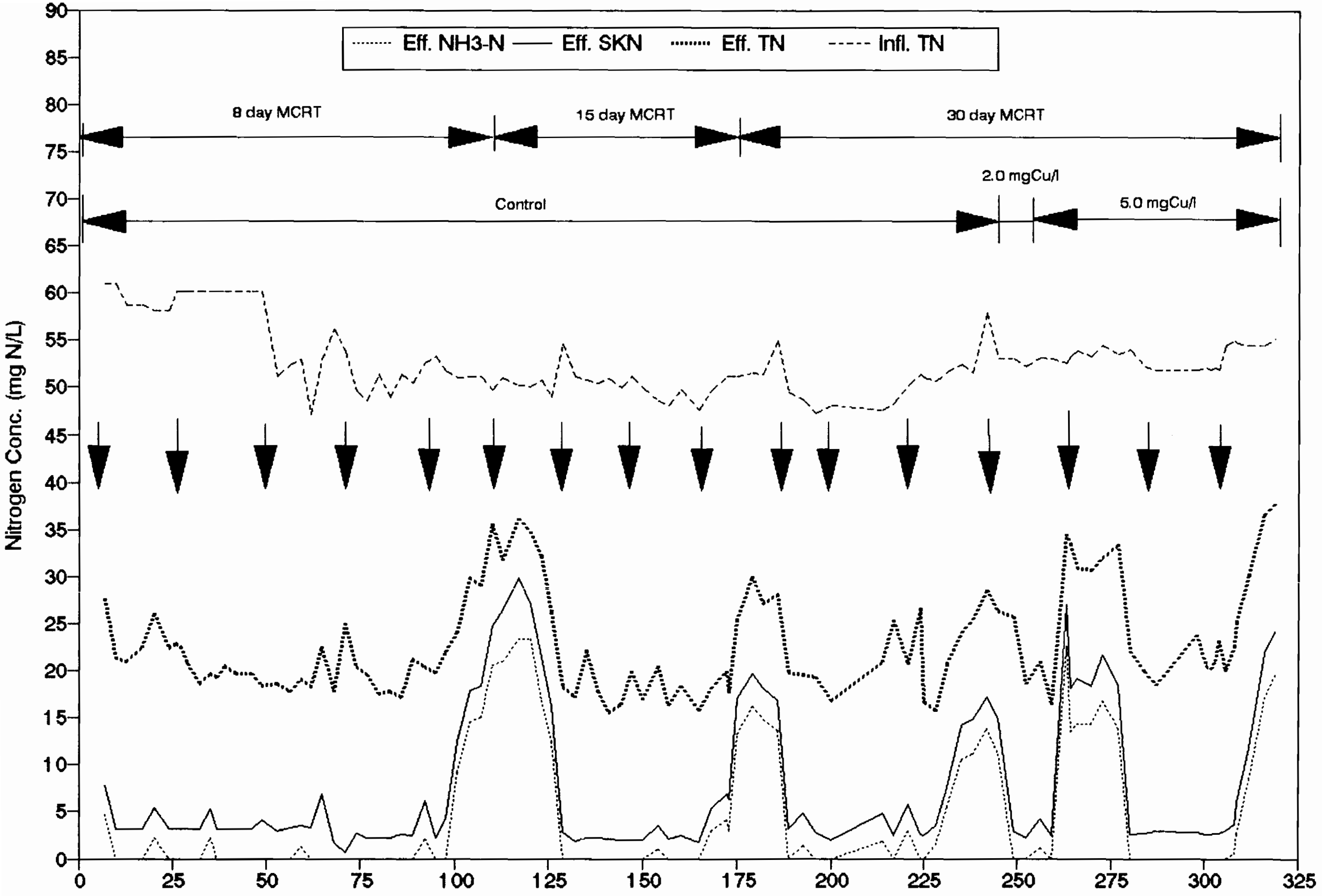

Figure 7. #1 System, Nitrogen Balance

Note: Arrows mark new leachate feed.

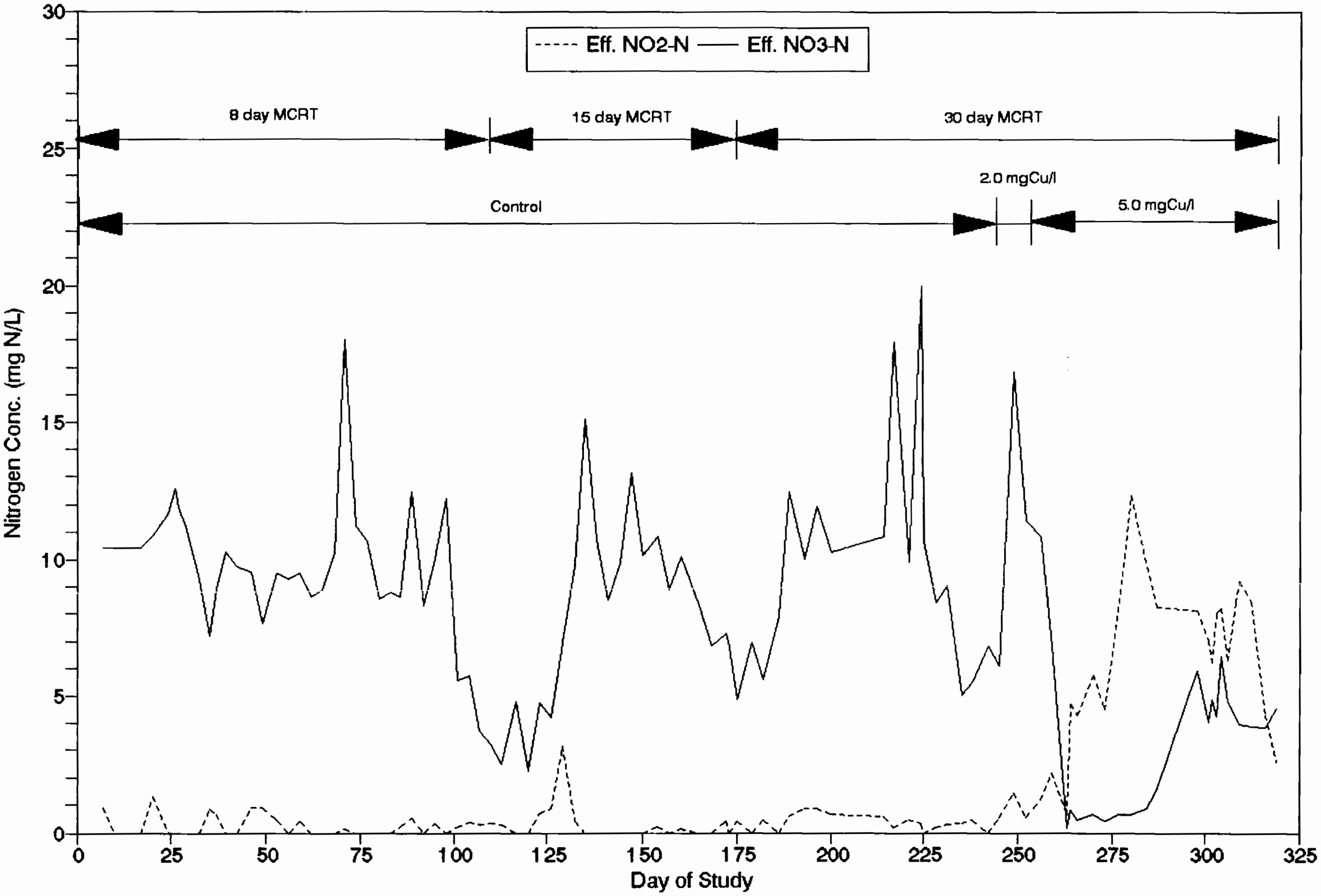

Figure 8. #1 System, Effluent Nitrite & Nitrate

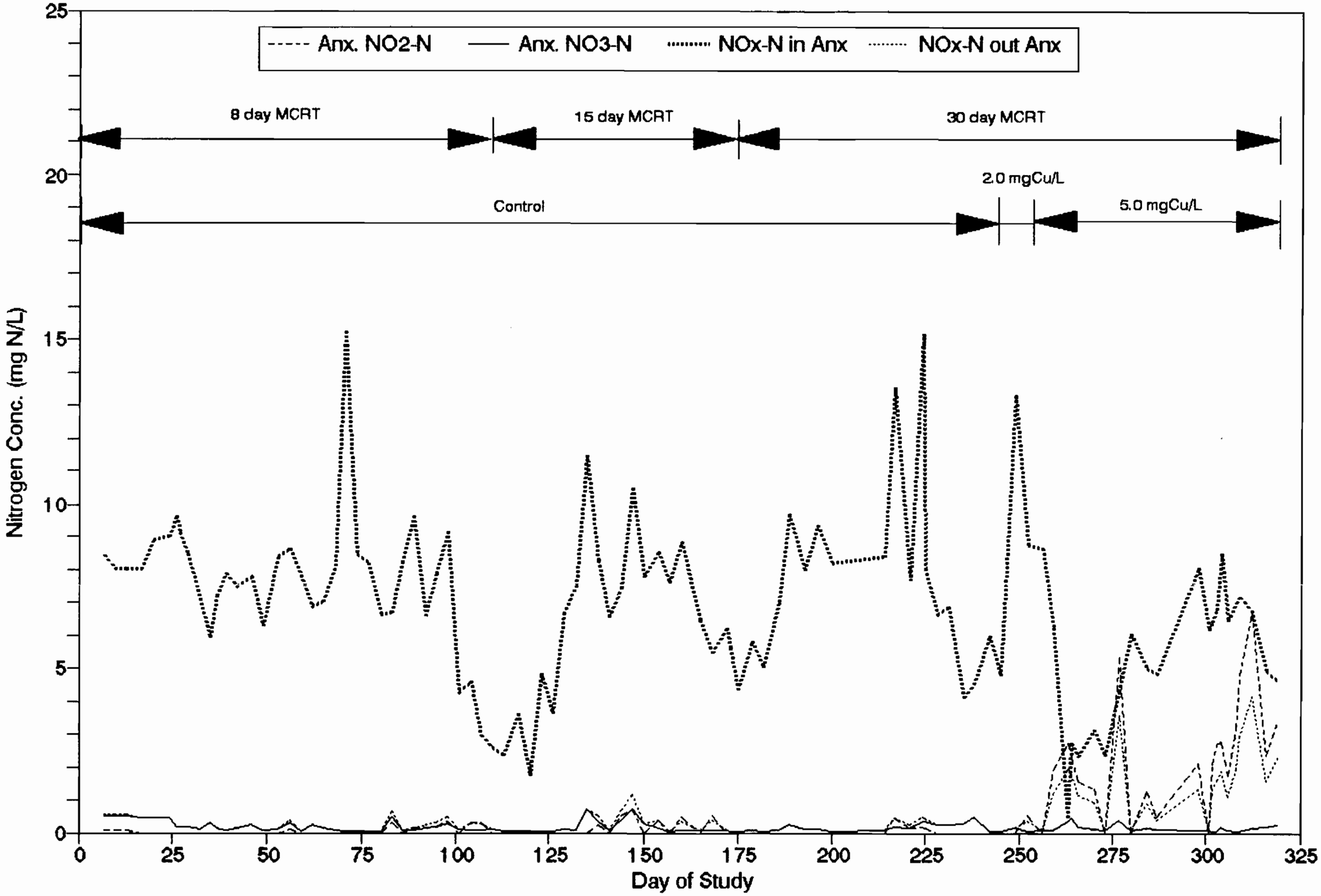

Figure 9. #1 System, Anoxic Nitrite & Nitrate

Note: NOx-N = 0.6 NO2-N + NO3-N, see equations 25 and 26.

system #1 was being operated as a control at an 8 day sludge age. When the system started to rebound, nitrite appeared in the effluent and it became obvious that the **Nitrobacters** were also being inhibited. The nitrate and nitrite did not build-up in the anoxic zone so the denitrifiers were not inhibited. On days 91 and 109 new leachate batches were started. On day 115 the sludge age was increased from 8 to 15 day, and on day 117 the inhibition of nitrification reached its peak and the system started to recover. The leachate batch, started on day 91, might have contained a toxin that the leachate batch, started on day 109, did not have, and/or the increase in the sludge age might have been the primary cause of the recovery.

From day 173 to 189, **Nitrosomonas** species were again inhibited and rebounded while system #1 was being operated as a control at a 15 day sludge age. Nitrite did not appeared in the effluent so the **Nitrobacters** were not inhibited. Nitrate and nitrite did not build-up in the anoxic zone and, therefore, the denitrifiers were not inhibited. On day 164 and 185 new leachate feeds were started, and on day 176 the sludge age was increased from 15 to 30 day. On day 179 the inhibition of nitrification reached its peak and the system started to recover. Thus, it appears that the increase in sludge age, not the change in leachate, caused the system to recover.

On day 228 to 249, the **Nitrosomonas** species were inhibited and recovered while system #1 was being operated as a control at a 30 day sludge age. Very low nitrite levels were in the effluent indicating the **Nitrobacters** were generally not inhibited. The nitrate and nitrite did not build-up in the anoxic zone and so the denitrifiers were not inhibited. On days 220 and 241 new leachate batches were started, and on day 245 the 2.0 mgCu/L addition was started. On day 242 the inhibition of nitrification reached its peak and the system started to recover. The leachate batch, started on day 220, possibly contained a toxin that the leachate batch started on day 241 did not have and/or the addition of copper might have been the cause of recovery. It appears unlikely that the copper addition would have improved nitrification because other experiments have shown copper to be inhibitory.

The addition of the 2.0 mgCu/L, started on day 245 and ending on day 253, did not inhibit **Nitrosomonas** and the denitrifiers. But the addition did inhibit **Nitrobacters** as indicated by the effluent nitrite increase.

The results indicate that during the addition of 5.0 mgCu/L to system #1, which started on day 253 and ended on day 319, the nitrifiers and denitrifiers were inhibited. On day 263 to 280, and again from day 308 to 319, the Nitrosomonads were inhibited while at a 30 day sludge age. On day 259 the effluent NH_3-N was 0.0 mg/L and increased to 22.6 mg/L by day 263, but on day 264 the effluent NH_3-N was back down to 13.4 mg/L. The aeration incident which occurred on day 263, and the lack of oxygen and mixing in the aerobic chamber, can account for the pronounced effluent NH_3-N peak on that day, but the effluent NH_3-N did not reach 0.0 mg/L again until day 280 of the study. The author believes that even if the aeration incident had not occurred, the system would have experienced loss of nitrification due to the copper addition. The high amounts of nitrite in the effluent show that the **Nitrobacter** were being severely inhibited. The nitrate and nitrite build-ups in the anoxic zone show that the denitrifiers were also being inhibited by the 5.0 mgCu/L addition.

The results show that system #2's nitrification and denitrification was, at times, inhibited by the leachate and copper additions, as shown in Figures 10, 11, and 12.

The 2.5 mgCu/L addition to system #2, from day 29 to 57 of the study, severely inhibited the nitrifiers and denitrifiers. System #2 was being operated at an 8 day sludge age when the 2.5 mgCu/L addition caused high ammonia and nitrite concentrations in the effluent, and a build-up of nitrite and nitrate in the anoxic zone. It is clear by the performance of system #1, which was operating as a control during

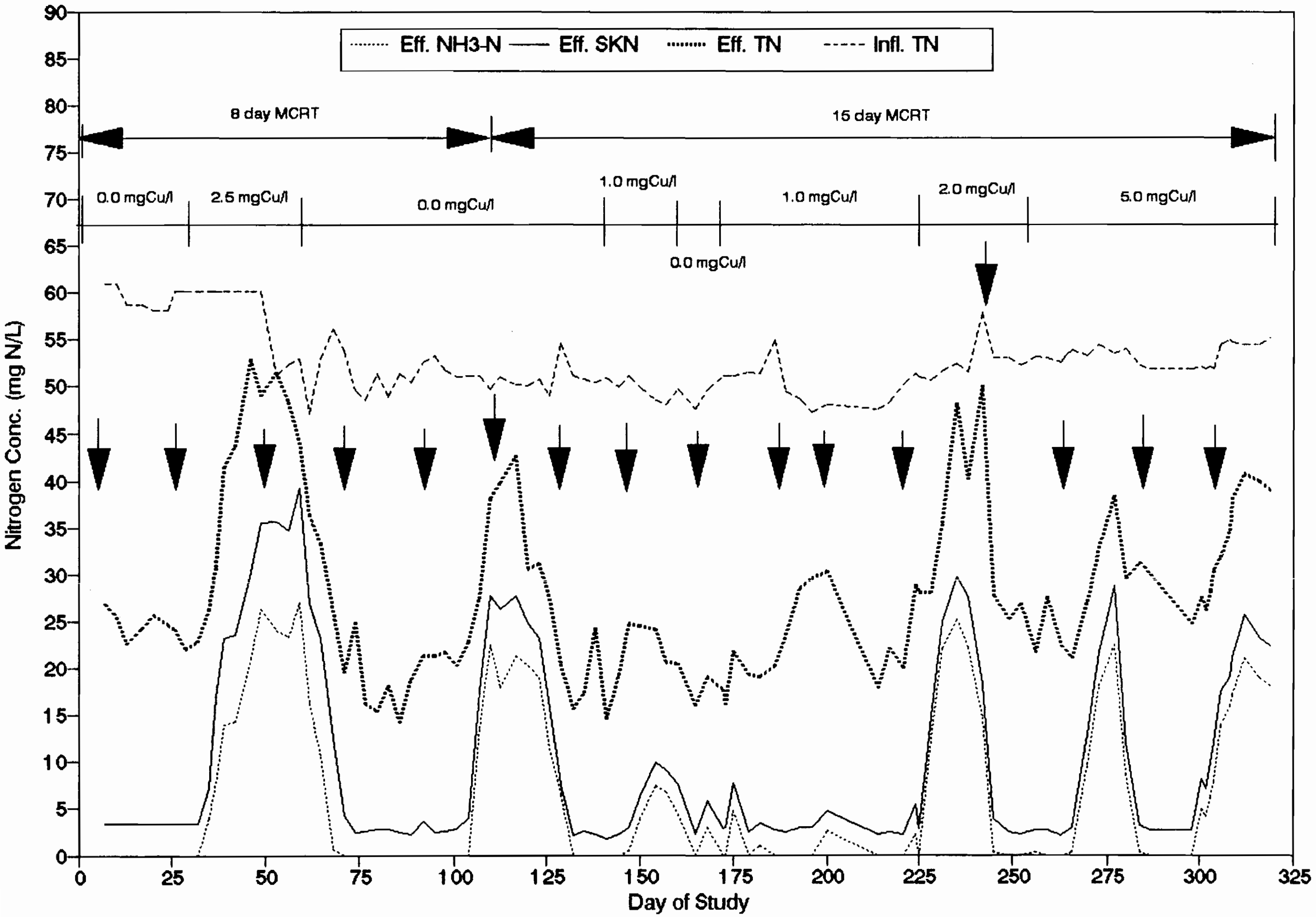

Fig. 10. #2 System, Nitrogen Balance

Note: Arrows mark new leachate feed.

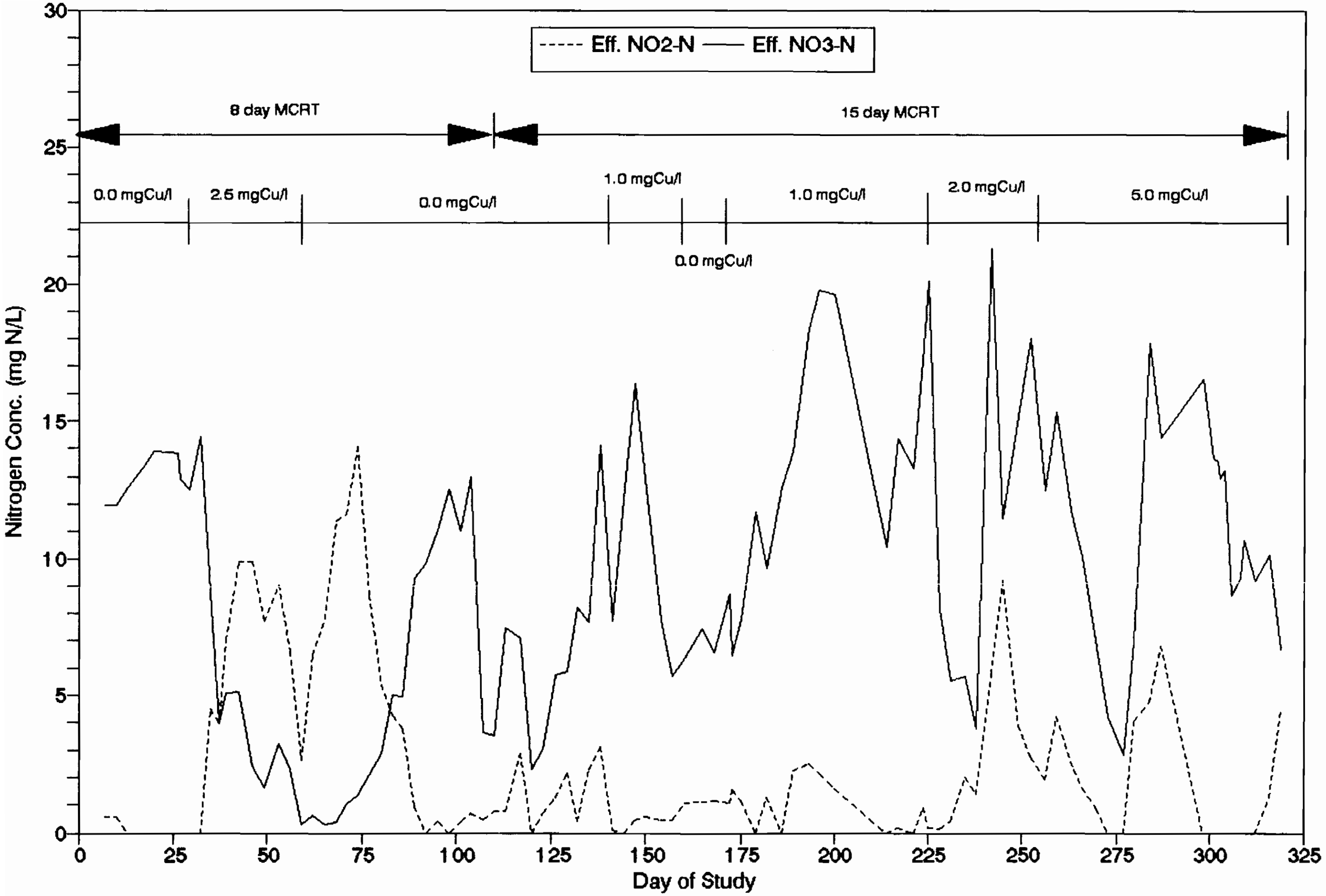

Figure 11. #2 System, Effluent Nitrite & Nitrate

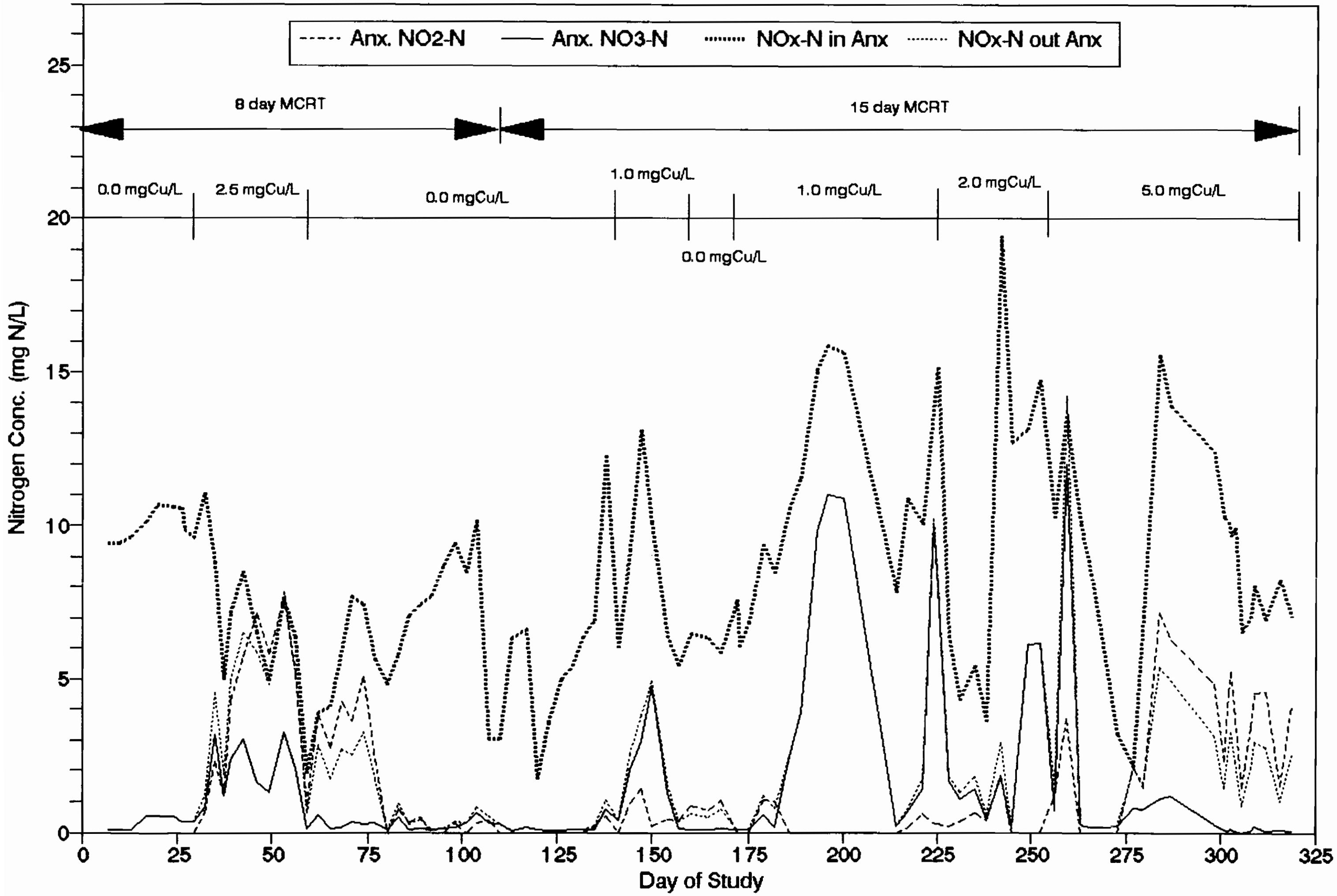

Figure 12. #2 System, Anoxic Nitrite & Nitrate

Note: NOx-N = 0.6 NO2-N + NO3-N, see equations 25 and 26.

this period of time, that the copper addition to system #2 was the cause of the failure of nitrification and denitrification.

From day 104 to 132, the **Nitrosomonas** species were inhibited and rebounded while system #2 was being operated with no copper addition at an 8 day sludge age. As previously noted, system #1 experienced an upset from day 98 to 129 of this study. Nitrite in the effluent of system #2 during this time period indicated that the **Nitrobacters** were also inhibited. The nitrate and nitrite concentrations did not build-up in the anoxic zone so the denitrifiers were not inhibited. On days 91 and 109 new leachate feeds were started, and on day 115 the sludge age was increased from 8 to 15 day. On day 117, the inhibition of nitrification reached its peak and the system started to recover. Toxin differences between the leachates started on day 91 and on day 109 and/or the increase in the sludge age might have been the primary cause of system recovery.

On day 141 to 160 of the study, 1.0 mgCu/L was added to system #2 while it was being operated at a 15 day sludge age. From day 144 to 165, the **Nitrosomonas** species were inhibited and then rebounded. Low levels of nitrite in the effluent indicated that the **Nitrobacters** were being partially inhibited. Nitrate and nitrite built-up in the anoxic zone and so the denitrifiers also were being inhibited. On day 154 the effluent ammonia-N reached its peak and the system started to recover. On day 160 the copper addition was stopped for a period of time. Note that system #1 was being operated as a control during this period of the study and did not experience any problems. Thus, the 1.0 mgCu/L addition was the cause of the nitrification and denitrification inhibitions.

From day 173 to 225 of the study, 1.0 mgCu/L was added to system #2 which was being operated at a 15 day sludge age. The **Nitrosomonas** species were not inhibited to any significant extent, but low levels of nitrite in the effluent indicated that the **Nitrobacters** were being partially inhibited. The high nitrate build-up in the anoxic zone indicated that the denitrifiers were significantly inhibited before recovery occurred towards the end of the time period. Note that system #1 was being operated as a control during this period of the study and experienced some inhibition of **Nitrosomonads**, from day 173 to 189, but **Nitrobacters** and denitrifiers were not inhibited. Thus, the 1.0 mgCu/L addition caused the inhibition of the **Nitrobacters** and denitrifiers in system #2 during this time period.

From day 225 to 253 of the study, 2.0 mgCu/L was added to system #2, which was being operated at a 15 day sludge age. From day 225 to 249 of the study, high levels of ammonia-N in the effluent indicated that the **Nitrosomonas** species were being inhibited, but then they rebounded. High levels of nitrite in the effluent indicated that the **Nitrobacters** were being inhibited. The high build-up of nitrate and nitrite in the anoxic zone indicated that denitrifiers also were being inhibited. On days 220 and 241 new leachate feeds were started. On day 235 the ammonia-N in the effluent peaked at 25.2 mg/L, while on day 242 the effluent ammonia-N was 22.2 mg/L and by day 245 the effluent ammonia-N was 14.6 mg/L. It is interesting to note that both system #1 and #3, which were being operated as 30 and 15 day controls, experienced inhibition of **Nitrosomonas** activity from day 225 to 249. Effluent ammonia-N in systems #1 and #3 peaked on day 242 of the study and were 13.7 and 14.2 mg/L, respectively. Neither of the two controls experienced significant **Nitrobacter** or denitrifier inhibitions. The results indicated that the leachate started on day 220 was inhibitory to **Nitrosomonas**, but the 2.0 mg/L was also inhibitory due to the significantly higher effluent ammonia-N from system #2. The 2.0 mgCu/L addition not only inhibited the **Nitrosomonas** species, but also inhibited the **Nitrobacters** and the denitrifiers.

The results show that 5.0 mgCu/L addition to system #2, which started on day

253 and ended on day 319 of the study, caused inhibition of the nitrifiers and the denitrifiers. From day 266 to 284, and again from day 301 to 319, **Nitrosomonas** was being inhibited while at a 15 day sludge age. On day 277 of the study, the effluent NH_3-N peaked at 22.4 mg/L, and it again peaked on day 312 at 21.0 mg/L. High amounts of nitrite in the effluent indicated that the **Nitrobacters** were being severely inhibited. The nitrate and nitrite build-up in the anoxic zone indicated that the denitrifiers were also being inhibited by the 5.0 mgCu/L addition. New leachate feeds were started on day 262, 283, and 304. The 5.0 mgCu/L results indicated that the different leachate batches were not responsible for the periods of nitrification and denitrification inhibition because the start of the leachate feeds did not match when the effluent ammonia-N started to increase or decrease.

The results show the effects of the leachate on system #3, which was operated at a 15 day sludge age and as a control system. Figures 13, 14, and 15 indicate that nitrification and denitrification were at times inhibited by the leachate. System #3 was started on day 153 and by day 193 it had reached 94% nitrification. Nitrification would have been 100%, but the effluent nitrite-N was 8.9 mg/L. By day 200 of the study the system had been operating for a period of 47 days, which is just over three sludge ages, so the system had operated long enough to be at steady state. Nitrification in the system, from day 200 to 319 of the study, averaged 89% with a range of 65% to 100%. From day 214 to 266, and again from day 306 to 319, **Nitrosomonas** was being inhibited. High levels of nitrite in the effluent indicated that the **Nitrobacters** were being inhibited while effluent nitrite-N averaged 3.2 mg/L with a range of 0.0 to 8.3 mg/L. The denitrifiers were not inhibited by the leachate and anoxic zone nitrite-N averaged 0.3 mg/L with a range of 0.0 to 1.5 and nitrate-N averaged 0.2 mg/L with a range of 0.0 to 1.2 mg/L.

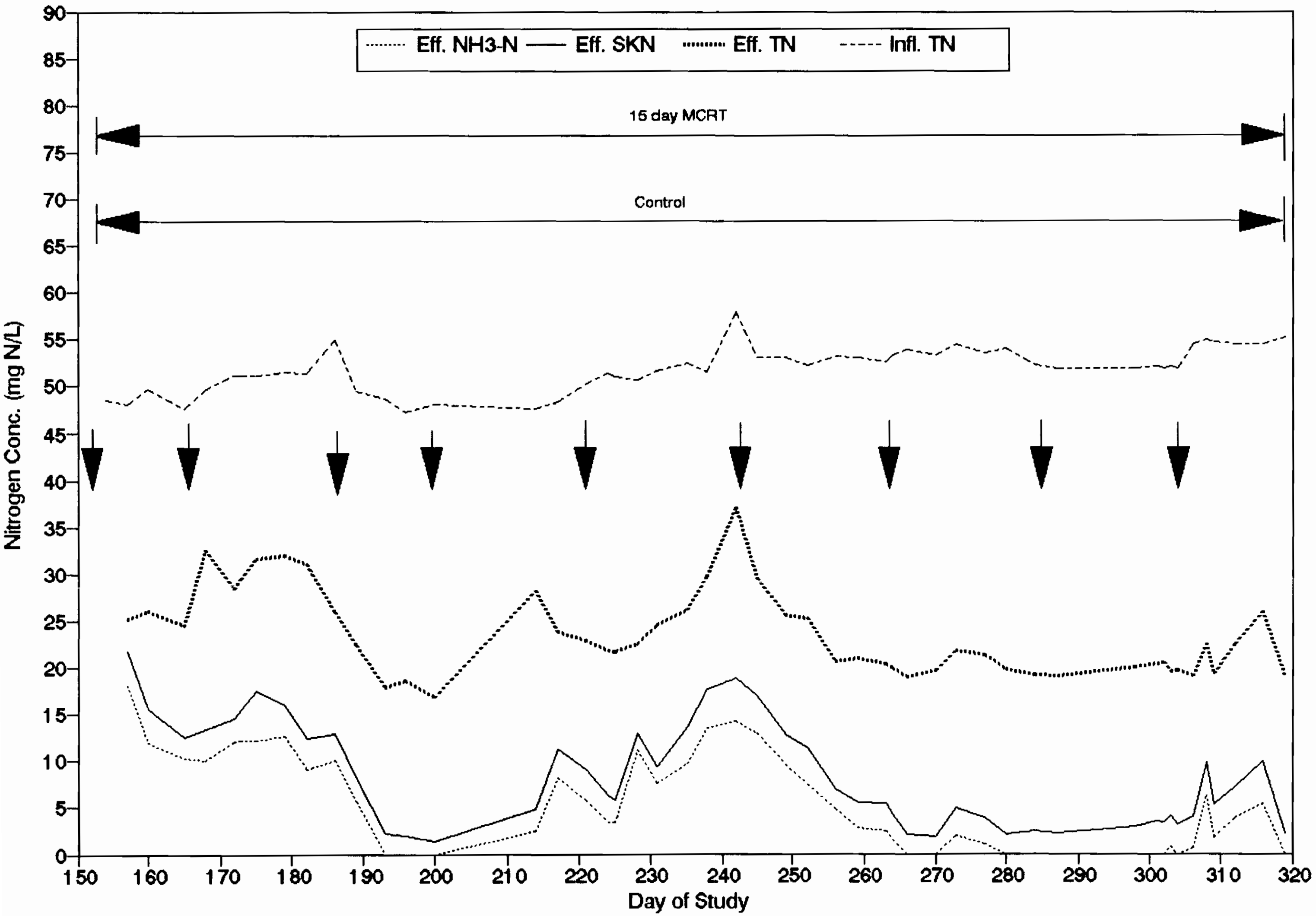

Fig. 13. #3 System, Nitrogen Balance

Note: Arrows mark new leachate feed.

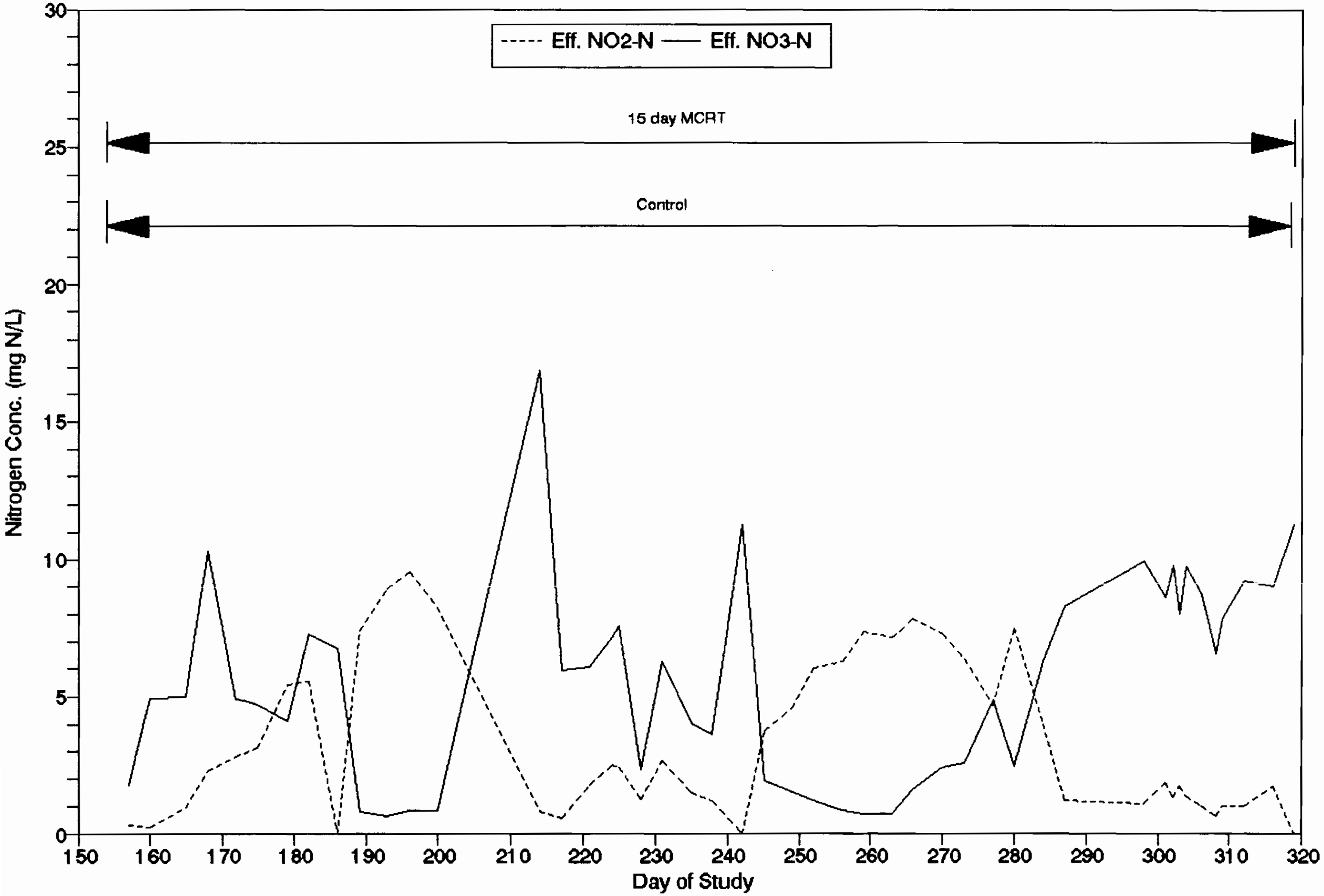

Figure 14. #3 System, Effluent Nitrite & Nitrate

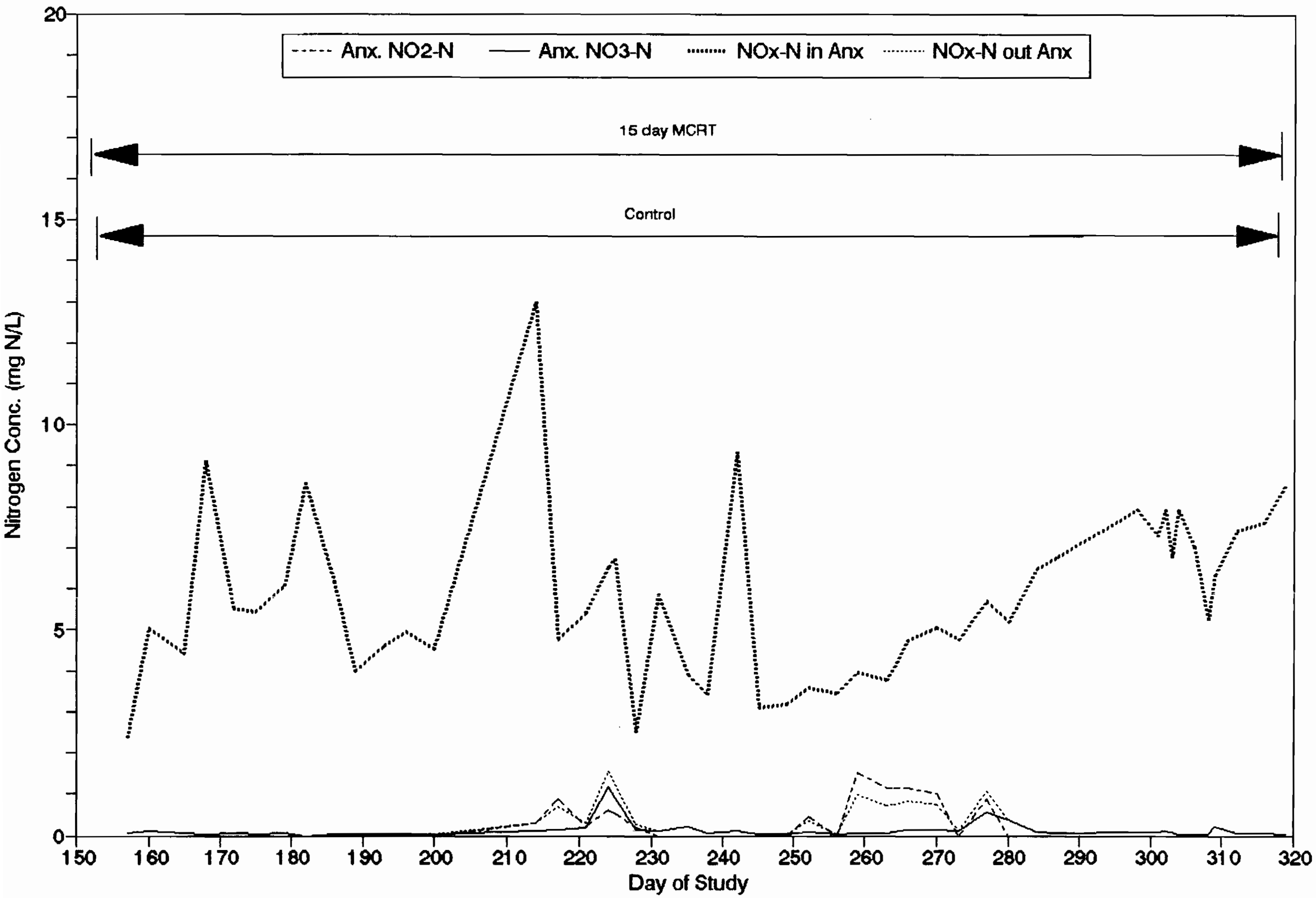

Figure 15. #3 System, Anoxic Nitrite & Nitrate
Note: NOx-N = 0.6NO2-N + NO3-N, see equations 25 and 26.

COD, THOD, and PO4 DATA

The COD, THOD and PO_4 data are given in Tables 9-12and graphed in Figures 16-18. Tables 9-12present the COD associated with the influent leachate, the effluent COD, the influent theoretical oxygen demand (THOD) from the addition of methanol, the effluent soluble phosphate-P, and the effluent soluble chloride. Also COD, soluble phosphate-P, and soluble chloride measured in the anoxic chambers are presented. Figures 16, 17, and 18 present the anoxic zone COD, effluent COD, and influent leachate COD. Appendix B contains all the measurements used to make the above Tables and Figures.

The results clearly show that soluble Phosphate-P in the anoxic zone and effluent was always high; thus, it never limited growth of the biomass. The soluble Phosphate-P added to the influents of all the systems never went below 8.6 mg/L. The lowest soluble Phosphate-P measured in any of the anoxic zones was 5.2 mg/L and the values averaged 10.6 mg/L in their anoxic zones. The lowest soluble Phosphate-P measured in the any of the effluents was 4.8 mg/L, and the values averaged 9.4 mg/L.

The purpose of adding methanol to the systems was to ensure that an organic carbon source was available for denitrification. Since the measured COD in the anoxic chamber was always significantly larger than the effluent COD, was concluded that the carbon source was never growth limiting. As the results show, the effluent COD was essentially equal to the influent leachate COD. Basically, the influent leachate's COD was non-biodegradable and the added methanol was being used up in the system. BOD_5 tests conducted on this leachate during previous research had concentrations consistently less than 10 mg/L with an average leachate BOD_5 of 4.8 mg/L with a range of 0.9 to 9.4 mg/L (1). Due to these low levels and the consistently small difference in effluent and influent CODs, the monitoring of BODs was never conducted. Note from Figures 16, 17, and 18 that the anoxic COD was always greater

Table 9. COD, THOD and Soluble PO4 - System #1 (Day 0 to 319)

Sludge Age	day	8	15	30	30	30
Copper Dose	mgCu/L	Control	Control	Control	2.0	5.0
Days of Study		0-115	115-176	176-245	245-253	253-319
Total Days		115	61	69	8	66
Days Used		24-115	147-176	214-245	245-253	253-319
Eff. PO_4*	Range	9.7-12.6	8.8-12.4	5.4-10.6		6.9-11.5
	Avg.	11.1	10.2	8.2	8.5	8.8
Eff. Cl*	Range	154-199	142-164	156-191		165-214
	Avg.	178	155	174	183	191
Anx. PO_4*	Range	9.8-13.5	9.2-12.5	7.6-12.4		8.6-13.8
	Avg.	11.5	10.8	9.4	9.6	11.2
Anx. Cl*	Range	153-214	141-167	155-192		183-221
	Avg.	176	155	174	185	198
Inf. THOD*	Range	259-358	259-410	265-450		326-414
	Avg.	320	275	310	299	377
Leachate COD*	Range	42.0-76.5	50.1-54.7	56.4-78.3		55.5-69.3
	Avg.	60.6	53.0	63.6	70.8	63.5
Eff. COD*	Range	36.9-90.7	46.2-53.6	57.5-86.3		64.3-96.0
	Avg.	59.7	49.7	63.4	70.8	81.8
Anx. COD*	Range	66.3-118	57.6-118	70.3-125		102-178
	Avg.	97.4	90.2	90.6	98.1	136

* All values mg/L

Table 10. COD, THOD, and Soluble PO4 - System #2 (Day 0 to 160)

Sludge Age	**day**	**8**	**8**	**8**	**15**	**15**
Copper Dose	**mgCu/L**	**0.0**	**2.5**	**0.0**	**0.0**	**1.0**
Days of Study		0-29	29-57	57-115	115-141	141-160
Total Days		29	28	58	26	19
Days Used		17-29	29-57	89-115	132-141	141-160
Eff. PO_4*	Range	10.4-11.4	8.2-11.3	10.5-12.2	8.4-10.5	9.0-10.1
	Avg.	10.8	9.8	11.3	9.4	9.6
Eff. Cl*	Range	194-196	182-208	154-199	155-164	141-167
	Avg.	195	195	167	161	155
Anx. PO_4*	Range		9.5-11.6	10.0-13.2	8.4-10.4	8.5-11.5
	Avg.	10.9	10.3	11.5	9.4	10.1
Anx. Cl*	Range		179-215	155-199	158-166	141-168
	Avg.	196	193	167	162	154
Inf. THOD*	Range	335-356	259-358	265-356	247-299	259-329
	Avg.	346	312	323	263	270
Leachate COD*	Range			42.0-65.5	48.5-54.2	51.9-58.2
	Avg.	76.5	71.6	55.6	52.3	54.5
Eff. COD*	Range		87.3-143	29.4-69.7	47.7-56.6	48.7-60.3
	Avg.	66.7	117	53.0	51.7	54.8
Anx. COD*	Range		116-169	78.5-118	56.7-87.0	66.5-103
	Avg.	106	149	93.3	73.0	90.0

* All values mg/L

Table 11. COD, THOD, & Soluble PO4 - System #2 (Day 160 to 319)

Sludge Age	**day**	**15**	**15**	**15**	**15**
Cu Dose	**mgCu/L**	**0.0**	**1.0**	**2.0**	**5.0**
Days of Study		160-173	173-225	225-253	253-319
Total Days		13	52	28	66
Days Used		160-173	173-225	225-253	253-319
Eff. PO_4*	Range	10.0-13.0	8.3-10.0	6.4-11.0	6.6-10.1
	Avg.	11.3	9.1	8.6	8.7
Eff. Cl*	Range	151-163	155-173	175-184	176-217
	Avg.	158	165	181	194
Anx. PO_4*	Range	10.8-14.7	8.7-10.9	7.8-12.2	6.3-12.6
	Avg.	12.6	9.6	9.9	9.9
Anx. Cl*	Range	150-173	158-173	173-191	181-230
	Avg.	161	167	185	200
Inf. THOD*	Range	272-410	256-326	265-450	326-414
	Avg.	341	277	330	377
Leachate COD*	Range	50.1-54.7	47.8-78.3	56.4-72.0	55.5-69.3
	Avg.	52.2	58.8	63.9	63.5
Eff. COD*	Range	53.5-49.3	52.6-68.9	60.4-96.8	62.7-81.5
	Avg.	51.7	58.6	69.6	69.7
Anx. COD*	Range	105-120	78.3-96.2	92.7-170	68.3-184
	Avg.	112	85.2	125	118

* All values mg/L.

Table 12. COD, THOD, & Soluble PO4 - System #3 (Day 153 to 319)

Sludge Age	**day**	**15**
Cu Dose	**mgCu/L**	**Control**
Days of Study		153-319
Total Days		166
Days Used		200-319
Eff. PO_4*	Range Avg.	4.8-12.0 9.0
Eff. Cl*	Range Avg.	156-204 181
Anx. PO_4*	Range Avg.	5.2-16.1 10.8
Anx. Cl*	Range Avg.	158-213 187
Inf. THOD*	Range Avg.	265-450 351
Leachate COD*	Range Avg.	54.0-78.3 63.7
Eff. COD*	Range Avg.	56.1-83.6 66.2
Anx. COD*	Range Avg.	86.3-158 111

* All values mg/L.

than the effluent COD and influent leachate COD. Thus, denitrification was never limited by the availability of a carbon source because there was always an excess of COD leaving the anoxic zone and being used up in the aerobic zone.

The results from Figure 16 show that system #1 had no problems using up the available energy source while operating as a control system at 8, 15, and 30 day sludge ages. As noted above the effluent COD was approximately equal to or slightly less than the influent leachate COD. It is interesting to note that when the nitrifiers were being inhibited that the COD in the anoxic zone increased. This was expected due to the fact that less nitrate and nitrite was being recycled for denitrification. Note that the effluent COD was substantially higher than the influent COD when the 5.0 mgCu/L addition was being added to system #1. This indicated that the 5.0 mgCu/L addition was inhibiting the aerobes from using all of the available energy source.

Figure 17 shows that copper affected the use of COD by the biomass. During the 2.5 mgCu/L addition, the anoxic zone COD was approximately equal to the effluent COD, and were both significantly greater than the influent leachate COD, indicating that aerobes were being severely inhibited and the system was experiencing failure. Also, during the 2.0 and 5.0 mgCu/L addition there were short times when the effluent COD became somewhat greater than the influent leachate COD. The aerobes were being slightly inhibited. At the lower copper additions and when no copper was being added to the system, the system had no problems using up the available energy source. Again, note that the anoxic zone COD increased when the nitrifiers were being inhibited.

The results, as shown in Figure 18, indicate that system #3 had no problems using up the available energy source. The effluent COD was approximately equal to the influent leachate COD. Also note that the anoxic zone COD increased when nitrification was not complete.

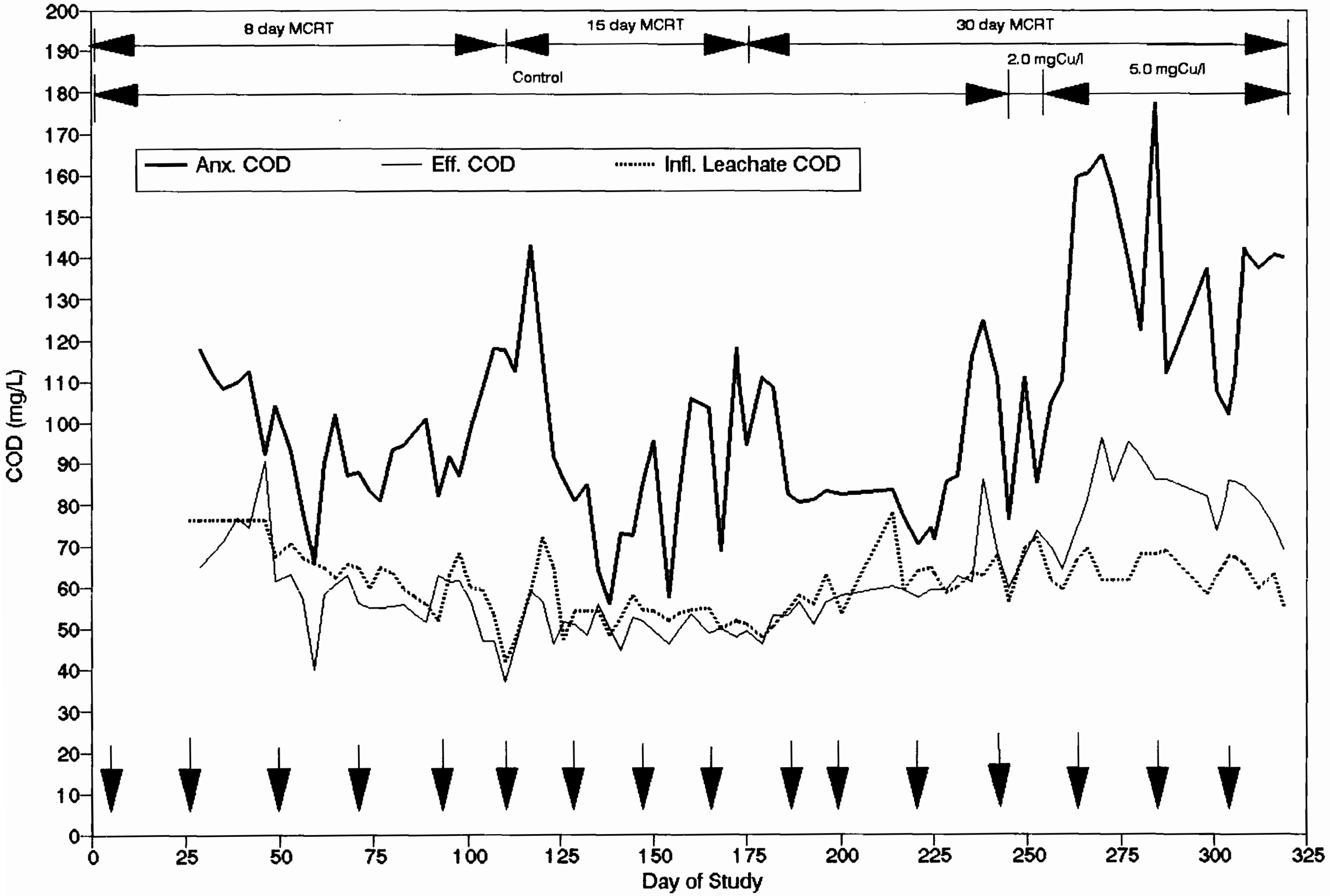

Figure 16. #1 System, COD in the Anoxic Zone, Effluent, and Influent Leachate

Note: Arrows mark new leachate feed.

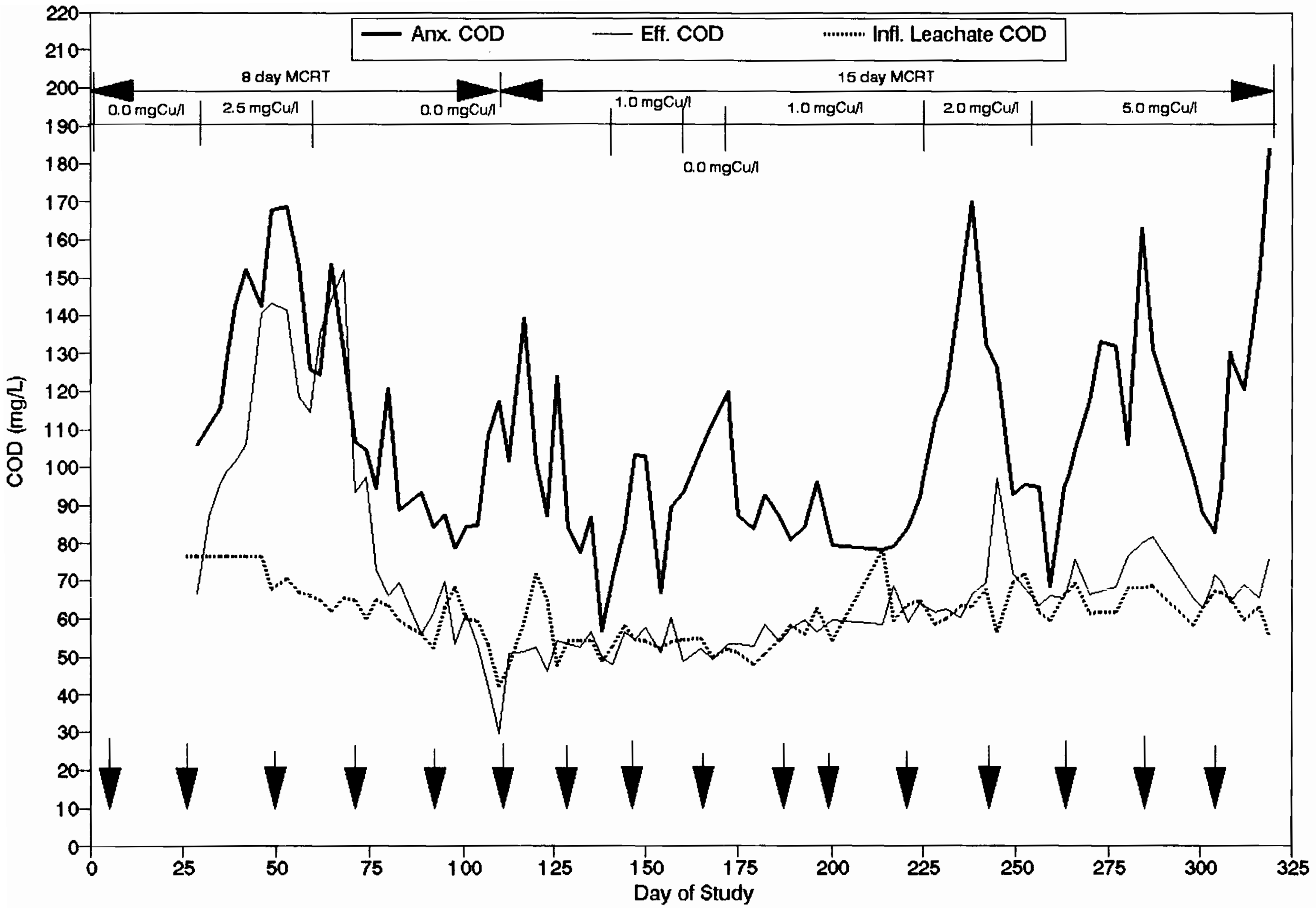

Figure 17. #2 System, COD in the Anoxic Zone, Effluent, and Influent Leachate

Note: Arrows mark new leachate feed.

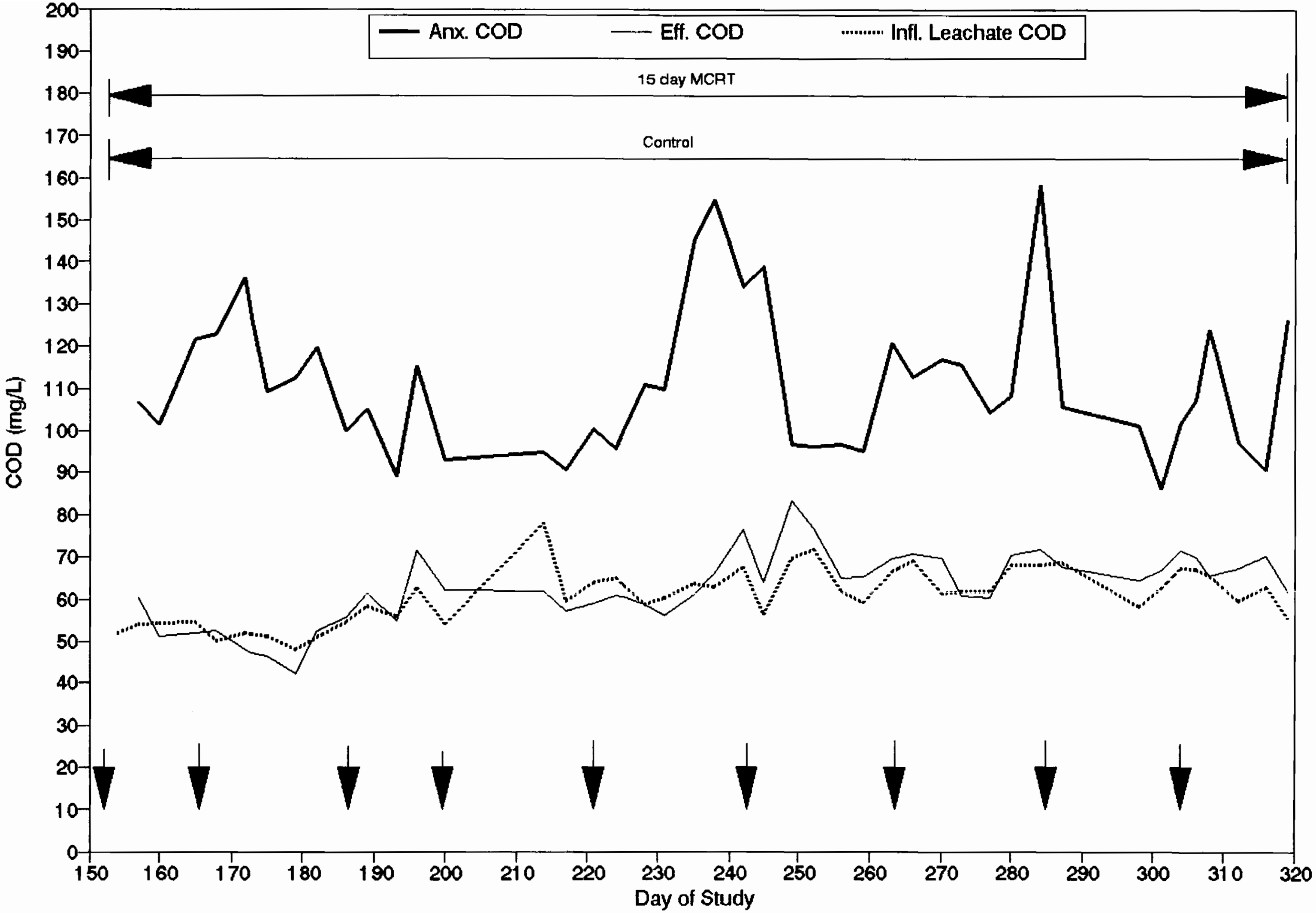

Figure 18. #3 System, COD in the Anoxic Zone, Effluent, and Influent Leachate

Note: Arrows mark new leachate feed.

DISSOLVED OXYGEN (DO) DATA

Table 13 gives a general picture of what the oxygen concentrations were in the anoxic zone, the aerobic zone, and the effluent.

The aerobic chamber was always vigorously mixed by compressed air to keep the DO at high concentrations. The long detention time of 4 hours in the clarifier accounts for any drop in DO in the effluent. As long as DO was kept above 2.0 mgO_2/L in the aerobic chamber, then nitrification was not limited by DO. A visual monitoring of aeration was conducted on a daily basis to assure energetic mixing. The systems were in a constant temperature room of 20 ^oC and the elevation was approximately 2,000 feet, so saturation of the DO was 8.5 mg/L. When the DO was measured in the aerobic zone it was at least 70% saturation or 6.0 mg/L, and had an average of 7.2 mg/L in systems #1 and #2, and 8.2 mg/L in system #3. DO did not limit nitrification.

DO in the anoxic chamber was also indirectly measured by the concentration of nitrite and nitrate in the anoxic chamber. The purpose of the anoxic chamber was to promote denitrification. Nitrate and nitrite were measured in the anoxic chamber every 3 or 4 days, and if the concentrations were near zero then denitrification was not being limited by oxygen. Figures 9, 12, and 15, show nitrite and nitrate concentrations in the anoxic zone. In general, nitrate and nitrite did not build-up in the anoxic zone and so denitrifiers experienced no problems reducing them to N gas. Thus, oxygen did not limit the denitrifiers. When nitrite and nitrate did build-up in the anoxic zone, there were other explanations of why denitrification was being limited, such as the addition of copper. The stated values of DO in the anoxic chambers, given in Table 13, help substantiate the indirect implications of the nitrate and nitrite measurements.

Table 13. Dissolved Oxygen in the Systems

Date	#1 Anx. mg/L	#1 Aer. mg/L	#1 Eff. mg/L	#2 Anx. mg/L	#2 Aer. mg/L	#2 Eff. mg/L	#3 Anx. mg/L	#3 Aer. mg/L	#3 Eff. mg/L
2/27/90	<0.35	6.0	4.6	<0.35	6.8	4.6			
4/3/90	<.15	7.5	4.9	<0.10	7.3	5.2			
7/4/90	<.35	7.6	5.1	<0.30	7.3	6.1	<.3	8.8	5.7
7/26/90	0.2	6.4	5.1	0.2	7.4	5.8	0.2	8.3	4.2
8/11/90	0.2	7.5	5.1	0.2	6.7	6.2	0.2	8.1	4.7
10/3/90	0.25	7.9	5.1	0.2	7.4	4.8	0.25	7.6	
Average	0.25	7.2	5.0	0.23	7.2	5.5	0.24	8.2	4.9

pH DATA

Table 14 gives a general characterization of what the pH concentration was in the anoxic chamber, the aerobic chamber, and the effluent. The influent leachate pH, as stated in Table 7, had a range from 6.36 to 6.80 and an average pH of 6.56. The pH going through the systems, as shown in Table 14, increased from about pH 6.56, to pH 7.6 in the anoxic chamber, to pH 8.0 in the aerobic chamber and effluent.

As noted in the literature review for nitrification and denitrification in Chapter 2, nitrification reduces alkalinity and thus tends to decrease pH. Denitrification, on the other hand, produces alkalinity and tends to increase pH. However, during these experiments the pH increased from the anoxic chamber to the aerobic chamber, which was unexpected. This phenomena can be explained by realizing that the influent leachate had a lower pH than both chambers and was probably saturated with carbon dioxide. The carbon dioxide would have been driven out of solution in the aerated chamber thus raising the pH.

As noted earlier in this chapter, the leachate had an average alkalinity of 540 mg/L as $CaCO_3$ and values ranged between 503 to 575 mg/L as $CaCO_3$. As stated in Chapter 2, the nitrification process destroys 7.14 mg of alkalinity as $CaCO_3$ when 1 mg of ammonia-N is oxidized to nitrate-N. Since the maximum influent ammonia-N was 55 mg/L, then the maximum amount of alkalinity destroyed should be 393 mg/L as $CaCO_3$. Denitrification was also occurring in the anoxic zone, which created alkalinity, and so there was more than enough alkalinity for complete nitrification. Effluent ammonia-N was tested on a regular basis and laboratory procedure required that the sample pH should be above 9.5 before distillation. Therefore a significant amount of base was added to the sample to overcome the buffering capacity of the alkalinity present. The amount of base added was not specifically measured, but was always significantly larger than the blank.

Table 14. pH in the Systems

Date	#1 Anx.	#1 Aer.	#1 Eff.	#2 Anx.	#2 Aer.	#2 Eff.	#3 Anx.	#3 Aer.	#3 Eff.
12/16/89	7.95		8.40	7.96		8.38			
1/9/90	7.48	8.09	7.99	7.75	8.18	8.14			
3/12/90	7.62	8.20	8.15	7.72	8.25	8.19			
5/9/90	7.14	7.88	7.77	7.29	7.84	7.84	7.10	8.01	7.89
7/4/90	7.53	8.00	7.82	7.54	7.88	7.78	7.60	8.11	7.94
7/26/90	7.46	7.77	7.76	7.37	7.81	7.80	7.66	8.27	8.13
8/11/90	7.71	8.27	8.12	7.44	8.03	8.05	7.35	8.14	7.94
10/3/90	8.01	8.38	8.29	7.79	8.22	8.12	7.79	8.24	8.05
Low	7.14	7.77	7.76	7.29	7.81	7.78	7.10	8.01	7.89
High	8.01	8.38	8.40	7.96	8.25	8.38	7.79	8.27	8.13
Average	7.61	8.08	8.04	7.61	8.03	8.04	7.50	8.15	7.99

COPPER DISTRIBUTION AND FATE

Figures 16 to 19 deal with the copper in system #2, and Figures 20 to 23 deal with the copper in system #1. Total copper concentration measured in the systems versus time is presented in Figures 16 and 20. Soluble copper concentration measured in the system versus time is presented in Figures 17 and 21. The ratio of total copper concentration in the system to MLVSS and MLSS concentration, multiplied by 10,000, versus time is plotted in Figures 18 and 22. The ratios of soluble copper concentration in the system to MLVSS and MLSS concentrations, multiplied by 10,000, versus time are plotted in Figures 19 and 23. Appendix C contains summary tables of the copper experiments and the entire data base of copper results. The soluble and total copper, averages and ranges, in systems #1 and #2 are presented in Tables C-1 and C-3. The ratios of soluble and total copper to MLVSS, multiplied by 10,000, are presented in Tables C-2 and C-4.

Figure 19 shows the build-up of total copper concentration in system #2. It is interesting to note that during the 2.5 mg/L experiment, when total system failure occurred, the total copper concentration peaked at 6.2 mg/L, and in each of the other experiments the total copper nearly equaled or exceeded this value. Since none of the other experiments experienced a solids failure, then total copper may not be a very accurate indicator of solids failure. The total copper concentration in system #2 during the two 1.0 mgCu/L experiments, from day 157 to 160 and then from day 193 to 224, averaged 5.5 and 8.2 mg/L, respectively. The total copper concentration during the 2.0 and 5.0 mgCu/L experiments, from day 228 to 252 and then from day 270 to 319, averaged 8.8 and 50.5 mg/L, respectively.

Figure 20 shows the soluble copper concentration in system #2. The soluble copper concentration during the 2.5 mgCu/L experiment, from day 39 to 46, was 0.82

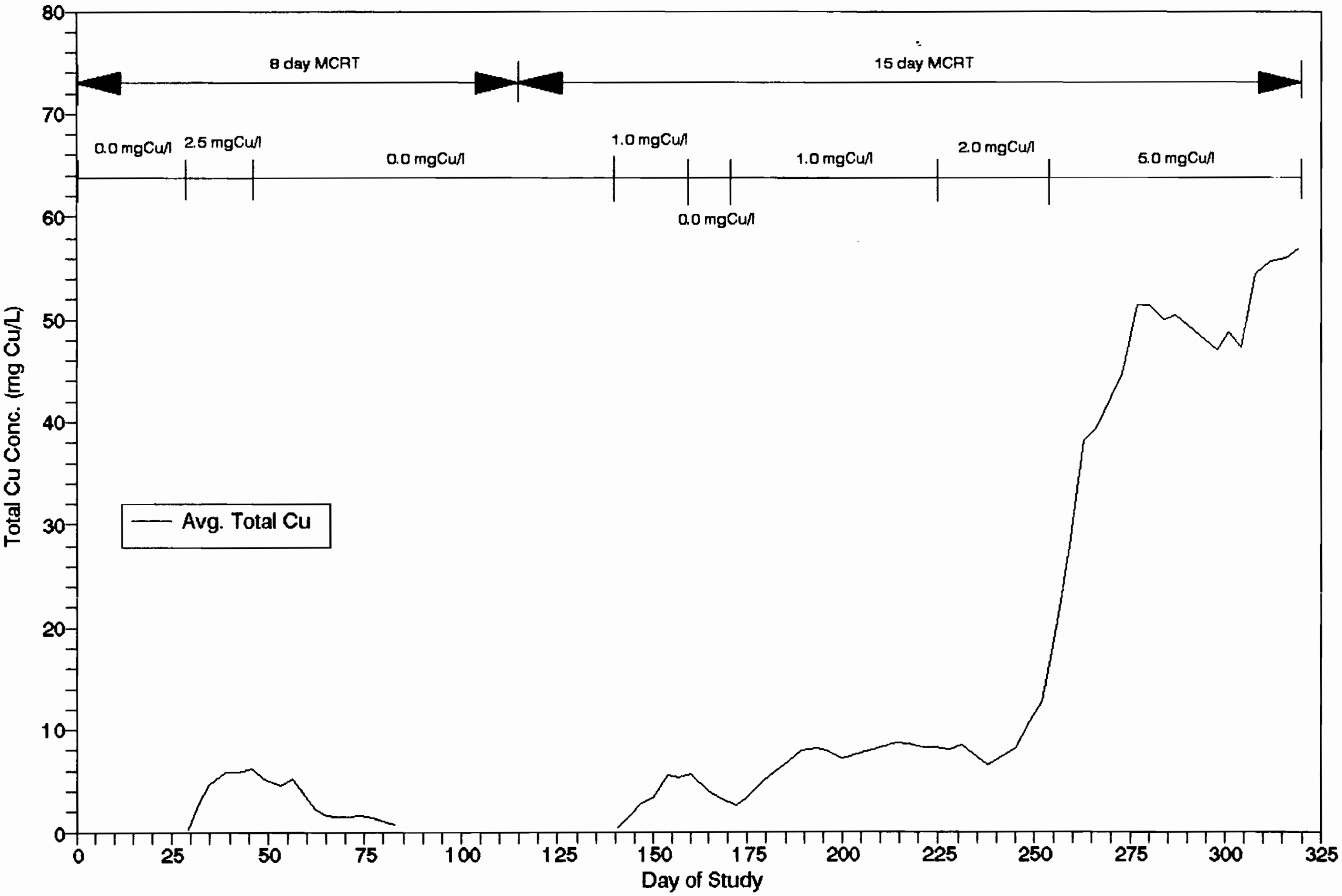

Figure 19. #2 System, Total Copper in System

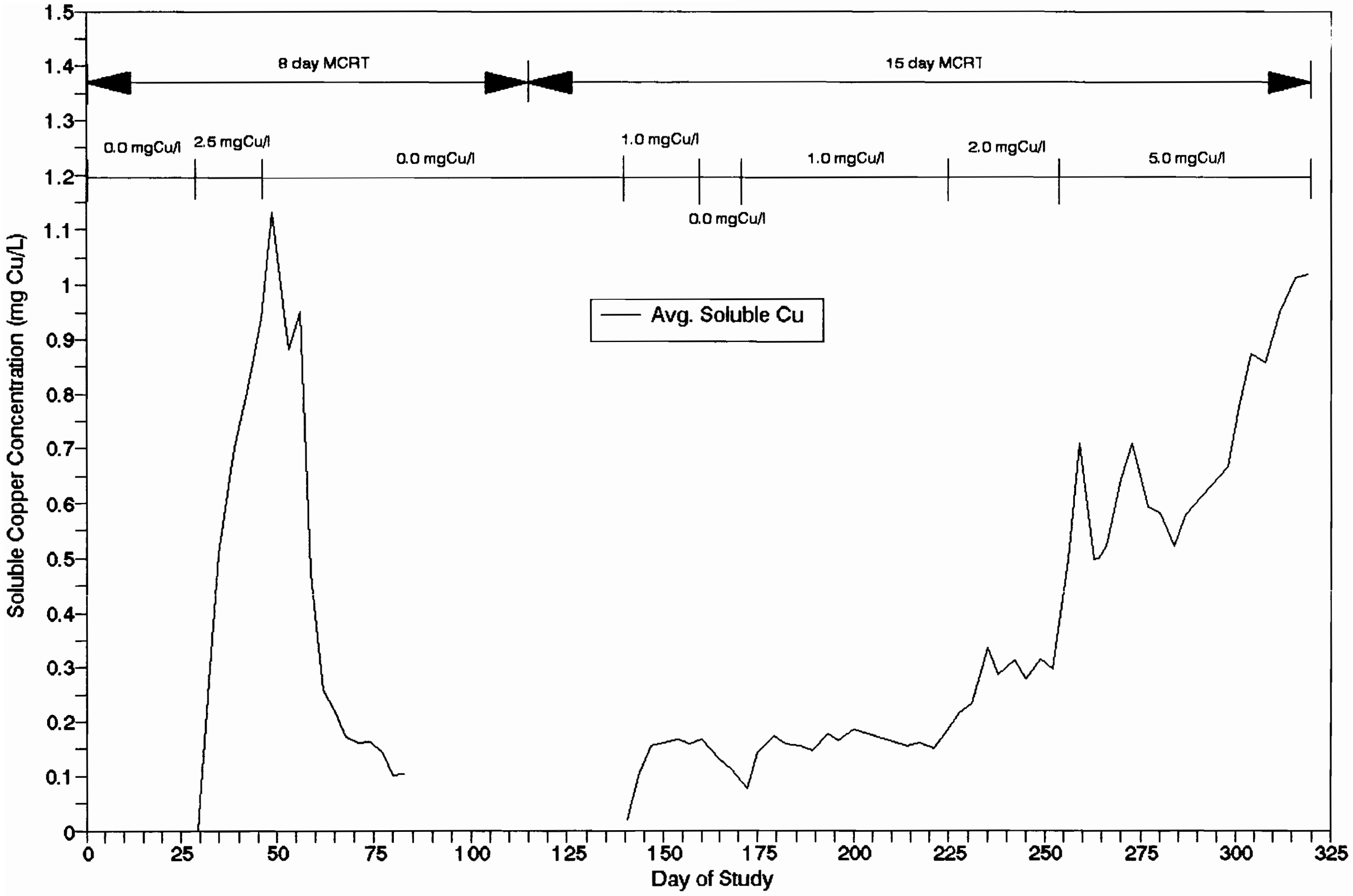

Figure 20. #2 System, Soluble Copper in System

mg/L, and the maximum soluble copper concentration was 1.13 mg/L on day 49. The soluble copper concentration in system #2 during the two 1.0 mgCu/L experiments, from day 157 to 160 and then from day 193 to 224, averaged 0.16 and 0.17 mg/L, respectively, which is essentially the same. The soluble copper concentration during the 2.0 and 5.0 mgCu/L experiments, from day 228 to 252 and then from day 270 to 319, averaged 0.28 and 0.75 mg/L, respectively. Towards the end of the study the soluble copper concentration reached 1.02 mg/L which is above the value at which the 2.5 mgCu/L experiment began to fail.

Figure 21 presents the ratios of total copper concentration to MLVSS and MLSS concentrations in system #2. Note that the peak during the 2.5 mgCu/L experiment, in Figure 21, was more pronounced than the peak in Figure 19, but was still lower than the peak of the 5.0 mgCu/L experiment in Figure 21. Since the 2.5 mgCu/L experiment experienced the most severe system upset, then one would expect that more toxins were present which caused the more severe system upset. The results indicate that the ratios of total copper concentration to MLVSS and MLSS concentrations in a system are a better indicator of system stability than just the total copper concentration. In general the total Cu/MLVSS and total Cu/MLSS ratios increased from day 141 to the end of the study.

Figure 22 presents the ratios of soluble copper concentration to MLVSS and MLSS concentrations in system #2. Note that the 2.5 mgCu/L experiment had a soluble Cu/MLVSS peak of 0.0055 and a soluble CU/MLSS peak of 0.0049, and that these ratios are significantly higher than the ratios during any of the other experiments. The two 1.0 mgCu/L experiments leveled off at a soluble Cu/MLVSS ratio of 0.00016 and 0.00018, respectively, and at a soluble Cu/MLSS ratio of 0.00012 and 0.00012, respectively. The 2.0 mgCu/L experiment leveled off at a soluble Cu/MLVSS ratio of 0.00038, and at a soluble Cu/MLSS ratio of 0.00028. The 5.0 mgCu/L experiment did

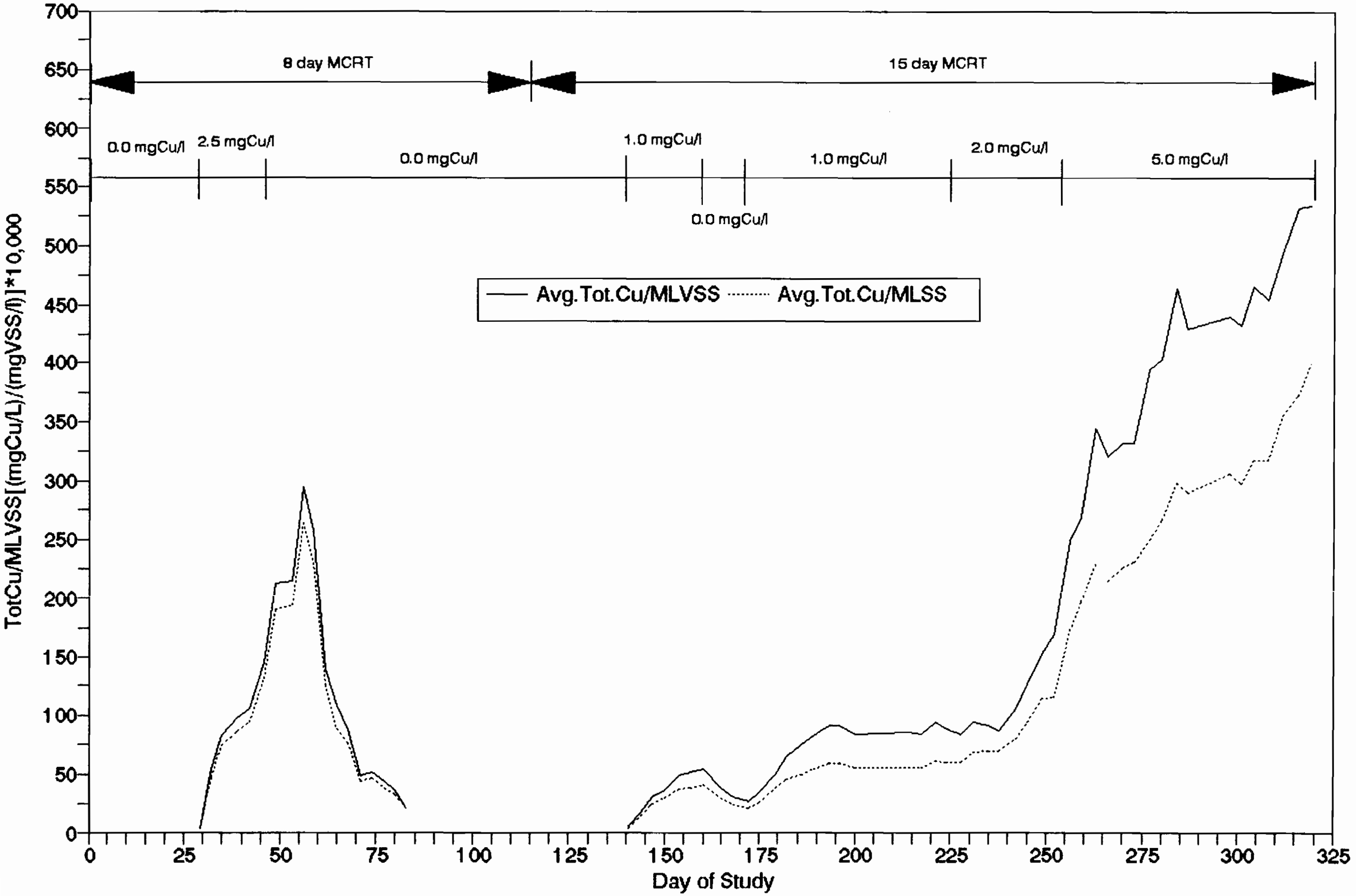

Figure 21. #2 System, Total Copper per MLVSS & MLSS in System

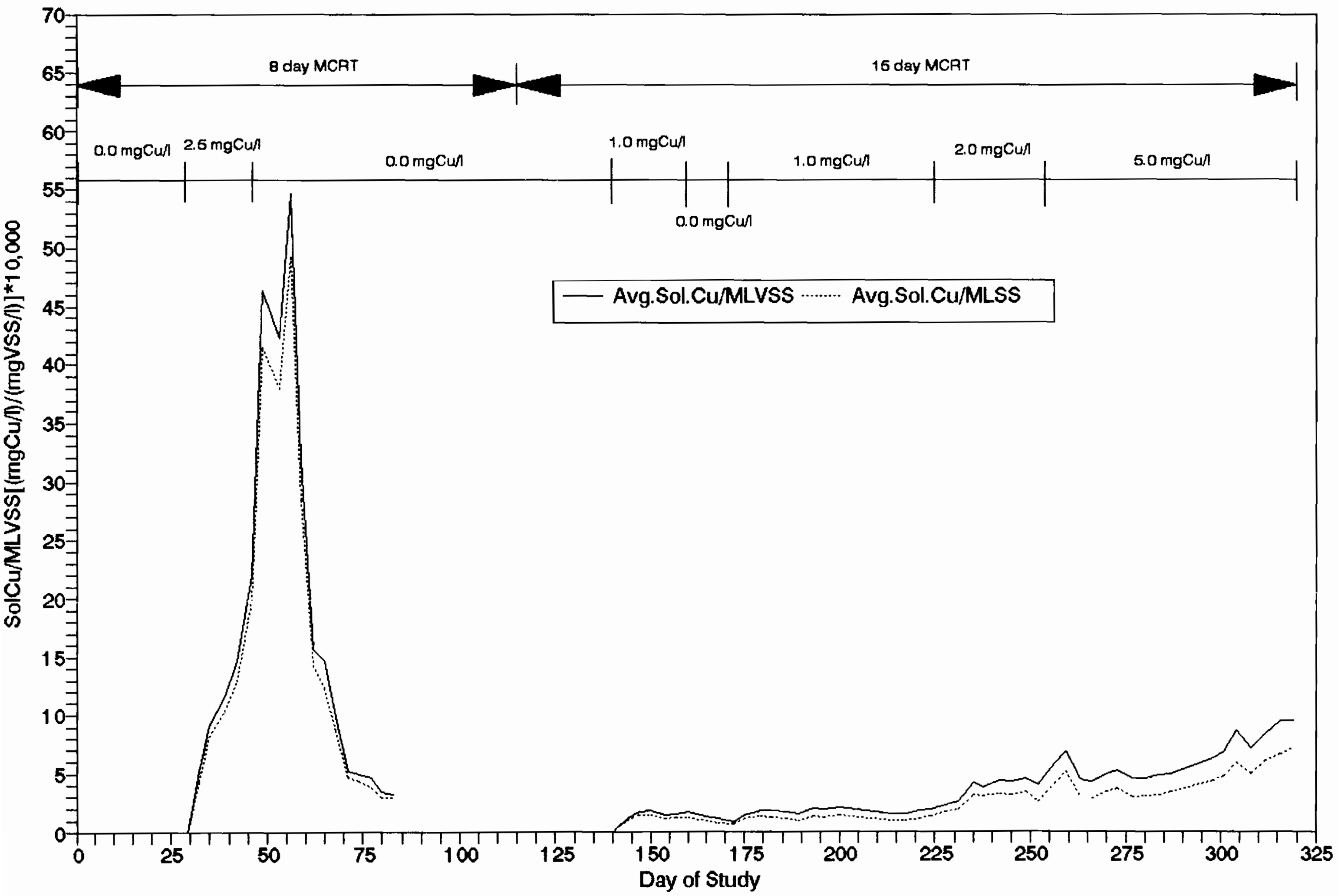

Figure 22. #2 System, Soluble Copper per MLVSS & MLSS in System

not level off but always continued to increase. The 5.0 mgCu/L experiment, from day 270 to 319, averaged a soluble Cu/MLVSS ratio of 0.00066, and a soluble Cu/MLSS ratio of 0.00046. The results indicate that the ratios of soluble copper to MLVSS and MLSS are a good indicator of system stability.

Figure 23 presents the total copper concentration in system #1 versus time. Note that the total copper concentration in the system continued to increase throughout the 2.0 and 5.0 mgCu/L experiments. Since the 2.0 mgCu/L experiment was so short in duration, the concentration on the last day of the experiment was used in the Discussion Chapter figures. On day 252, the end of the 2.0 mgCu/L experiment, the total copper concentration was 8.71 mg/L. The average total copper concentration during the 5.0 mgCu/L experiment, from day 270 to 310, was 82.4 mg/L. It is interesting to note that the aeration incident that occurred on day 263 of this study caused the only decrease in total copper concentration build-up, even if it was only a slight decline.

Figure 24 presents the soluble copper concentration in system #1 versus time. The soluble copper increased throughout the 2.0 mgCu/L test and on day 252 the soluble copper concentration was 0.20 mg/L. It is of great interest to note that during the aeration incident, on day 263 of the study, the soluble copper concentration was 2.11 mg/L and by the next day the soluble copper concentration was back down to 0.73 mg/L. The soluble copper concentration during the 5.0 mg/L experiment leveled off and was remarkably constant. The average soluble copper concentration during the 5.0 mgCu/L experiment, from day 270 to 310 of the study, was 0.51 mg/L.

Figure 25 presents the ratios of total copper concentration to MLVSS and MLSS concentrations in system #2. Throughout the 2.0 and 5.0 mgCu/L experiments the ratios continued to increase. At the end of the 2.0 mgCu/L experiment, on day 252 of the study, the ratio of total Cu/MLVSS was 0.0051 and the ratio of total Cu/MLSS was

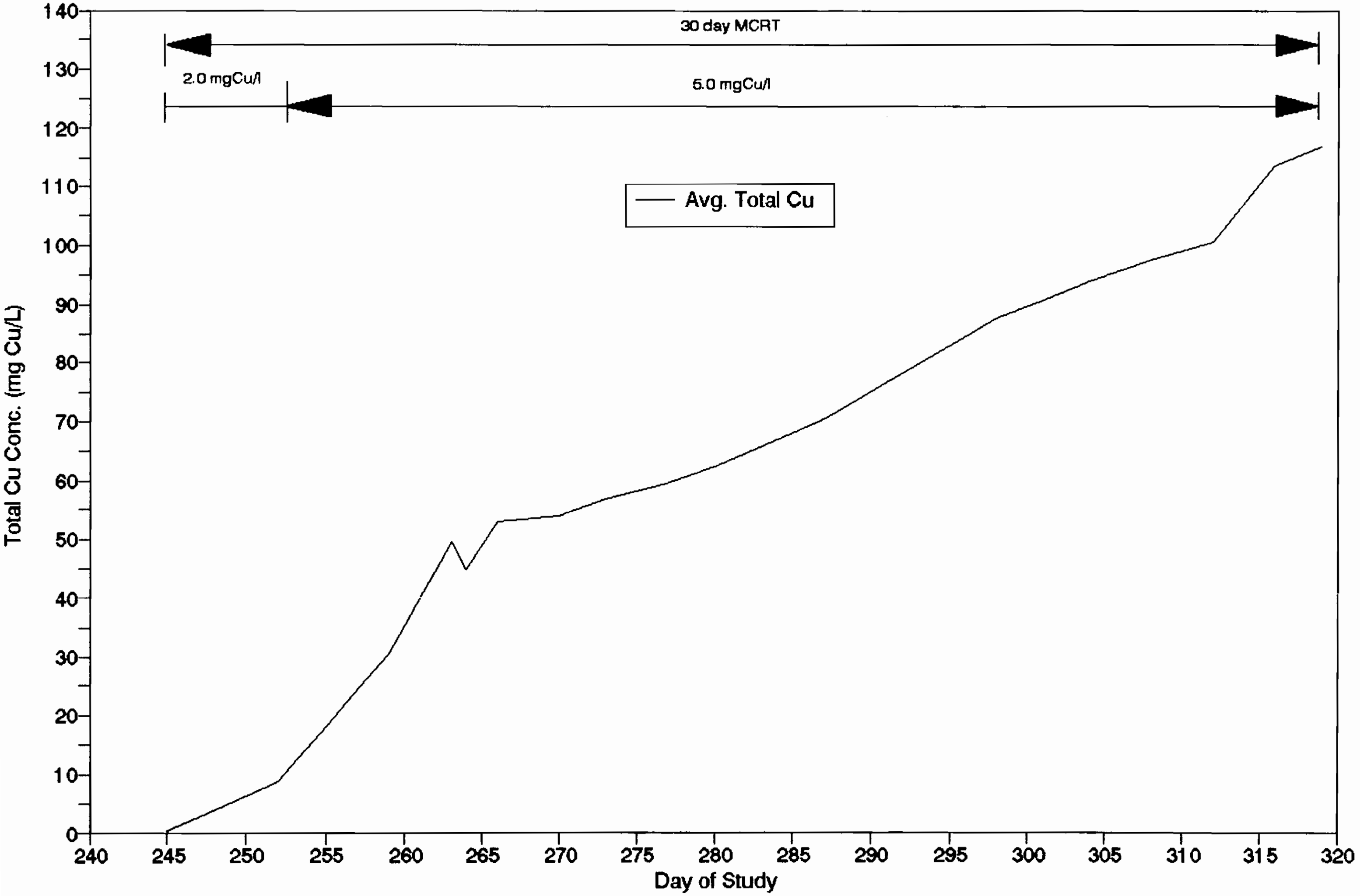

Figure 23. #1 System, Total Copper in System

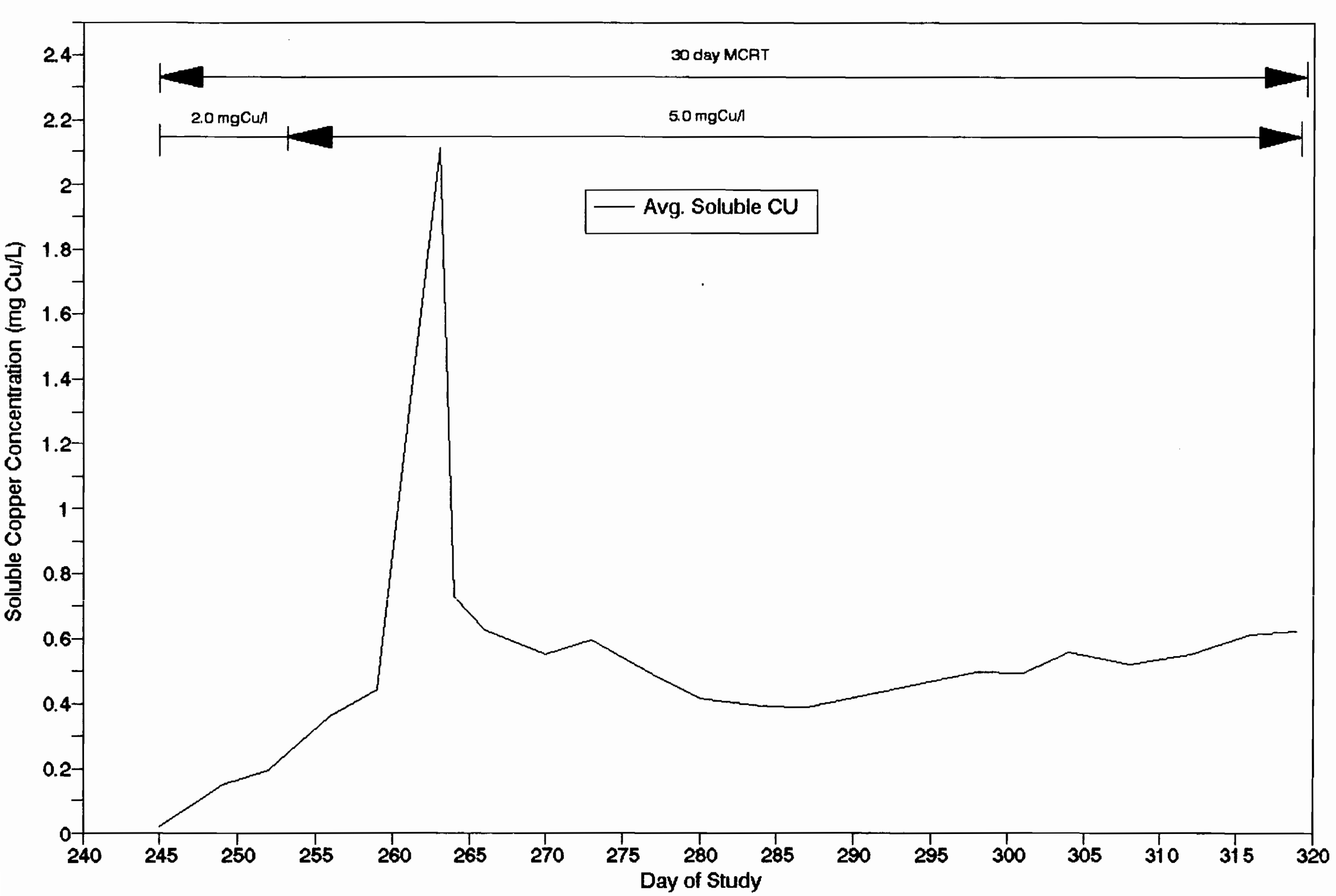

Figure 24. #1 System, Soluble Copper in System

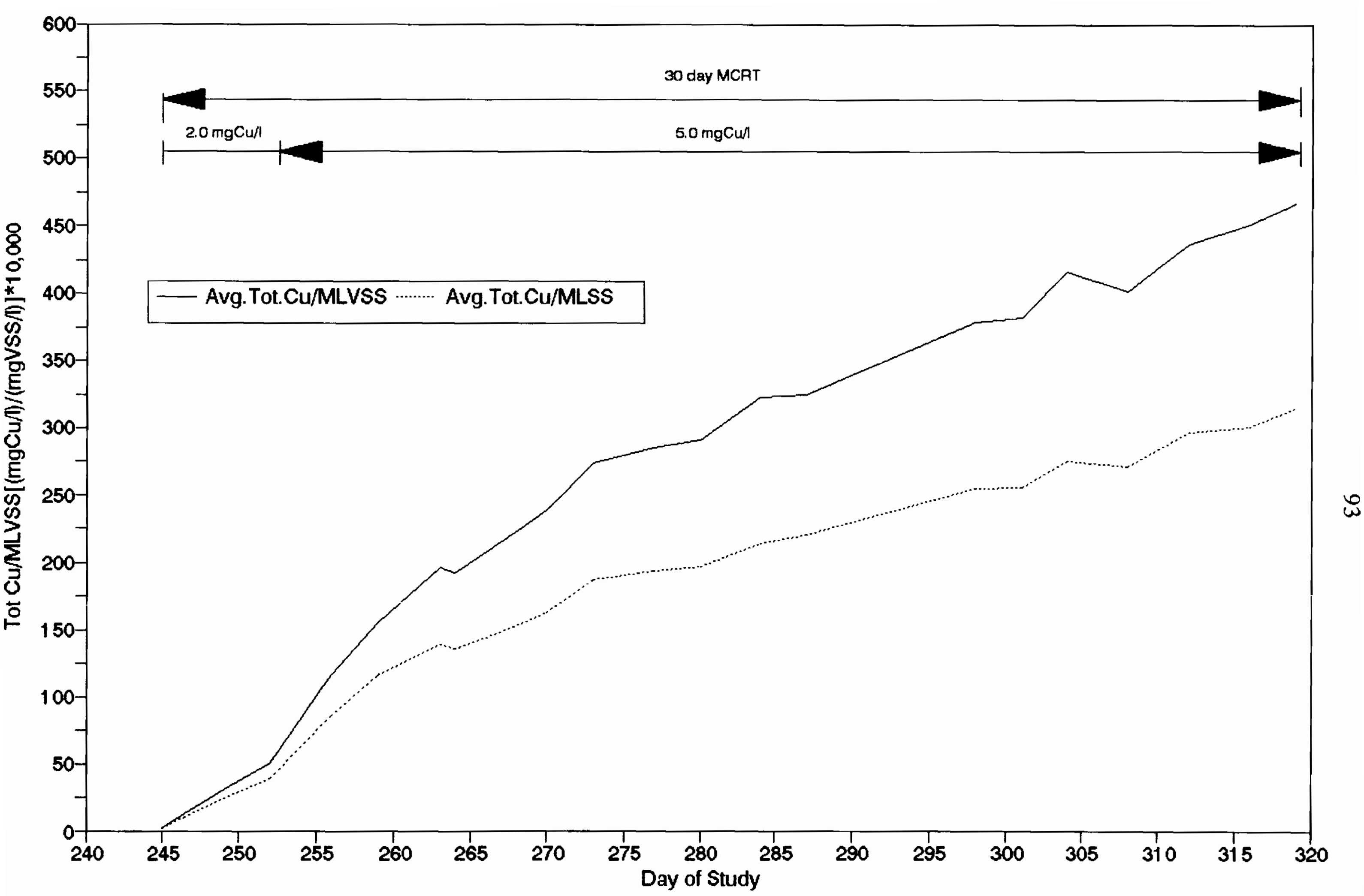

Figure 25. #1 System, Total Copper per MLVSS & MLSS in System

0.0039. During the 5.0 mgCu/L experiment, from day 270 to 319, the ratio of total Cu/MLVSS was 0.0359 and the ratio of total Cu/MLSS was 0.0242.

Figure 26 presents the ratios of soluble copper concentration to MLVSS and MLSS concentrations in system #1. The ratios of soluble Cu/MLVSS and soluble Cu/MLSS increased throughout the 2.0 mgCu/L experiment and on day 252 the ratio of soluble Cu/MLVSS was 0.00012 and the ratio of soluble Cu/MLSS was 0.000087. Note that during the aeration incident, on day 263 of the study, the ratio of soluble Cu/MLVSS was 0.00084 and the ratio of soluble Cu/MLSS was 0.00059, and by the next day the ratio of soluble Cu/MLVSS was 0.00031 and the ratio of soluble Cu/MLSS was 0.00022. The ratio of soluble copper concentration to MLVSS and MLSS concentrations during the 5.0 mgCu/L experiment leveled off and was remarkably constant. The ratios of soluble copper concentration to MLVSS and MLSS concentrations during the 5.0 mgCu/L experiment, from day 270 to 310 of the study, were 0.00023 and 0.00015, respectively.

In Appendix C, two theoretical copper balances have been calculated to compare with the actual recovered total copper measured in the system. The actual recovered total copper measured (Cu_{tot}) in the system was determined from the concentration of copper measured in the anoxic and aerobic chambers. The first copper balance is based on the amount of copper added ($Cu_{in\ Added}$) to the influent carboy, and the total accumulated amount of copper in the system was calculated and called "copper total added theoretically" ($Cu_{tot\ Added\ Theory}$) with units of mg/reactor. The term "theoretically" is used to describe this addition of copper because some copper mixed in the carboy could have been absorbed by the carboy and never pumped into the system. This balance assumes that the copper added to the leachate, in the leachate feeding carboy, actually entered the system. The second copper balance used the amount of copper measured ($Cu_{in\ Measured}$) in the influent, and the total accumulated

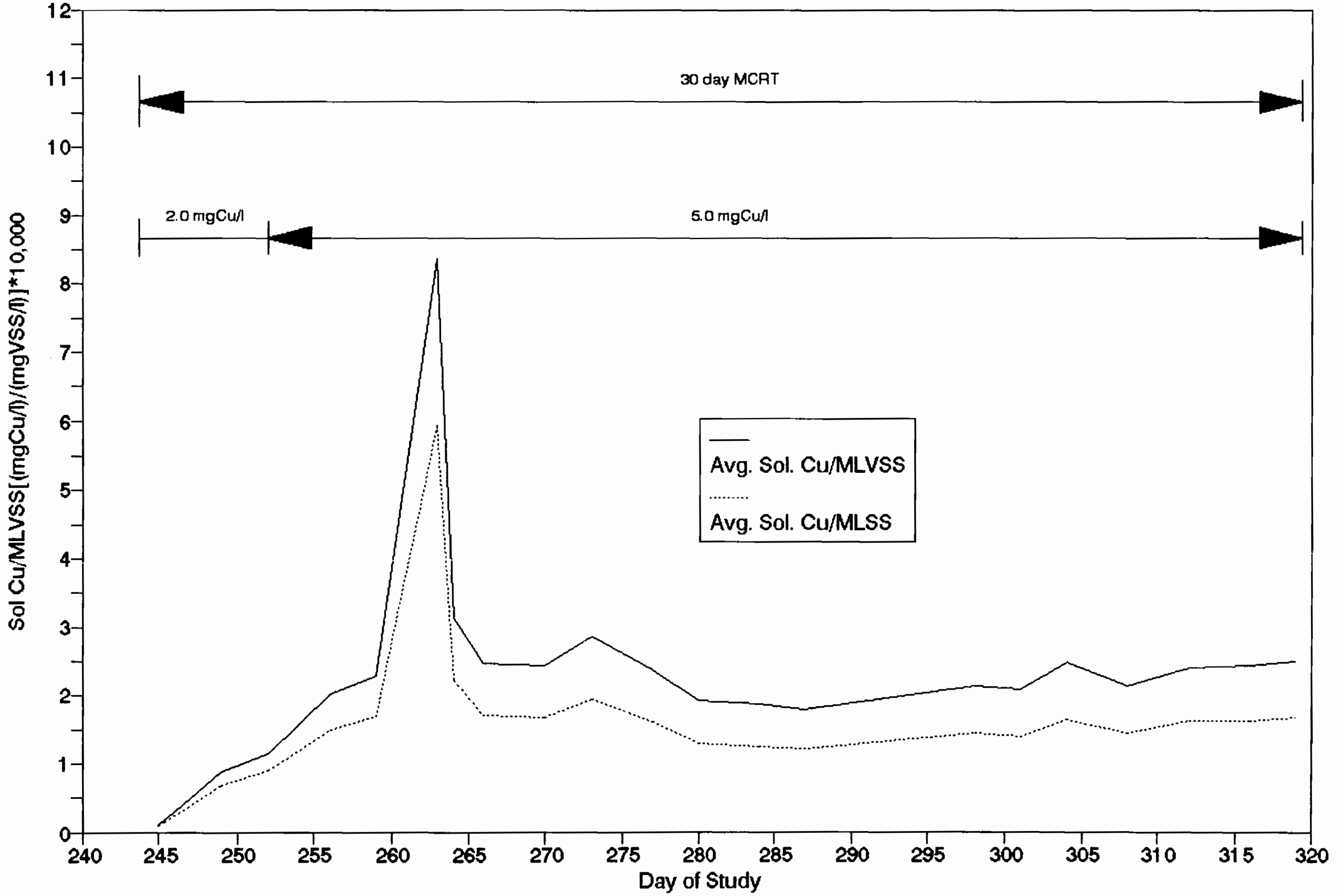

Figure 26. #1 System, Soluble Copper per MLVSS & MLSS in System

amount of copper in the system was calculated and called "copper total measured theoretically" ($Cu_{tot\ Measured\ Theory}$) with units of mg/reactor. Note that the term "measured" is being used to designate that the influent copper was actually tested and the term "theoretically" is being used because some the total copper may not have been in the mixed liquor. This balance assumes that the copper measured was representative of the whole influent.

In calculating the copper balances, calculated concentrations of copper in the mixed liquor were used to determine the amount of copper lost in the volume of mixed liquor wasted. In other words if the copper balance being performed assumes that all the copper added to the influent carboy entered the system, then the amount of copper wasted in the mixed liquor, to retain sludge age, was based on what should have been in the mixed liquor. To illustrate the copper balances the following summaries are presented for each experiment:

1) On day 57 of the study, the addition of 2.5 mgCu/L was stopped to system #2. Total copper in system #2's reactor volume (4.5 L) was Cu_{tot} = 21.2 mgCu/reactor and from the copper balances the copper total added theoretically was $Cu_{tot\ Added\ Theory}$ = 155 mgCu/reactor, and the copper total measured theoretically was $Cu_{tot\ Measured\ Theory}$ = 101 mgCu/reactor. Thus, only (21.2/155)*100 = 14% and (21.2/101)*100 = 21% of the recovered copper in the system was accounted for by the two copper balances.

2) On day 160 of this study, at the end of the first 1.0 mgCu/L experiment in system #2, the Cu_{tot} = 25.6 mgCu/reactor, $Cu_{tot\ Added\ Theory}$ = 56.4 mgCu/reactor, and $Cu_{tot\ Measured\ Theory}$ = 40.3 mgCu/reactor. Thus, only (25.6/56.4)*100 = 45% and (25.6/40.3)*100 = 64% of the recovered copper, respectively, was accounted for by the two copper balances.

3) On day 224 of this study, at the end of the second 1.0 mgCu/L experiment in

system #2, the Cu_{tot} = 37.3 mgCu/reactor, $Cu_{tot\ Added\ Theory}$ = 85.8 mgCu/reactor, and $Cu_{tot\ Measured\ Theory}$ = 56.0 mgCu/reactor. Thus, only (37.3/85.8)*100 = 44% and (37.3/56.0)*100 = 67% of the recovered copper, respectively, was accounted for by the two copper balances.

4) On day 252 of this study, at the end of the 2.0 mgCu/L experiment in system #2, the Cu_{tot} = 57.2 mgCu/reactor, $Cu_{tot\ Added\ Theory}$ = 211 mgCu/reactor, and $Cu_{tot\ Measured\ Theory}$ = 105 mgCu/reactor. Thus, only 27% and 54% of the recovered copper, respectively, was accounted for by the two copper balances.

5) On day 319 of this study, at the end of the 5.0 mgCu/L experiment in system #2, the Cu_{tot} = 255 mgCu/reactor, $Cu_{tot\ Added\ Theory}$ = 413 mgCu/reactor, and $Cu_{tot\ Measured\ Theory}$ = 317 mgCu/reactor. Thus, only 62% and 81% of the recovered copper, respectively, was accounted for by the two copper balances.

6) On day 252 of this study, at the end of the 2.0 mgCu/L experiment in system #1, the Cu_{tot} = 39.2 mgCu/reactor, $Cu_{tot\ Added\ Theory}$ = 64.7 mgCu/reactor, and $Cu_{tot\ Measured\ Theory}$ = 45.6 mgCu/reactor. Thus, only 61% and 86% of the recovered copper, respectively, was accounted for by the two copper balances.

7) On day 319 of this study, at the end of the 5.0 mgCu/L experiment in system #1, the Cu_{tot} = 525 mgCu/reactor, $Cu_{tot\ Added\ Theory}$ = 861 mgCu/reactor, and $Cu_{tot\ Measured\ Theory}$ = 656 mgCu/reactor. Thus, only 61% and 80% of the recovered copper, respectively, was accounted for by the two copper balances.

Note that the copper balance calculated using the copper actually added to the influent carboy did not predict the concentration of copper in the mixed liquor very accurately, whereas the copper balance calculated using the copper measured in the influent was more precise. As the copper dose added to the system increased the amount of copper accounted for in the system increased.

CHAPTER V. DISCUSSION

GENERAL COMMENTS ON TREATABILITY

The control systems include the operation of system #1 from day 1 to 245 when copper was added, and the whole operational period of system #3. These systems experienced no problems in retaining SS and in consuming the available methanol energy source. The removal of BOD by the MLE system was consistent. The leachate did not contain a large BOD portion and therefore the removal of leachate BOD was not a significant treatment goal. Effluent TSS, at times, reached levels of 60 mg/L and thus would violate the typical 30 mg/L secondary treatment limit.

The control systems were able to treat nitrogen in the leachate at an 8, 15, and 30 day MCRT, but they also experienced periods of partial nitrification inhibition. Inhibition of nitrification occurred in system #1, while operating as a control, from day 100 to 129 at an 8 day MCRT, from day 168 to 189 at a 15 day MCRT, and from day 228 to 249 at a 30 day MCRT. Inhibition of nitrification also occurred in system #3 during the period from day 214 to 259 at a 15 day MCRT. To encourage system #1 to recover from its first two periods of nitrification inhibition, the sludge age was increased from 8 to 15 day and from 15 to 30 day. During the third period of inhibition in system #1, 2.0 mgCu/L was added into the influent and the effluent NH_3-N decreased from 11.09 mg/L to 0.0 mg/L in four days. It is not clear whether the addition of copper actually improved nitrification or whether the nitrifiers were already recovering. Nitrification inhibition may have been caused by either toxins within the landfill leachate during some periods, and/or by an accumulation of toxins within the biomass.

Denitrification was never inhibited in the anoxic chamber of either control system. The denitrifiers did not appear to be affected by any toxins within the landfill leachate.

COPPER ACCUMULATION

A number of questions should be addressed with regard to copper accumulation within the MLE system. Does the total copper build up in the mixed liquor or does it pass through the system? Will the soluble copper build up in the system? What controls the accumulation of soluble and total copper in the system, and what role does the biomass play? How does the total copper loading on the system affect the copper build up in the system? These questions and others will be discussed in this section.

Figures 19 and 23 show that the total copper does build up in the mixed liquor to levels well above the copper in the influent. The total copper in the mixed liquor was a direct function of the copper loading on the system and the biomass within the system. Figures 20 and 24 show that the system's soluble copper concentration leveled off at a fraction of the influent's total copper concentration unless the system experienced failure.

The accumulation of soluble copper within the treatment systems as a function of the specific copper loading is of great interest in the study of copper toxicity. Figure 27 shows that a linear relationship existed between the average soluble copper in the mixed liquor and the specific copper loading on a system. The specific copper loading on a system is defined as the total copper entering the system within a day

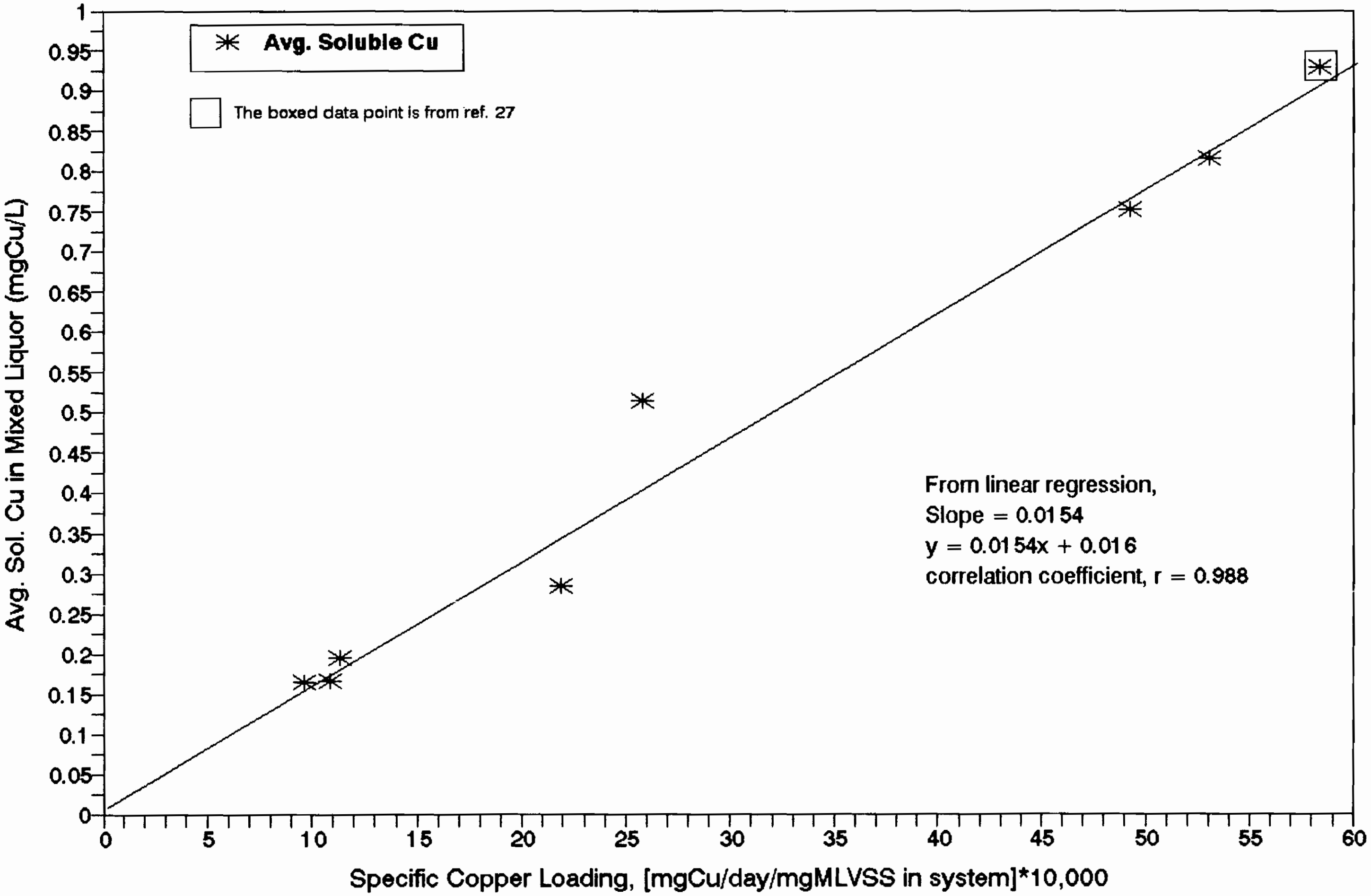

Figure 27. Average Soluble Copper in Mixed Liquor vs. Specific Copper Loading on the System, for a series of experiments with differing Sludge Ages and Copper Loadings.

(mgCu/day) divided by the total biomass within the system (mg MLVSS). Each data point within the figure is from a separate experiment. Even if a system failed, the correlation between the specific copper loading on a system with the average soluble copper remained. Thus, the soluble copper in the system was a direct function of the daily copper loading and the amount of biomass within the system.

Figure 28 shows the average soluble copper concentration in the mixed liquor versus the ratio of the total copper concentration in the mixed liquor to the MLVSS concentration in a system. A linear relationship exists between soluble copper and the ratio of the total copper concentration to the concentration of MLVSS (biomass). Note that two data points were not included in the linear regression of Figure 28. The neglected points are from the 2.5 mgCu/L experiment of system #2 and Marickovich's 5.0 mgCu/L experiment (27), in which the systems experienced failure. When a system fails, solids and copper wash out of the system and the total copper in the system is affected. The results shown in Figure 28 indicate that if the system does not fail then the ratio of total copper to MLVSS accurately correlates with the concentration of average soluble copper.

When analyzing the uptake of copper in an activated sludge treatment system, it is useful to view the biomass as a "sorbent" capable of adsorbing copper. "*Adsorption* is the collection of a substance onto the surface of the adsorbent solids, whereas *absorption* is the penetration of the collected substance into the solid. Since both of these frequently occur simultaneously, some choose to call the phenomena *sorption*" (22). Sorption data is usually correlated according to the Freundlich Isotherm (6) using the following empirical formula:

$$X/M = KC^{1/n} \qquad \text{[Eq. 28]}$$

where X/M = amount of solute adsorbed per unit weight of adsorbent

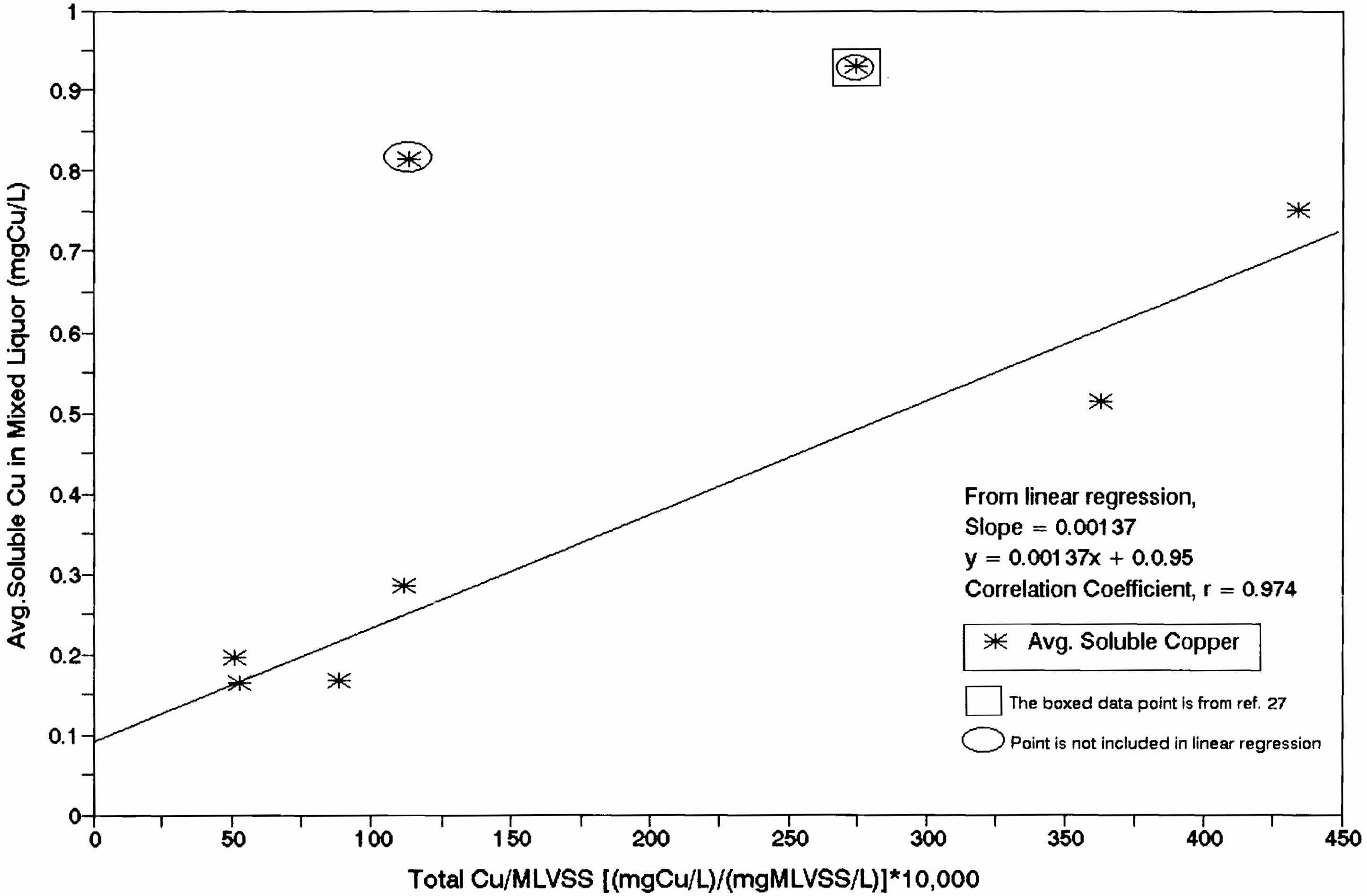

Figure 28. Average Soluble Copper in Mixed Liquor vs. Ratio of Total Copper in Mixed Liquor to MLVSS, for a series of experiments with differing Sludge Ages and Copper Loadings.

C = concentration of solute remaining in solution at equilibrium

K, **n** = experimental constants.

"The constants **K** and **n** define the nature of the adsorbent and the adsorbate. Generally, **K** and **n** decrease with increasing wastewater complexity. High **K** and **n** values indicate high adsorption throughout the concentration range studies; conversely, low values indicate a low adsorption at dilute concentrations. A low value of **n** (steep slope) indicates high adsorption at strong solute concentrations and poor adsorption at dilute concentrations. In case of complex wastewaters a portion of the organics present in the wastewater may not be adsorbed, which yields a residual regardless of the adsorbent dosage" (6).

The Freundlich Isotherm of Figure 30 presents the log of the ratio of the total copper concentration in the mixed liquor to MLVSS concentration (**X/M**) versus the log of the average soluble copper in the mixed liquor (**C**). The constant **K** was 326 which is a high value and indicates high adsorption throughout the concentration range studied. The constant **n** was 1.12 expressed in L*system vol/mg*day.

This research indicated that if the total copper load on an activated sludge system is known and the MLVSS concentration of the system is known, then the average soluble copper concentration in the system can be predicted. The results also indicated, for the range of copper concentrations studied, that the biomass can be thought of as a "sorbent" adsorbing the copper.

EFFECTS OF COPPER ON NITRIFICATION

This section deals with the effects of copper on nitrification and the different relationships of copper to the biomass that best reflect its influence on nitrification. Nitrification is the conversion of ammonia (NH_3-N) to nitrite and nitrate, and

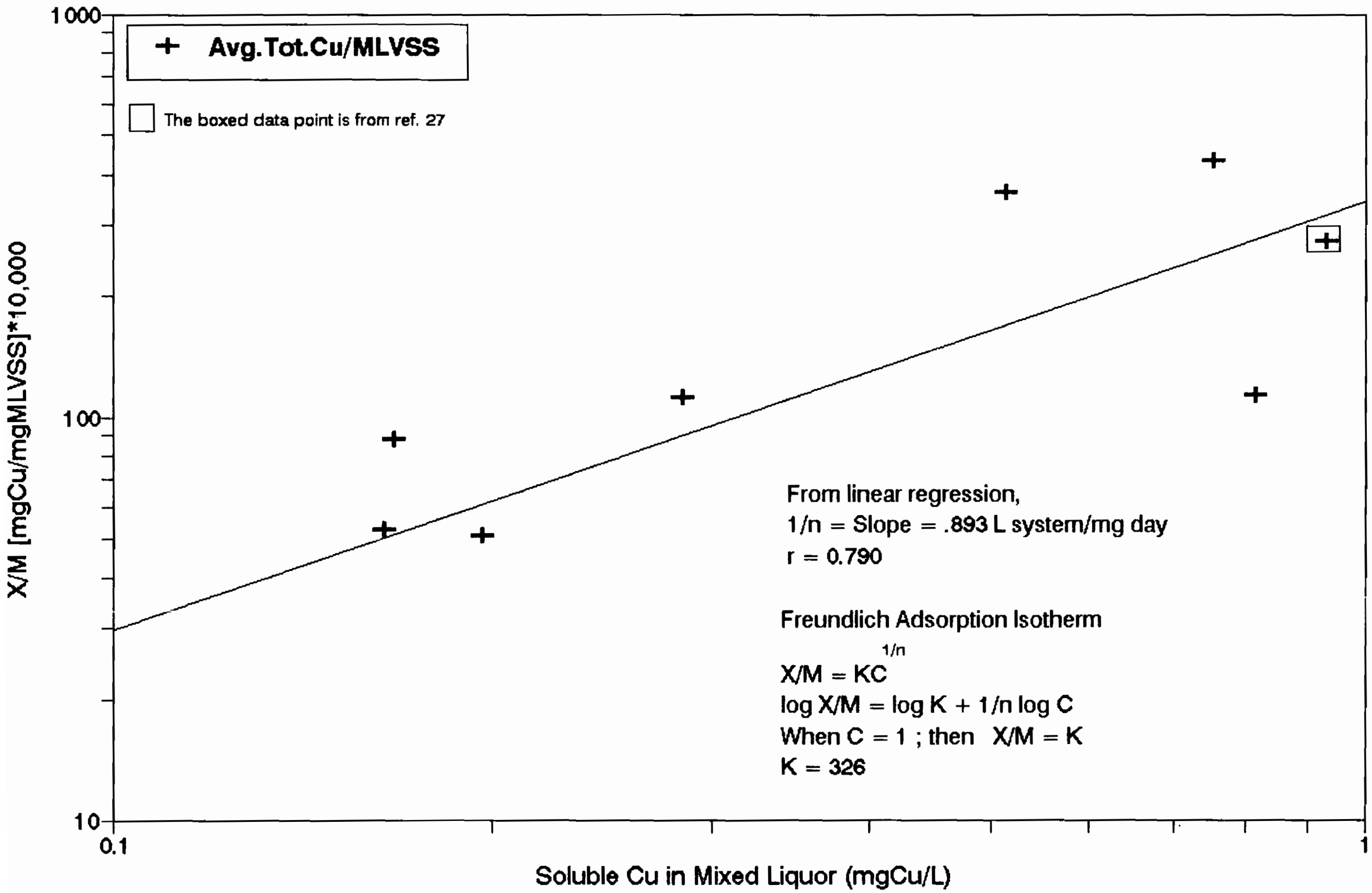

Figure 29. Avg. Total Cu in Mixed Liquor per MLVSS vs. Avg. Soluble Cu in Mixed Liquor for a series of experiments with different Sludge Ages and Cu Loadings.

therefore the amount of ammonia in the effluent is an indicator of the extent of nitrification. Figures 30 through 34 present the effluent ammonia and TKN for each experiment versus different relationships of copper to the biomass. Relationship factors include the concentration of soluble copper in the mixed liquor divided by the concentration of MLVSS, the concentration of soluble copper in the mixed liquor, the concentration of total copper in the mixed liquor divided by the concentration of MLVSS, the concentration of total copper in the mixed liquor, and the specific copper loading.

Figure 30 shows that a strong relationship exists between the ratio of soluble copper to MLVSS and the inhibition of nitrification. At a soluble copper to MLVSS ratio of about 0.001, (i.e., 0.001 * 10,000 = 10 on the graph scale), the nitrification process was almost totally inhibited and system failure occurred. One set of data points was slightly lower than the drawn curve. The data was from the 5.0 mgCu/L experiment conducted on system #2 and included a soluble copper to MLVSS ratio of 6.59, an effluent TKN of 14.6 and an effluent ammonia of 11.0. This could be due to the fact that the microorganisms had just recovered from the 2.0 mgCu/L experiment and were thus already acclimated to copper, which reduced its affect on the microorganisms.

Figure 31 indicates that a definite relationship exists between effluent ammonia and the average soluble copper in the mixed liquor. Inhibition generally increased as the soluble copper increased. This relationship was not as strong as the relationship shown in Figure 30, in which the ratio of soluble copper to biomass is plotted on the X-axis. The soluble copper concentration in the system directly affects nitrification, but the amount of biomass also affects the tolerance level of the nitrifiers to copper inhibition. Thus the ratio of soluble copper to MLVSS predicts copper inhibition more precisely than soluble copper concentration alone.

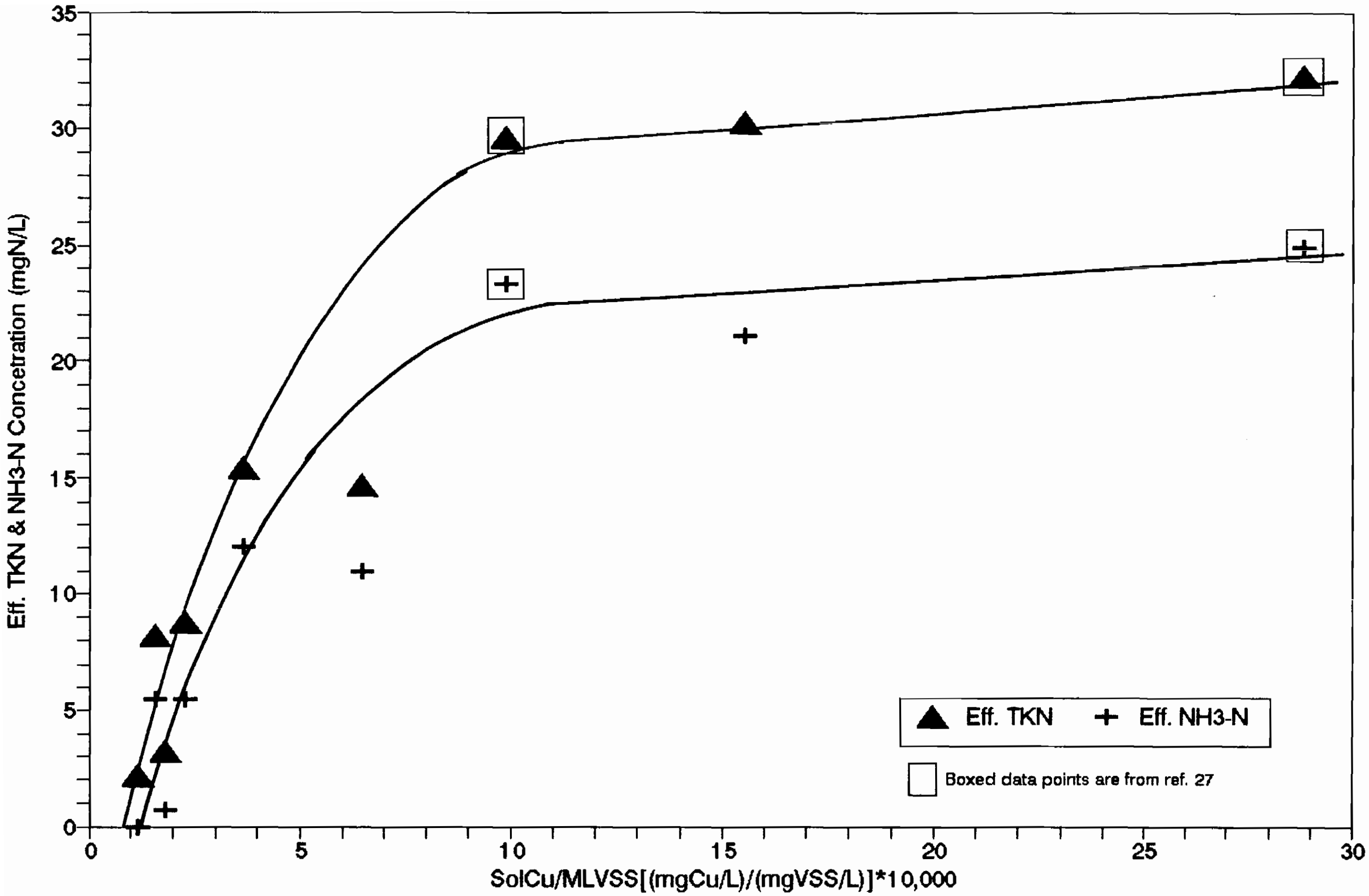

Figure 30. Avg. Eff. TKN & NH3-N vs. Ratio of Mixed Liquor Sol. Cu to MLVSS, for a series of experiments with differing Sludge Ages and Cu Loadings.

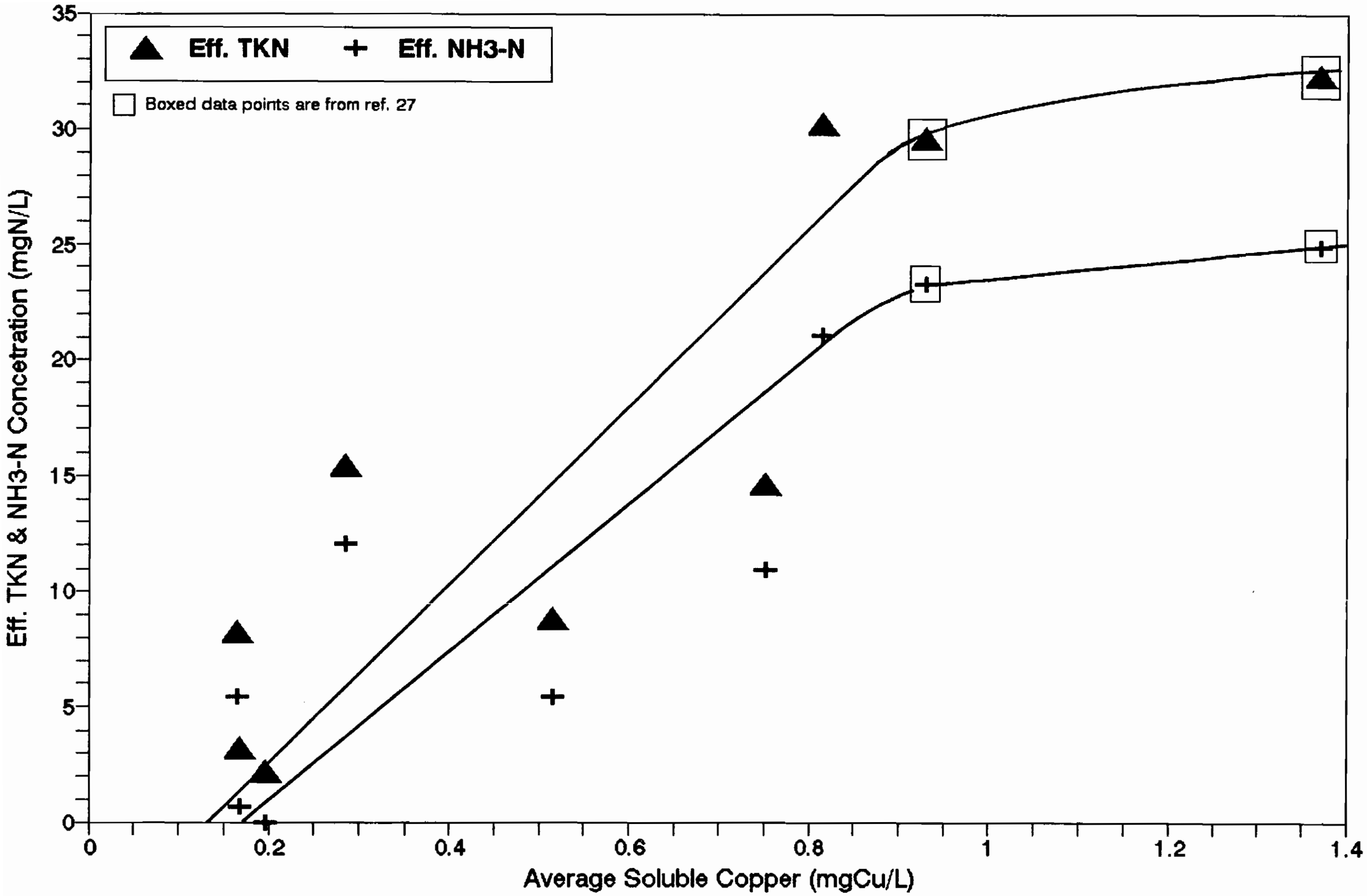

Figure 31. Average Effluent TKN & NH3-N vs. Average Soluble Cu in Mixed Liquor, for a series of experiments with different Sludge Ages and Cu Loadings.

Figures 32 and 33 are presented to demonstrate that the concentration of total copper within the mixed liquor and the ratio of the concentration of total copper to the concentration of MLVSS did not have a direct correlation to nitrification inhibition. The data plotted in Figures 32 and 33 display a random distribution. One would expect that as the total copper concentration, or ratio of total copper to MLVSS, increased, the inhibition to nitrification would increase, but this was not always the case.

Figure 34 shows a linear correlation of nitrification inhibition as a function of specific copper loading up to the point were system failure occurs. System failure occurred near a specific copper loading range of 0.005 to 0.0058 (mgCu/day)/(mgMLVSS in system).

Figures 35 and 36 present the percent nitrification and denitrification through the systems versus the ratio of soluble copper to MLVSS and the specific copper loading. Denitrification will be discussed in the next section. Note that Figures 35 and 30, which show effluent ammonia instead of percent nitrification, are inversions of each other. In Figure 35, the percent nitrification decreases as the ratio of soluble copper to MLVSS increased. The percent nitrification varied from 100% to about 35%. When the percent nitrification went below 45%, all of the experiments experienced system failure. Figures 36 and 34, which again show effluent ammonia instead of percent nitrification, are also inversions of each other. Figures 36 and 34 indicate that at a specific copper loading of about 0.005, the nitrification process was almost totally inhibited and system failure occurred.

The soluble copper causes inhibition to nitrification and not the total copper built up in the system. The ratio of soluble copper concentration in the system to the MLVSS predicts the inhibition of nitrification especially well. The specific total copper loading on the system has a direct relationship to the soluble copper concentration within the system, as shown in Figure 27; thus, the specific copper

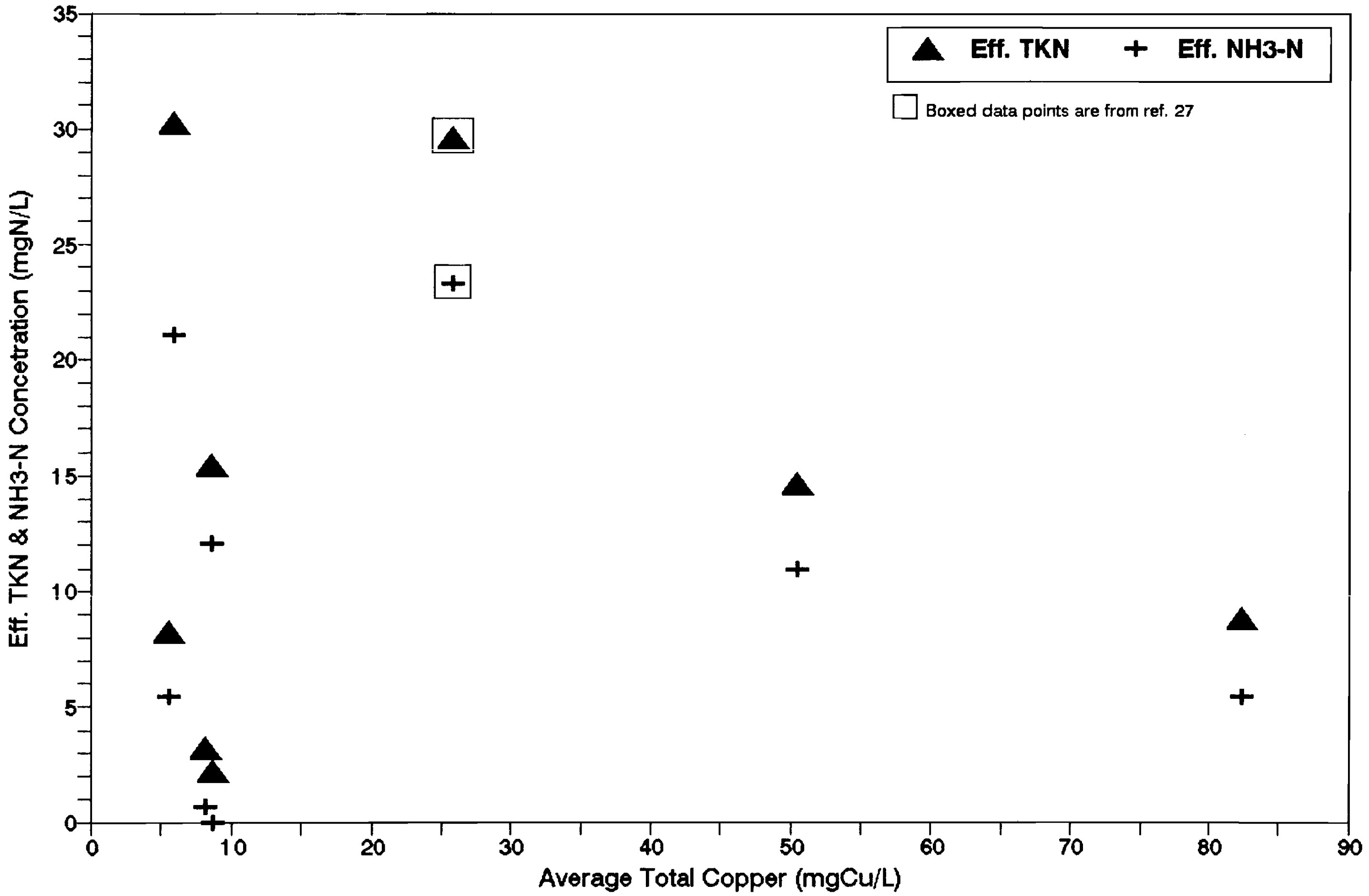

Figure 32. Average Effluent TKN & NH3-N vs. Average Total Cu in Mixed Liquor, for a series of experiments with different Sludge Ages and Cu Loadings.

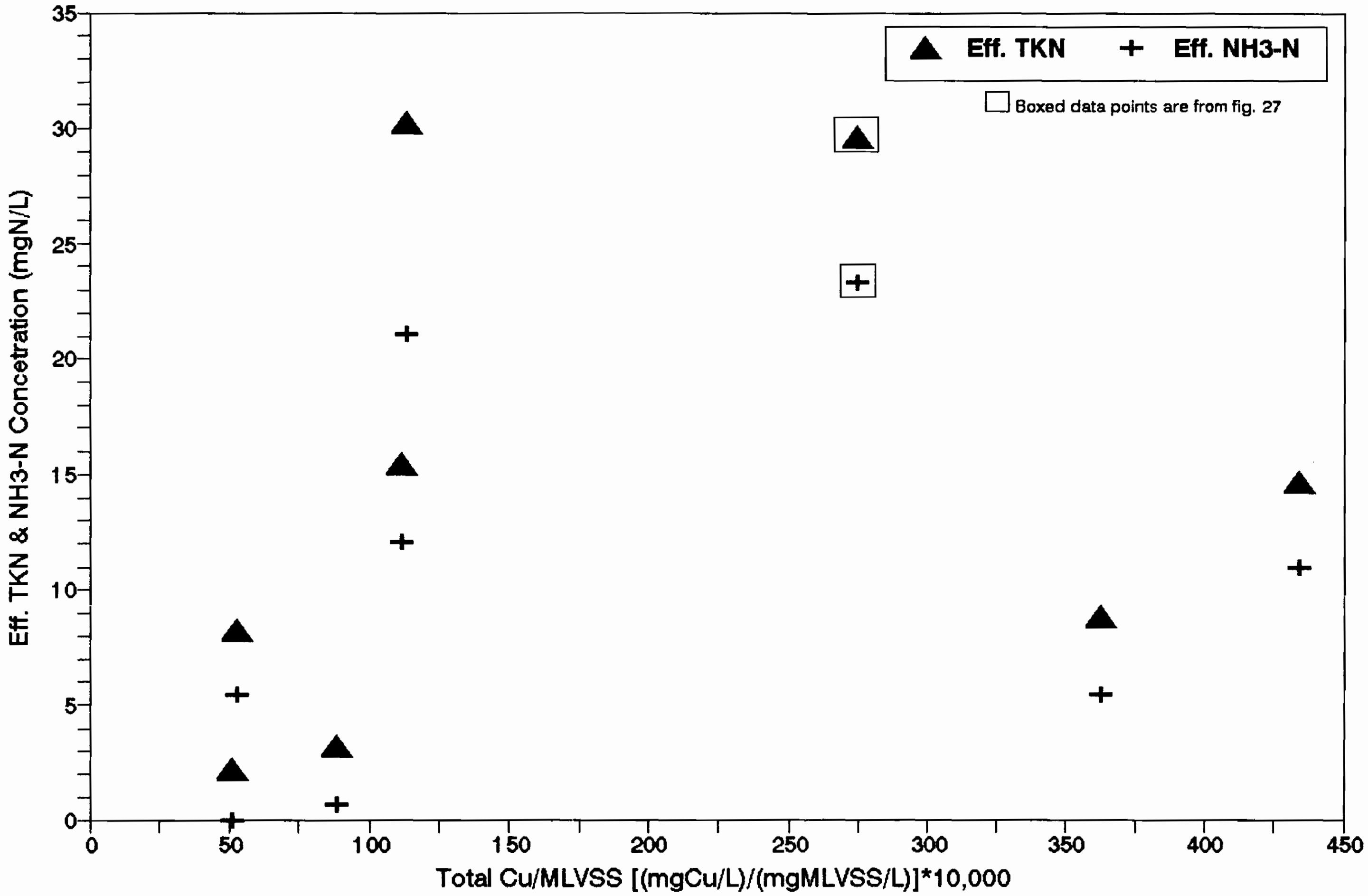

Figure 33. Average Effluent TKN & NH3-N vs. Ratio of Total Copper in Mixed Liquor to MLVSS, for a series of experiments with different Sludge Ages and Cu Loadings.

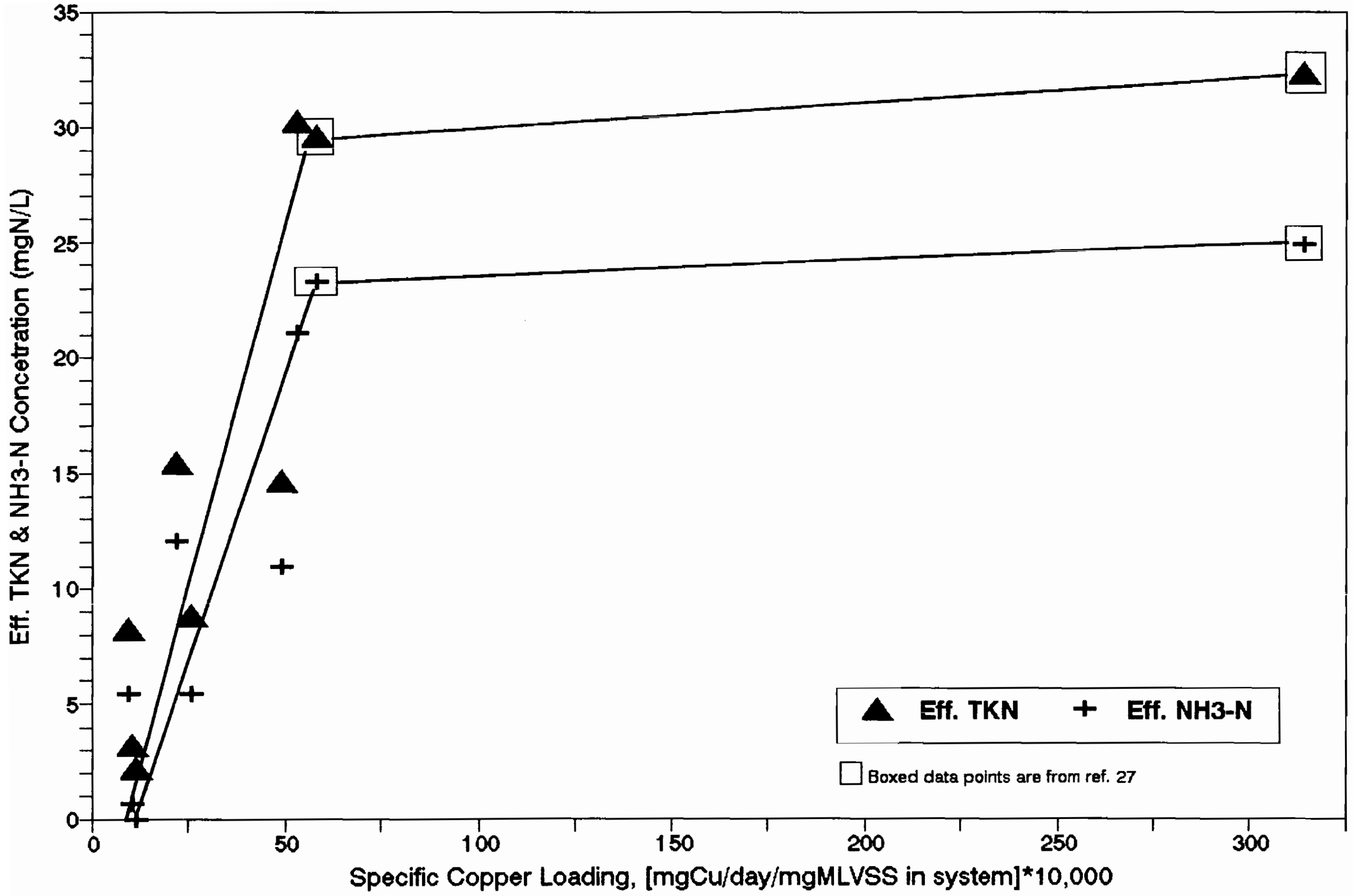

Figure 34. Average Effluent TKN & NH3-N vs. Specific Copper Loading to System, for a series of experiments with different Sludge Ages and Cu Loadings.

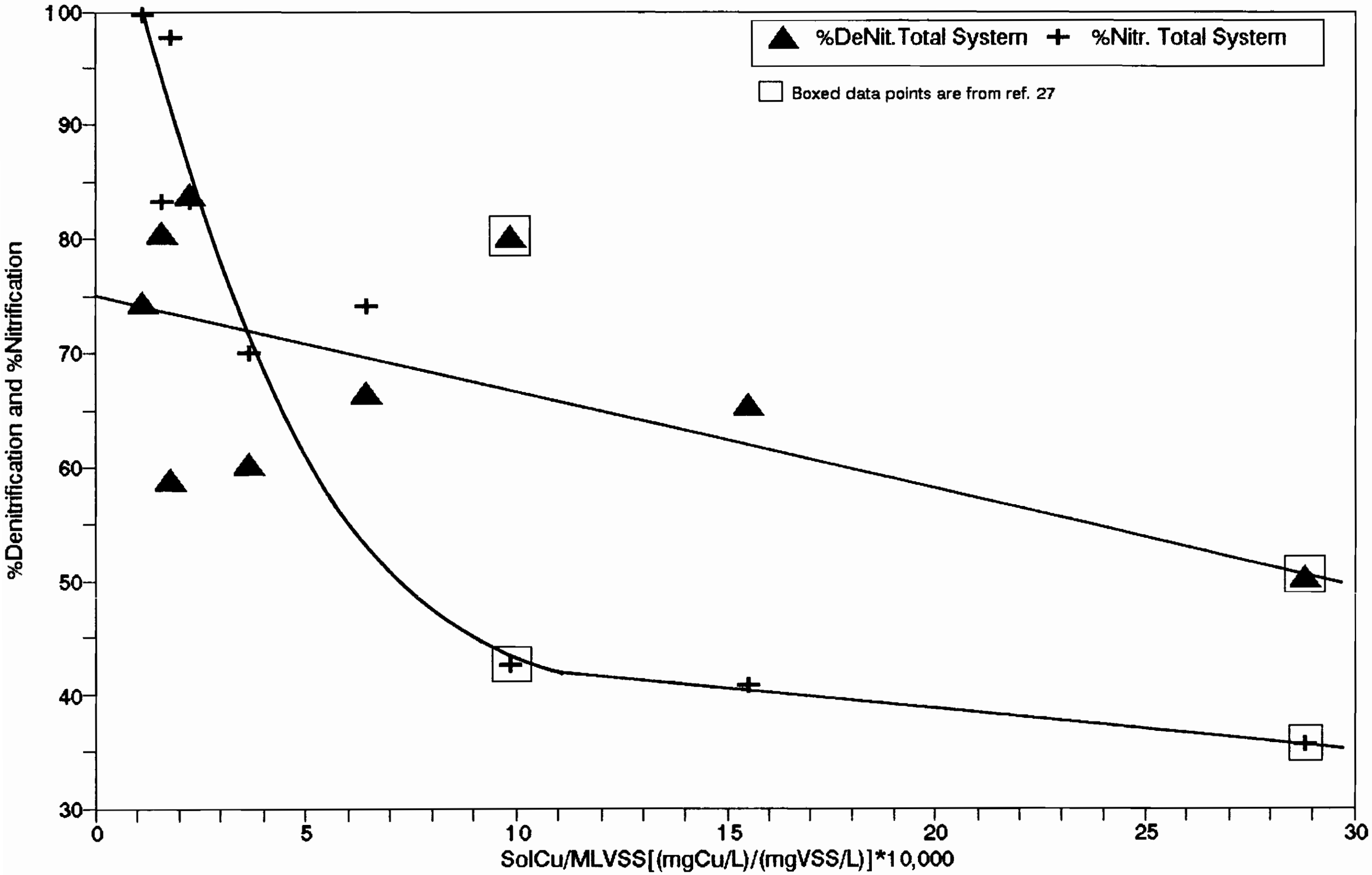

Figure 35. %Denitrification & %Nitrification over total system vs. Ratio of Mixed Liquor Sol. Cu to MLVSS, for a series of experiments with differing Sludge Ages and Cu Loadings.

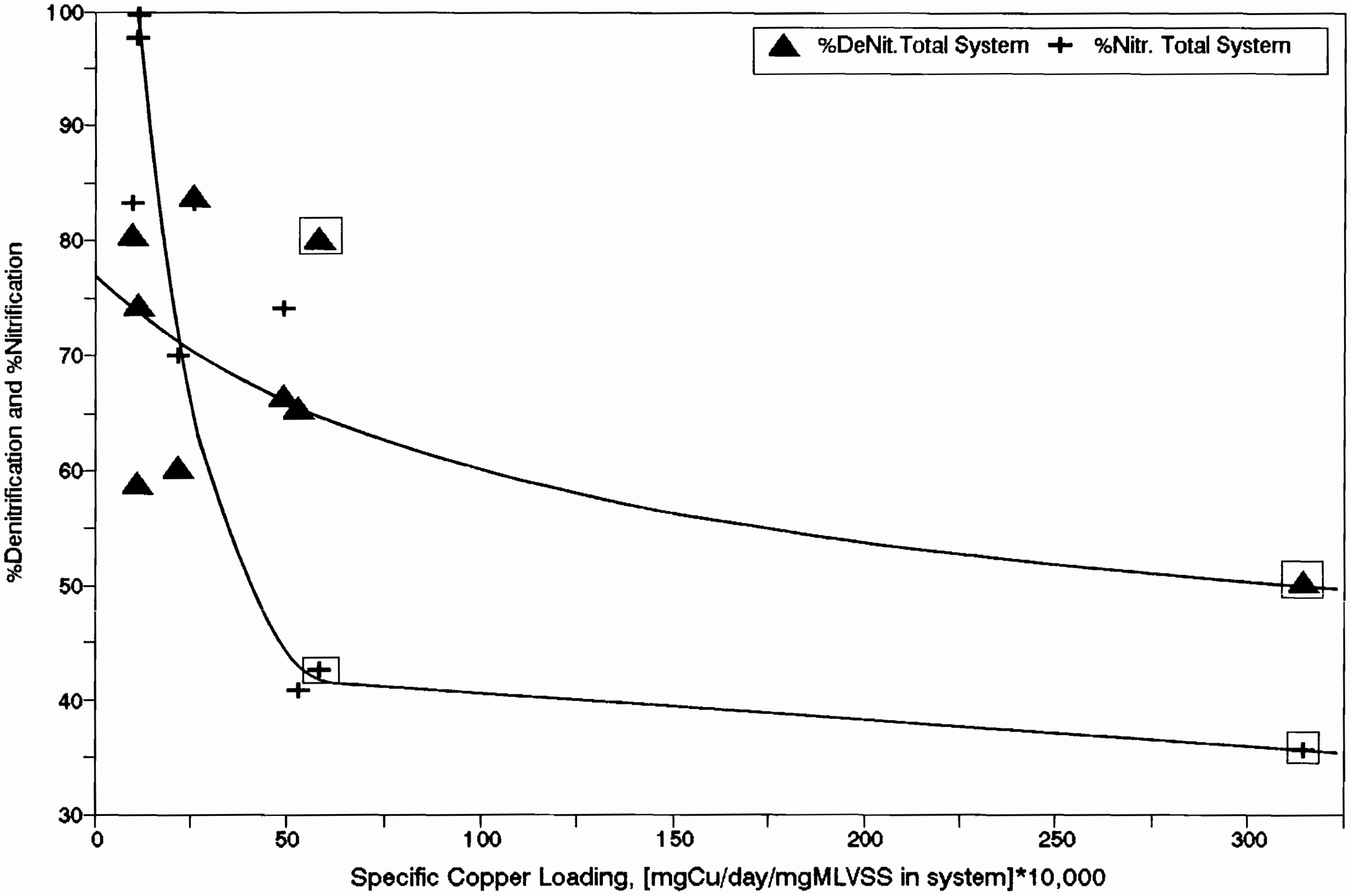

Figure 36. %Denitrification & %Nitrification through the Total System vs. Specific Copper Loading to the System, for a series of experiments with differing Sludge Ages and Cu Loadings.

loading also directly predicts the inhibition of nitrification.

EFFECTS OF COPPER ON DENITRIFICATION

This section addresses the affects of copper on denitrification and analyzes denitrification through the total system and through the anoxic chamber. Figures 35 and 36 suggest that nitrification is affected more by copper than denitrification because percent denitrification through the system was greater than percent nitrification through the system at the higher soluble copper to MLVSS ratios. This may not be the case because ammonia must first be nitrified (converted to nitrite and nitrate) before it can be denitrified. If nitrification was being inhibited then there would be less ammonia converted to nitrate and nitrite and less total nitrogen converted to nitrogen gas. The biomass would have the same denitrifier population with less nitrate and nitrite available, thus, a higher percentage of denitrification could occur even if some of the denitrifiers were inhibited. A closer examination of the nitrate and nitrite entering and departing the anoxic chamber reveals that the actual percent denitrification, through the anoxic chamber, is less than the percent denitrification through the total system when a system failure is occurring as shown in Figure 37.

Figure 37 shows that as the soluble copper to MLVSS ratio increased, the percent denitrification in the anoxic chamber decreased. When a system failed at the higher soluble copper to MLVSS ratios the denitrification in the anoxic chamber was also greatly inhibited. An exact explanation of why the percent denitrification through the total system is greater than the percent denitrification through the anoxic chamber, at the higher soluble copper to MLVSS ratios, is not known. It may be speculated that some denitrification was taking place in the aerobic chamber in the center of mixed liquor flocs.

Figure 38 shows the nitrogen available for denitrification and the nitrogen that was denitrified through the total system. "Nitrogen available for denitrification" is defined as the nitrogen that has been nitrified plus the influent nitrate and nitrite. As expected in a recycle system, not all the nitrogen nitrified is recycled to the anoxic chamber. The mixed liquor recycle rate from the aerobic chamber is two times the influent to the system and the sludge return flow from the clarifier is the same as the influent to the system, and so the total recycle rate was 3 to 1. That is, for every particle leaving the system there were three being returned, and so the maximum denitrification percentage should be 75%. This assumes that all denitrification was taking place in the anoxic chamber. Since the influent leachate TKN ranged from 59.4 to 44.7 mg/L, with an average of 46.1 mg/L, then the maximum anoxic zone influent nitrate-N was about 11.1 mg/L. The 11.1 mg/L result accounts for two dilutions of nitrogen. The leachate coming into the system was diluted by 3 parts so that the recycle nitrate-N, after nitrification in the aerobic chamber, was 59.4/4 = 14.9 mg/L. This assumes all the TKN was nitrified. In addition, the recycle was diluted by 1 part influent leachate so that the nitrate-N concentration, going into the anoxic zone, was [(3 * 14.9)/4] = 11.1 mg/L, plus a forth of the leachate nitrate-N and nitrite-N.

Figure 39 shows the summation of the nitrate and nitrite concentration entering and departing the anoxic chamber. Note that the anoxic zone influent nitrite-N and nitrate-N were calculated from the effluent nitrite-N and nitrate-N while assuming that no nitrification occurred in the clarifier and that the aerobic chamber was completely mixed. As the soluble copper to MLVSS ratio increased, the concentration of NO_x-N leaving the anoxic chamber increased and denitrification was inhibited. Figure 37 shows the same information but as percent denitrification in the anoxic chamber.

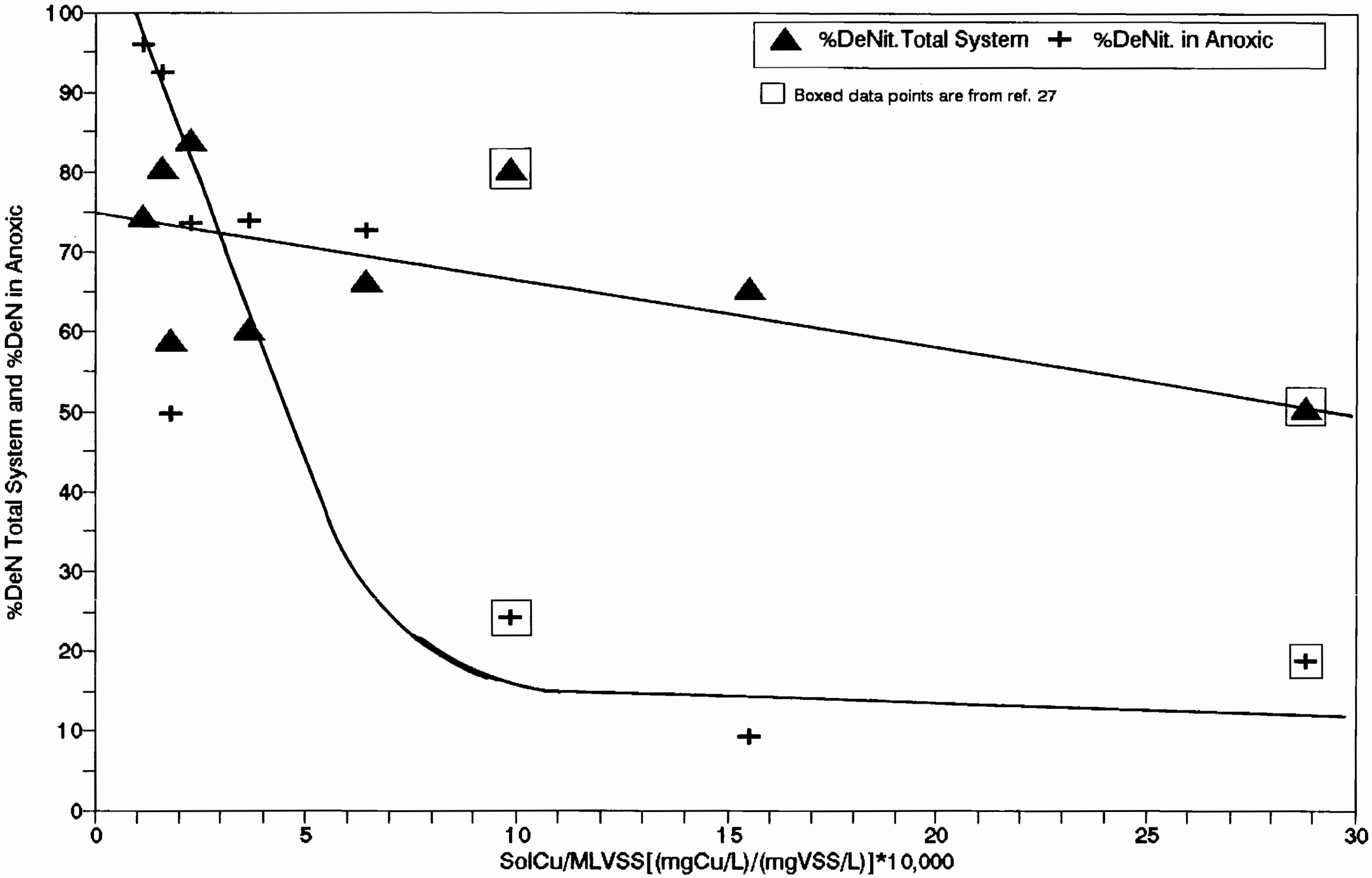

Figure 37. %Denitrification over Total System & %Denitrification in Anoxic Chamber vs. Ratio of Mixed Liquor Sol. Cu to MLVSS, for a series of experiments with differing Sludge Ages and Cu Loadings.

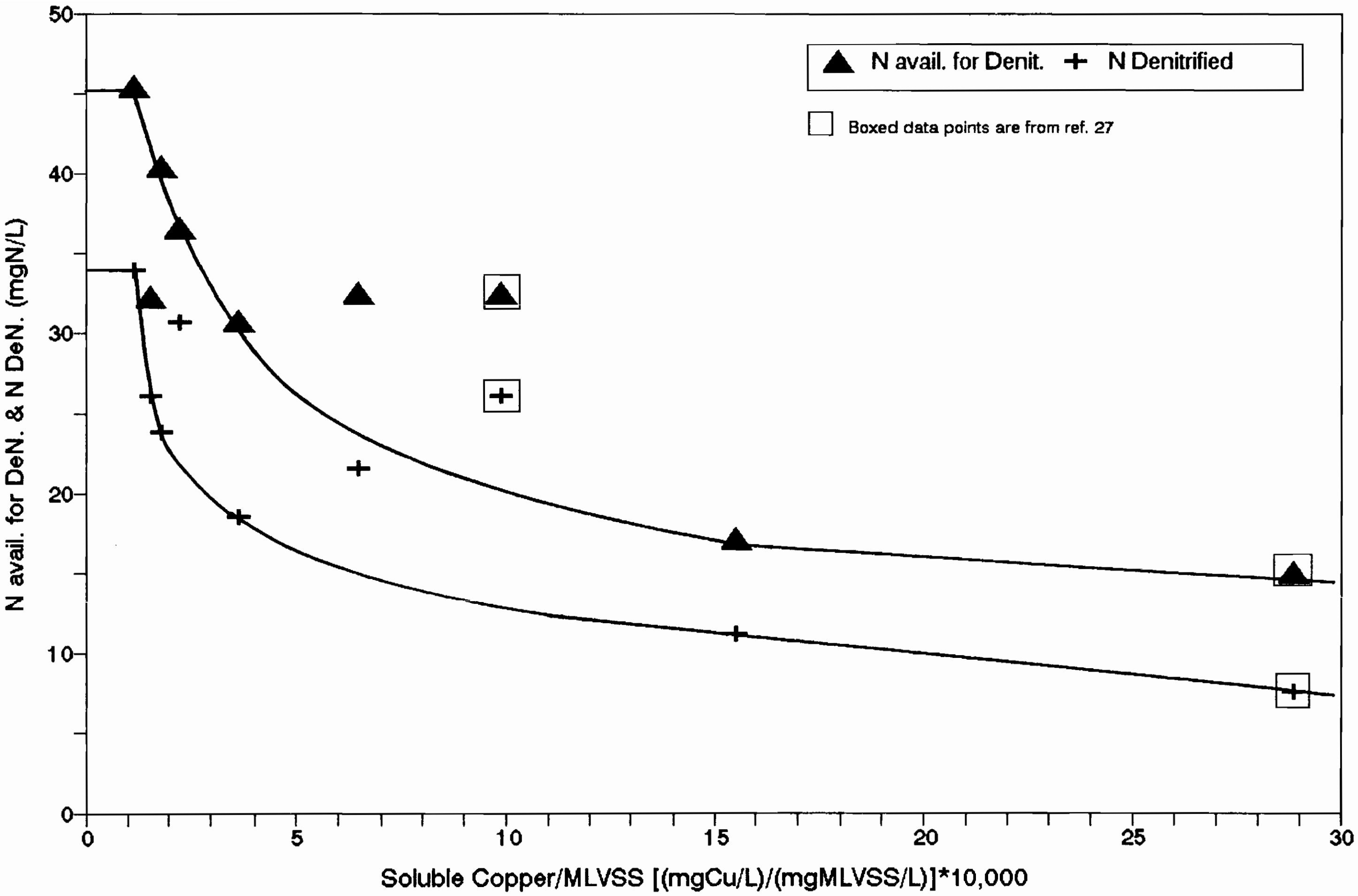

Figure 38. Nitrogen Available for Denitrification & Total Nitrogen Denitrified vs. Ratio of Mixed Liquor Sol. Cu to MLVSS, for a series of experiments with differing Sludge Ages and Cu Loadings.

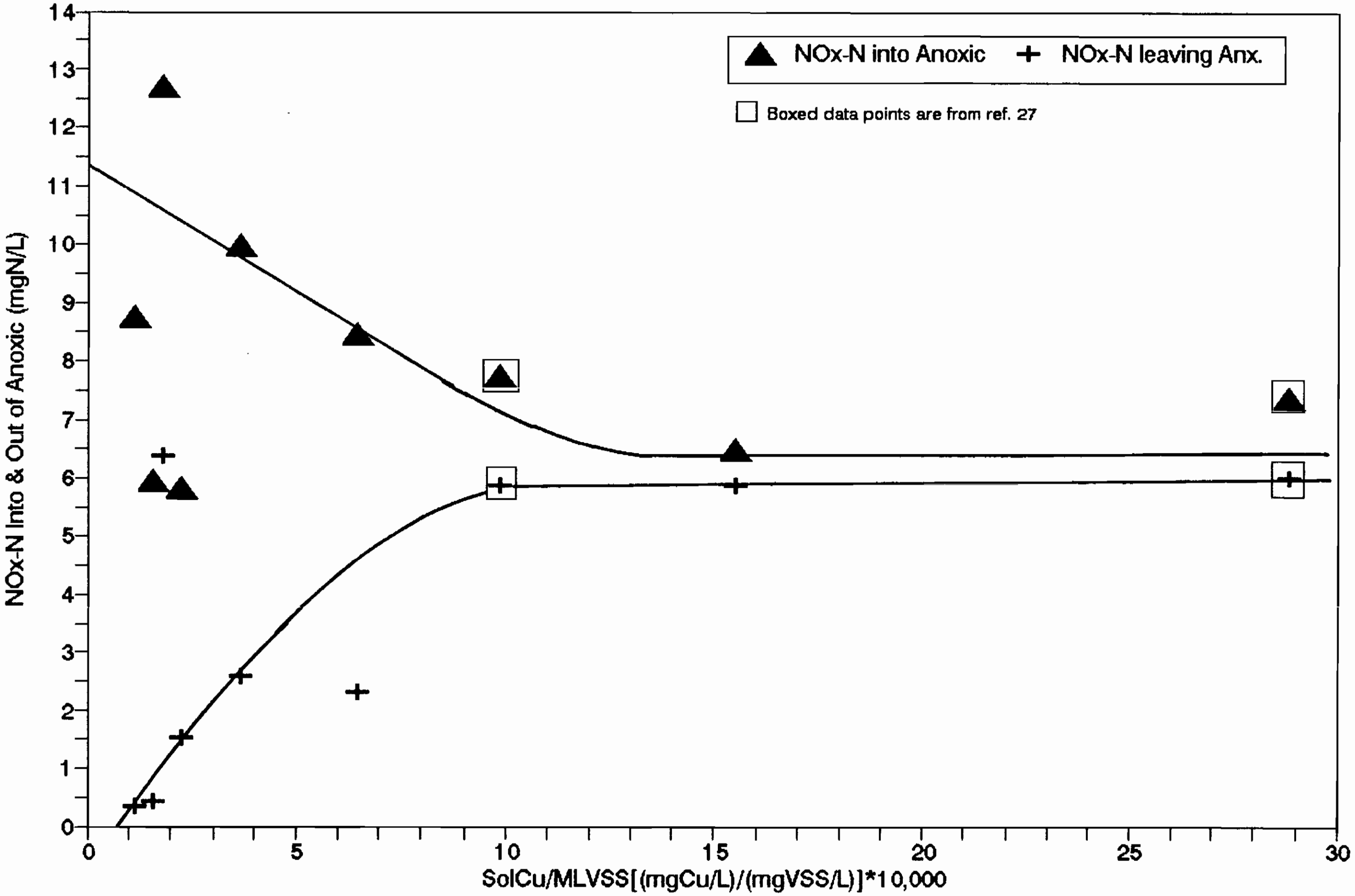

Figure 39. Nitrogen (NOx-N) Entering and Leaving the Anoxic Chamber vs. Ratio of Mixed Liquor Sol. Cu to MLVSS, for a series of experiments with differing Sludge Ages and Cu Loadings.

CHAPTER V. CONCLUSIONS

The following are the conclusions derive from this research;

1) Intermittent inhibition of nitrification occurred during treatment of the Dixie Caverns Landfill leachate with a Modified Ludzack Ettinger (MLE) single-sludge, activated sludge system. The inhibiting substance was not identified during this study. It did not significantly inhibit denitrification, but did cause elevated effluent suspended solids concentrations. An additional treatment step would be needed for reliable treatment of the wastewater.

2) The soluble copper concentration in the experimental system was a linear function of the specific copper loading rate to the system.

3) The adsorption of copper by the activated sludge, and the resulting soluble copper concentration in the mixed liquor, could be generally described by the Freundlich Isotherm.

4) Copper additions caused inhibition of both nitrification and denitrification. The inhibition of nitrification/denitrification in the MLE systems was a strong function of the soluble copper to MLVSS ratio in the reactors.

5) The nitrifiers and the denitrifiers appeared to be equally sensitive to copper. Both were severely inhibited at a soluble copper to MLVSS ratio of 0.001 in the aerobic and anoxic reactors, respectively.

6) *Nitrosomonas* species were more strongly inhibited by copper concentrations than were the *Nitrobacter* species. The denitrifiers appeared to be as sensitive to copper as the *Nitrosomonas* species.

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APPENDIX A

SAMPLE CALCULATIONS

Data taken on 4/26/1990 from System #2 is be used in most of these calculations.

A1. Sample Calculation for mixed liquor wasted to maintain Mean Cell Residence Time (MCRT).

MCRT = 15 day.
Q_w = Volume of mixed liquor wasted each day (l/day) = ?.
X = Average MLVSS concentration = 1040 mg/l.
V = Reactor Volume (aerobic & anoxic chambers) = 4.5L.
Q = Influent flow rate = 6.0 l/day.
X_{eff}=Effluent VSS conc. = 3.16 mg/l.

$$Q_w = (X * V - Q * X_{eff} * MCRT)/[MCRT * (X - X_{eff})]$$
$$Q_w = (1041 * 4.5 - 6 * 3.16 * 15)/[15 * (1041 - 3.16)]$$
$$Q_w = 0.283 \text{ liter}$$

A2. Nitrogen Wasted per liter of flow (N_w)

N_s = Nitrogen in Volatile Solids (10.4%) (ref. 1)
N_w = Nitrogen wasted per liter of flow (mg/l).

$$N_w = \{ N_s * [Q_w * X + (Q - Q_w) * X_{eff}] / Q \}$$
$$N_w = \{.104 *[0.283 * 1040 +(6.0 - 0.283)* 3.16]/6.0\}$$
$$N_w = 5.42 \text{ mg/l}$$

A3. Total Influent Nitrogen (TN_{in})

TKN_{in} = Influent Total Kjeldahl Nitrogen = 41.76 mg/l.
NO_{2in} = Influent Nitrite Nitrogen = 7.78 mg/l.
NO_{3in} = Influent Nitrate Nitrogen = 0.24 mg/l.
TN_{in} = Total Influent Nitrogen

$$TN_{in} = (TKN_{in} + NO_{2in} + NO_{3in})$$
$$TN_{in} = (41.76 + 7.78 + 0.24) = 49.78 \text{ mg/l}$$

A4. Total Effluent Nitrogen (TN_{eff})

TKN_{eff} = Effluent Total Kjeldahl Nitrogen = 7.54 mg/l.
NO_{2eff} = Effluent Nitrite Nitrogen = 1.06 mg/l.
NO_{3eff} = Effluent Nitrate Nitrogen = 6.36 mg/l.
TN_{eff} = Total Effluent Nitrogen.

$$TN_{eff} = TKN_{eff} + NO_{2eff} + NO_{3eff} + N_w$$
$$TN_{eff} = 7.54 + 1.06 + 6.36 + 5.42 = 20.38 \text{ mg/l}$$

A5. Nitrogen Available for Nitrification per liter of Q (N_aN)

NH_{3eff} = Effluent Ammonia Nitrogen = 4.28 mg/l.
N_aN = Nitrogen available for nitrification (mg/l).

$$N_aN = TKN_{in} - N_w - (TKN_{eff} - NH_{3eff})$$
$$N_aN = 41.76 - 5.42 - (7.54 - 4.28) = 33.08 \text{ mg/l}$$

A6. Total Nitrogen Nitrified per liter of flow (TNN)

TNN = Total Nitrogen Nitrified per liter of flow (mg/l).

$$TNN = TKN_{in} - N_w - TKN_{eff} - (0.25 * NO_{2eff})$$
$$TNN = 41.76 - 5.42 - 7.54 - (0.25 * 1.06) = 28.54 \text{ mg/l}$$

A7. Percent Nitrification (%N)

%N = Percent Nitrification.

$$\%N = TNN * 100/ N_aN$$
$$\%N = 28.54 * 100/ 33.08 = 86.3\%$$

A8. Nitrogen Available for Denitrification (N_aDeN)

N_aDeN = Nitrogen Available for Denitrification (mg/l).

$$N_aDeN = TNN + (0.60 * NO_{2in}) + NO_{3in}$$
$$N_aDeN = 28.54 + (0.60 * 7.78) + 0.24 = 33.45 \text{ mg/l}$$

A9. Total Nitrogen Denitrified per liter of flow (TNDeN)

TNDeN = Total Nitrogen Denitrified per liter of flow (mg/l).

$$TNDeN = TKN_{in} + 0.60 * NO_{2in} + NO_{3in} - N_w - TKN_{eff} - NO_{3EFF} - 0.60 * NO_{2eff}$$
$$TNDeN = 41.76 + 0.60 * 7.78 + 0.24 - 5.42 - 7.54 - 6.36 - 0.60 * 1.06 = 26.71 \text{ mg/l}$$

A10. Percent Denitrification (%DeN)

%DeN = Percent Denitrification.
$$\%DeN = TNDeN * 100/ N_aDeN$$
$$\%DeN = 26.71 * 100/ 33.45 = 79.9\%$$

A11. Theoretic Oxygen Demand (THOD) for methanol.

$2CH_3OH + 3O_2$ -------> $2CO_2 + 4H_2O$ [Eq. 10]
$CH_3OH + 3/2\ O_2$ -------> .....

One mole CH_3OH weighs 32 gm.
One mole O_2 weighs 32 gm.

So: 32 gm/mole + (3/2) 32 gm/mole ------> ....
Thus 48 gm of oxygen is oxidized per 32 gm methanol.
And 1 gm CH_3OH uses 48/32 = 1.5 gm O_2.

Calculate the THOD for stock methanol feed solution used in this research.

Note: the stock methanol feed solution was made up by adding 7.2 gm of methanol per L of water.
Assume that the 140 ml/day is being pumped into the system.

THOD = [(1.5 gm O_2/gm CH_3OH) * (7.2 gm CH_3OH/L) * 0.140 L/day] / 6 L/day
THOD = 0.252 gm/L
THOD = 252 mg/L = 250 mg/L

APPENDIX B

TREATMENT OF DIXIE CAVERNS LANDFILL LEACHATE

OPERATING RESULTS

NITROGEN, SOLIDS, AND COD

Table B-1. Characteristics of Dixie Caverns Leachate

DATE	TN_{in} mg/l	TKN_{in} mg/l	NH_{3in} mg/l	NO_{2in} mg/l	NO_{3in} mg/l	PO_{4in} mg/l	CL_{in} mg/l
11/24/89	61.01	60.20*	55.38	0	0.81	0.19	183
11/30/89	58.78	57.97*	53.17	0*	0.81*		
12/04/89	58.78	57.97*	52.51	0*	0.81*		
12/11/89	58.12	57.31*	52.51	0*	0.81*		
12/13/89	60.16	59.35	54.55	0*	0.81*		
12/16/89	60.16	59.35	54.55	0*	0.81*		
1/05/90	60.16	59.35	54.55	0*	0.81*		
1/09/90	51.14	46.27	40.38	1.30	3.57		
1/12/90	52.29	44.68	38.57	2.60	5.01	0.26	185
1/15/90	52.97	50.90	44.97	0	2.07	0.07	188
1/18/90	47.08	45.25	39.37	0*	1.83*		
1/21/90	52.94	51.36	44.85	0	1.58	0	214
1/24/90	56.19	54.30	44.46	0	1.89	0	190
1/27/90	53.79	46.94	38.18	0	6.85	0.04	179
1/30/90	49.63	49.32	43.78	0	0.31	0	174
2/02/90	48.51	47.85	44.23	0	0.66	0	165
2/05/90	51.33	50.45	44.46	0	0.88	0.07	170
2/08/90	48.92	48.50	43.45*	0	0.42	0.15	168
2/11/90	51.40	44.30	38.75	1.10	6.00	0.05	165
2/14/90	50.54	50.46	42.00	0	0.08	0.04	183
2/17/90	52.59	51.18	44.69	0	1.41	0	199
2/20/90	53.30	52.36	45.98	0	0.94	0.14	199
2/23/90	51.75	51.74	44.18	0	0.01	0.02	172
2/26/90	51.03	51.02	45.64	0	0.01	0	174
3/01/90	51.18	50.68	45.30	0	0.5	0.03	175
3/04/90	51.20	50.96	46.09	0	0.24	0.07	173
3/07/90	49.74	49.56	43.40	0	0.18	0.08	176
3/10/90	51.02	49.50	40.77	0.16	1.36	0.08	163
3/14/90	50.24	50.23	43.18	0	0.01	0.06	198
3/17/90	50.11	49.84	44.52	0	0.27	0.05	198
3/20/90	50.79	46.82	39.31	0.38	3.59	0.03	159
3/23/90	49.04	48.38	42.34	0.29	0.37	0.09	162
3/26/90	54.62	54.49	45.36	0	0.13	0.12	164
3/29/90	51.26	51.16	47.22	0	0.1	0.09	194
4/01/90	50.71	50.26	46.71	0	0.45	0.03	180
4/04/90	50.51	49.47	45.59	0	1.04	0.06	179
4/07/90	50.94	50.15	47.11	0	0.79	0.05	184
4/10/90	49.89	49.53	45.92	0	0.36	0.15	175
4/13/90	51.19	47.61	42.49	3.02	0.56	0.16	174
4/16/90	49.95	48.91	44.52	0.81	0.23	0.14	178
4/20/90	48.46	46.26	42.32	2.10	0.1	0.04	146
4/23/90	48.08	41.87	37.31	5.99	0.22	0.08	146
4/26/90	49.78	41.76	36.98	7.78	0.24	0.10	154
5/01/90	47.58	46.09	44.24	1.20	0.29	0.13	177
5/04/90	49.64	47.56	42.15	1.52	0.56	0.05	201
5/08/90	51.16	47.84	44.12	2.72	0.60	0.03	173
5/11/90	51.14	48.01	43.00	2.81	0.32	0.07	173
5/15/90	51.50	47.67	42.60	3.55	0.28	0	183
5/18/90	51.37	47.22	42.32	3.87	0.28	0	181
5/22/90	54.96	48.01	44.24	6.24	0.71	0.05	188
5/25/90	49.44	49.13	45.02	0	0.31	0.13	208
5/29/90	48.67	48.23	41.65	0	0.44	0.05	188
6/01/90	47.14	46.99	43.00	0	0.15	0.15	184
6/05/90	48.04	46.77	43.67	1.25	0.02	0.07	186
6/19/90	47.67	47.65*	44.35	0	0.02	0	214
6/22/90	48.41	48.23	44.74	0	0.18	0.21	201
6/26/90	50.14	49.92	46.88	0	0.22	0.09	205
6/29/90	51.39	51.21	47.61	0	0.18	0	187
6/30/90	50.99	50.94*	47.73	0	0.05	0.11	211
7/03/90	50.69	49.70	46.88	0.28	0.71	0.16	193

7/06/90	51.56	51.55	47.05	0	0.01	0.14	215
7/10/90	52.52	51.10	46.15	1.35	0.07	0	206
7/13/90	51.46	50.15	45.53	1.28	0.03	0	216
7/17/90	57.83	52.51	46.32	4.62	0.70	0	238
7/20/90	53.07	53.07	47.50	0	0	0	258
7/24/90	53.02	53.02	48.63	0	0	0.11	230
7/27/90	52.23	52.23	46.94	0	0	0	230
7/31/90	53.13	53.13	49.02	0	0	0.14	242
8/03/90	53.02	52.45	47.56	0.22	0.35	0.20	231
8/07/90	52.63	52.51	49.81	0	0.12	0.04	241
8/08/90	53.30	53.24*	49.81	0*	0.06*		
8/10/90	53.97	53.97	48.96	0	0	0.21	242
8/14/90	53.36	53.35	47.73	0	0.01	0.21	244
8/17/90	54.43	54.42	48.18	0	0.01	0.08	195
8/21/90	53.53	53.52	46.71	0	0.01	0	261
8/24/90	54.03	53.97	49.08	0	0.06	0.08	249
8/28/90	52.22	52.17	47.05	0	0.05	0	239
8/31/90	51.93	51.89	46.71	0	0.04	0.04	236
9/11/90	51.96	51.95	47.33	0	0.01	0	243
9/14/90	52.02	52.00	47.61	0	0.02	0.07	239
9/15/90	51.97	51.95*	47.61	0*	0.02*		
9/17/90	51.93	51.89	47.22	0	0.04	0.08	223
9/19/90	54.51	54.31*	49.08	0	0.20	0.08	259
9/21/90	54.94	54.76	49.53	0	0.18	0.12	256
9/25/90	54.50	54.31	48.85	0	0.19	0.03	244
9/29/90	54.40	54.03	48.29	0	0.37	0	256
10/02/90	55.24	54.87	49.75	0	0.37	0	250
Average	**52.91**	**51.54**	**46.56**	**0.60**	**0.67**	**0.07**	**200**

* Estimated Value.

Table B-2a. Leachate Average Nitrogen Concentration

TRIP	DATE	Total Nitrogen mg/l	TKN mg/l	NH_3 mg/l	NO_2 mg/l	NO_3 mg/l
1	11/22/89	59.30	58.49	53.58	0	0.81
2	12/13/89	60.16	59.35	54.55	0*	0.81*
3	1/04/90	52.34	48.53	41.54	0.56	3.26
4	1/27/90	50.42	48.86	43.05	0.16	1.39
5	2/16/90	51.69	51.35	45.44	0	0.34
6	3/06/90	50.80	49.83	42.70	0.12	0.84
7	3/27/90	50.75	49.70	45.84	0.50	0.55
8	4/14/90	49.07	44.70	40.28	4.17	0.20
9	4/30/90	50.51	47.47	43.14	2.64	0.40
10	5/21/90	49.65	47.83	43.52	1.5	0.33
11	6/06/90	48.04	47.94	44.55	0	0.10
12	6/25/90	51.25	50.65	46.88	0.42	0.18
13	7/16/90	53.72	52.73	47.66	0.81	0.17
14	8/06/90	53.61	53.57	48.61	0	0.04
15	8/27/90	52.00	51.97	47.28	0	0.03
16	9/17/90	54.72	54.47	49.11	0	0.25
Average		**52.38**	**51.09**	**46.11**	**0.68**	**0.61**

* Estimated Value.

Table B-2b. Leachate Characteristics

TRIP	DATE	DAY	pH	Alkalinity mg/l	PO_4 mg/l	CL mg/l
1	11/22/89	5	6.67	575	0.19	183
2	12/13/89	26	6.80	551		
3	1/04/90	48	6.64	507	0.07	191
4	1/27/90	71	6.63	503	0.05	175
5	2/16/90	91	6.58	528	0.05	179
6	3/06/90	109	6.66	532	0.07	174
7	3/27/90	130	6.76	530	0.09	181
8	4/14/90	148	6.50	522	0.09	156
9	4/30/90	164	6.49	509	0.05	181
10	5/21/90	185	6.49	522	0.09	191
11	6/06/90	201	6.36	554	0.10	208
12	6/25/90	220	6.41	541	0.07	205
13	7/16/90	241	6.38	562	0.08	238
14	8/06/90	262	6.44	568	0.10	239
15	8/27/90	283	6.55	567	0.04	236
16	9/17/90	304	6.55	563	0.05	253
Average		**19 Days**	**6.56**	**540**	**0.08**	**199**

Table B-3. Summary of Nitrogen for each Experiment

Exper.	Reactor #	MCRT day	Cu Dose	Days Used	MLVSS mg/L	MLSS mg/L
1	1	30	2.0	252	1707	2250
2	1	30	5.0	270 to 319	2270	3365
3	2	8	2.5	39, 42, 46	525	588
4	2	15	1.0	157, 160	1037	1387
5	2	15	1.0	193 to 224	925	1414
6	2	15	2.0	228 to 252	778	1058
7	2	15	5.0	270 to 319	1162	1696
8	Don's	8	5.0	534, 538, & 546	941	1219
9	Don's	8	15.0	474	475	623

Exper.	TKN_{eff} mg/L	NH_{3eff} mg/L	NO_{2eff} mg/L	NO_{3eff} mg/L	N_w mg/L	TKN_{in} mg/L
1	2.19	0.00	0.51	11.39	4.45	52.23
2	8.79	5.47	7.4	3.27	6.24	53.28
3	30.28	21.07	9.87	2.46	10.28	59.35
4	8.27	5.43	0.76	6.02	5.4	41.82
5	3.22	0.68	1.05	16.23	4.81	48.43
6	15.42	12.09	3.19	11.14	5.44	51.66
7	14.64	10.98	1.31	10.44	5.97	53.28
8	29.6	23.3	13.2	1.78	9.17	59.3
9	32.3	24.9	9.4	4.2	8.16	57.9

Exper.	NaN mg/L	TNN mg/L	%Nitrif.	NaDeN mg/L	TNDeN mg/L	%DeN
1	45.59	45.46	99.7	45.46	33.89	74.5
2	43.72	36.41	83.3	36.51	30.65	83.9
3	39.86	16.32	40.9	17.13	11.22	65.5
4	33.58	27.97	83.3	32.33	26.04	80.5
5	41.08	40.14	97.7	40.42	23.82	58.9
6	42.89	30.01	70	30.77	18.51	60.2
7	43.65	32.34	74.1	32.45	21.55	66.4
8	43.83	18.66	42.6	32.45	26.06	80.3
9	42.34	15.09	35.6	15.09	7.6	50.4

Exper.	$N_{to\ anx}$ mg/L	$N_{out\ anx}$ mg/L	%$DeN_{in\ anx}$	$NO_{2\ anx}$ mg/L	$NO_{3\ anx}$ mg/L
1	8.77	0.35	96	0.51	0.04
2	5.81	1.53	73.7	2.36	0.11
3	6.49	5.88	9.4	7.12	1.61
4	5.95	0.45	92.4	0.63	0.08
5	12.71	6.38	49.8	0.14	6.29
6	9.97	2.61	73.8	0.43	2.35
7	8.45	2.31	72.7	3.37	0.29
8	7.75	5.88	24.1	9.8	0.0
9	7.38	6.0	18.7	6.09	2.32

Table B-4. Suspended Solids Data - System #1 (Day 0 to 319)

Sludge Age	**days**	**8**	**15**	**30**	**30**	**30**
Copper Dose	**mgCu/L**	**Control**	**Control**	**Control**	**2.0**	**5.0**
Days of Study		0-115	115-176	176-245	245-253	253-319
Total Days		115	61	69	8	66
Steady State Days		24-115	147-176	214-245	252	270-319
Avg. MLVSS*	Range	533-797	927-1150	1400-1860		2080-2520
	Avg.	659	1060	1690	1710	2270
Avg. MLSS*	Range	592-940	1080-1360	1820-2380		3040-3780
	Avg.	738	1240	2170	2250	3370
Aer. MLVSS*	Range	441-810	925-1190	1380-2220		2120-2550
	Avg.	607	1080	1730	1740	2310
Aer. MLSS*	Range	490-960	1090-1400	1780-2900		3080-3790
	Avg.	681	1260	2230	2300	3430
Anx. MLVSS*	Range	545-995	930-1150	1000-2000		1860-2610
	Avg.	762	1030	1610	1640	2190
Anx. MLSS*	Range	595-1130	1080-1330	1280-2550		2820-3910
	Avg.	850	1200	2050	2150	3240
Aerobic %MLVSS/MLSS	Range	84.4-94.5	83.5-87.8	75.3-80.5		66.1-68.8
	Avg.	89.4	85.3	77.7	75.7	67.4
Anoxic %MLVSS/MLSS	Range	84.7-97.1	84.5-86.8	76.7-81.8		66.0-68.3
	Avg.	89.8	85.8	78.8	76.3	67.6
Eff. VSS*	Range	0.9-13.4	2.9-5.9	5.2-22.0		27.0-52.7
	Avg.	3.6	4.9	10.4	10.0	44.8
Eff. SS*	Range	1.0-14.9	3.0-7.2	6.5-28.8		35.0-103
	Avg.	3.9	5.9	13.1	12.2	75.3
Effluent %VSS/SS	Range	80.0-100	77.4-96.9	75.0-91.1		50.0-77.1
	Avg.	94.6	83.8	80.4	82.0	60.8
Nitrogen Wasted*	Range	2.6-7.46	2.99-5.99	3.65-4.83		5.41-6.97
	Avg.	6.26	5.21	4.40	4.5	6.25
Actual Sludge Age	Range					24.2-30.1
	Avg.	8	15	30	30	28.4

* mg/L

Table B-5. Suspended Solids Data - System #2 (Day 0 to 160)

Sludge Age	**days**	**8**	**8**	**8**	**15**	**15**
Copper Dose	**mgCu/L**	**0.0**	**2.5**	**0.0**	**0.0**	**1.0**
Days of Study		0-29	29-57	57-115	115-141	141-160
Total Days		29	28	58	26	19
Steady State Days		17-29	39-46	89-115	132-141	157-160
Avg. MLVSS*	Range	627-873	427-604	545-798	927-950	1030-1040
	Avg.	747	525	650	942	1040
Avg. MLSS*	Range	730-1010	473-678	625-888	1080-1150	1380-1390
	Avg.	867	588	734	1120	1390
Aer. MLVSS*	Range	635-950	435-583	610-825	940-1140	1110-1120
	Avg.	760	525	703	1040	1110
Aer. MLSS*	Range	740-1090	480-655	700-915	1090-1340	1470-1490
	Avg.	883	587	793	1240	1480
Anx.MLVSS*	Range	610-970	410-645	365-745	510-945	880-890
	Avg.	720	527	546	741	885
Anx. MLSS*	Range	710-1170	460-725	420-835	575-1090	1200-1210
	Avg.	834	592	616	866	1200
Aerobic	Range	79.3-88.8	89.0-90.6	85.0-94.0	81.9-86.6	
%MLVSS/MLSS	Avg.	86.0	89.5	88.6	84.1	75.2
Anoxic	Range	82.9-89.6	89.0-89.1	84.0-94.8	83.1-88.7	73.6-73.9
%MLVSS/MLSS	Avg.	86.6	89.0	88.5	85.7	73.8
Eff. VSS*	Range	0.64-5.01	63.8-95.1	2.97-52.2	0.8-2.9	3.2-5.7
	Avg.	2.57	63.8	16.3	1.5	4.5
Eff. SS*	Range	1.59-5.39	49.0-100	3.69-61.7	0.6-2.9	3.9-8.4
	Avg.	3.03	69.4	18.5	1.4	6.1
Effluent	Range	40-100	89.0-95.1	80.6-93.8	77.8-100	68.7-81.6
%VSS/SS	Avg.	80.0	91.0	88.0	92.6	75.1
Nitrogen	Range	6.11-8.52	5.12-10.3	5.25-7.79	4.82-4.94	5.37-5.42
Wasted*	Avg.	7.28	7.17	6.29	4.90	5.39
Actual	Range		3.24-8.32	7.99-8.79		
MCRT	Avg.	8	6.42	8.09	15	15

* mg/L

Table B-6. Suspended Solids Data -System #2 (Day 160 to 319)

MCRT	days	15	15	15	15
Copper Dose	mgCu/L	0.0	1.0	2.0	5.0
Days of Study		160-173	173-225	225-253	253-319
Total Days		13	52	28	66
Steady State Days		160-173	193-224	228-252	270-319
Avg. MLVSS*	Range	968-1060	853-1020	647-962	1010-1350
	Avg.	1020	925	778	1160
Avg. MLSS*	Range	1250-1400	1300-1560	877-1350	1420-2050
	Avg.	1350	1410	1060	1700
Aer. MLVSS*	Range	1070-1160	905-1080	690-1040	1020-1420
	Avg.	1110	982	805	1210
Aer. MLSS*	Range	1370-1530	1390-1660	930-1460	1500-2160
	Avg.	1460	1510	1100	1770
Anx.MLVSS*	Range	775-880	745-950	560-870	930-1220
	Avg.	849	811	723	1070
Anx. MLSS*	Range	1000-1200	1130-1420	770-1190	1260-1840
	Avg.	1120	1220	969	1540
Aerobic %MLVSS/MLSS	Range	74.8-77.7	64.0-66.9	66.1-80.2	63.4-74.0
	Avg.	75.9	65.0	73.4	68.3
Anoxic %MLVSS/MLSS	Range	73.6-77.5	65.4-67.2	71.5-80.2	63.6-76.2
	Avg.	75.6	66.3	74.8	69.6
Eff. VSS*	Range	1.3-3.2	9.2-17.9	5.68-93.6	11.2-31.3
	Avg.	2.0	13.6	37.0	17.8
Eff. SS*	Range	1.4-3.9	13.2-24.8	6.8-123	16.5-52.4
	Avg.	2.7	19.0	47.0	31.4
Effluent %VSS/SS	Range	60.9-92.3	69.1-77.4	69.9-86.5	46.5-73.6
	Avg.	76.7	71.9	78.9	59.1
Nitrogen Wasted*	Range	5.03-5.52	4.44-5.30	3.36-10.7	5.27-7.00
	Avg.	5.31	4.81	5.44	6.04
Actual MCRT	Range			5.83-15	
	Avg.	15	15	12.5	15

* mg/L

Table B-7. Suspended Solids Data - System #3 (Day 153 to 319)

MCRT	days	15
Copper Dose	**mgCu/L**	**Control**
Days of Study		153-319
Total Days		166
Steady State Days		200-319
Avg. MLVSS*	Range	957-1550
	Avg.	1260
Avg. MLSS*	Range	1200-2130
	Avg.	1660
Aer. MLVSS*	Range	990-1590
	Avg.	1290
Aer. MLSS*	Range	1240-2200
	Avg.	1700
Anx.MLVSS*	Range	800-1470
	Avg.	1200
Anx. MLSS*	Range	960-1980
	Avg.	1570
Aerobic	Range	70.6-84.6
%MLVSS/MLSS	Avg.	76.1
Anoxic	Range	69.4-85.7
%MLVSS/MLSS	Avg.	76.7
Eff. VSS*	Range	7.5-54.8
	Avg.	20.6
Eff. SS*	Range	8.2-71.9
	Avg.	26.2
Effluent	Range	70.5-95.1
%VSS/SS	Avg.	79.6
Nitrogen	Range	4.98-8.05
Wasted*	Avg.	6.54
Actual	Range	
MCRT	Avg.	15

* mg/L

Table B-8. Nitrogen Balance - System #1 (Day 0 to 319)

System		#1	#1	#1	#1	#1
Sludge Age	days	8	15	30	30	30
Copper Dose	mgCu/l	Control	Control	Control	2.0	5.0
Days of Study	Range	0-115	115-176	176-245	245-253	253-319
Total Days		115	61	69	8	66
Steady State Days	Range	24-115	147-176	214-245	252	270-319
N Available for Nitrif.*	Range	35.7-50.2	33.7-42.2	39.95-45.58		42.22-45.35
	Avg.	43.39	38.78	43.35	45.59	43.72
Total N Nitrified*	Range	17.5-50.0	27.9-42.2	30.6-45.0		23.6-43.77
	Avg.	40.66	36.36	38.01	45.46	36.41
Percent Nitrif.	Range	45.91-100	67.8-100	69.2-100		54.1-96.5
	Avg.	93.31	94.01	87.74	99.7	83.24
N Available for DeNitr.*	Range	17.7-50.8	29.9-43.2	31.4-45.12		23.97-43.97
	Avg.	42.15	38.56	38.62	45.46	36.51
Total N Denitrified*	Range	14.4-42.2	24.9-32.8	23.26-34.91		18.55-36.98
	Avg.	32.84	29.81	28.50	33.89	30.65
Percent Denitrif.	Range	61.5-88.2	69.5-83.3	55.43-84.58		77.4-92.3
	Avg.	78.18	77.54	74.48	74.5	83.98
Eff. N Waste*	Range	2.60-7.46	2.99-6.0	3.65-4.83		5.41-6.97
	Avg.	6.27	5.16	4.33	4.45	6.24
Eff. N Sum*	Range	17.1-35.5	15.7-25.26	15.74-28.53		18.39-37.72
	Avg.	21.51	18.82	22.77	18.54	25.7
Eff. TKN*	Range	.57-26.38	1.58-17.0	2.28-17.17		2.48-24.14
	Avg.	5.78	4.84	8.13	2.19	8.79
Eff. NH_3*	Range	0.0-20.83	0.0-13.2	0.0-13.73		0.0-19.42
	Avg.	2.67	2.39	5.26	0.0	5.47
Eff. NO_2*	Range	0.0-.93	0.0-.42	0.0-.55		2.58-12.32
	Avg.	.22	.12	.30	.51	7.40
Eff. NO_3*	Range	2.48-18.0	4.86-13.2	5.01-20.0		0.44-6.44
	Avg.	9.22	8.71	10.02	11.39	3.27
Anx. NO_2*	Range	0.0-.36	0.0-.73	0.0-.41		0.0-6.70
	Avg.	.06	.23	.08	.51	2.36
Anx. NO_3*	Range	.01-.48	.03-.72	.03-.49		.01-.38
	Avg.	.14	.15	.21	.04	.11
NO_x in Anx.*	Range	2.35-15.27	4.34-10.47	4.12-15.19		2.36-8.53
	Avg.	7.39	7.14	7.8	8.77	5.81
NO_x out Anx.*	Range	0.01-0.65	0.03-1.16	0.03-0.49		0.06-4.15
	Avg.	0.18	0.28	0.26	0.35	1.53
%DeN in Anx.	Range	90.3-99.9	88.9-99.6	89.1-99.4		16.6-99
	Avg.	97.3	96.7	96.31	96.0	73.37

* All values mg/l

Eff. N Waste is the amount of influent nitrogen used for biomass growth.

Table B-9. Nitrogen Balance - System #2 (Day 0 to 160)

System		#2	#2	#2	#2	#2
Sludge Age	days	8	8	8	15	15
Copper Dose	mgCu/l	0.0	2.5	0.0	0.0	1.0
Days of Study	Range	0-29	29-57	57-115	115-141	141-160
Total Days		29	28	58	26	19
Steady State Days	Range	17-29	39-46	89-115	132-141	157-160
N Available for Nitrif.*	Range	45.5-49.1	39.86-45.02	35.7-42.8	42.4-44.2	33.1-34.1
	Avg.	47.85	42.97	40.66	43.27	33.58
Total N Nitrified*	Range	45.5-49.9	16.32-28.37	15.5-42.8	41.6-44.1	27.4-28.54
	Avg.	47.85	24.3	34.55	42.90	27.97
Percent Nitrification	Range		40.9-64.4	40.7-100	98.2-100	80.3-86.3
	Avg.	100	56.0	83.94	99.18	83.35
N Available for Denitr.*	Range	46.3-50.7	17.13-29.18	15.7-43.4	42.7-44.3	31.2-33.45
	Avg.	48.66	25.11	35.08	43.49	32.33
Total N Denitrified*	Range	32.4-38.2	11.22-21.65	11.5-32.2	27.4-36.6	25.36-26.71
	Avg.	35.27	17.76	25.86	33.54	26.04
Percent Denitrif.	Range	69.9-75.3	65.5-74.2	59.7-86.1	64.3-82.5	79.9-81.3
	Avg.	72.45	70.0	73.49	77.04	80.6
Eff. N Waste*	Range	6.11-8.52	5.12-10.3	5.25-7.79	4.81-4.94	5.37-5.42
	Avg.	7.28	7.17	6.28	4.90	5.40
Eff. N Sum*	Range	21.97-25.8	41.31-52.9	18.8-39.8	14.5-24.3	20.38-20.51
	Avg.	23.98	45.97	25.70	17.90	20.45
Eff. TKN*	Range		23.11-30.28	2.24-27.7	1.69-2.48	7.54-9.0
	Avg.	3.31	25.65	9.87	2.10	8.27
Eff. NH$_3$*	Range		13.9-21.07	0.0-22.5		4.28-6.58
	Avg.	0	16.44	5.99	0	5.43
Eff. NO$_2$*	Range		7.0-9.88	0.0-.97	.05-3.13	0.46-1.06
	Avg.	0	8.92	.49	1.48	.76
Eff. NO$_3$*	Range	12.5-13.9	2.46-5.15	3.52-13.0	7.67-14.1	5.68-6.4
	Avg.	13.39	4.23	9.05	9.43	6.02
Anx. NO$_2$*	Range		4.28-7.12	0.0-.48	0.0-.49	0.39-0.86
	Avg.	0	5.72	.16	.18	0.63
Anx. NO$_3$*	Range	0.35-0.53	1.61-3.03	.03-.63	.07-.75	.06-0.09
	Avg.	.44	2.34	.22	.32	0.08
NO$_x$ in Anx.*	Range	9.62-10.65	6.49-8.51	3.03-10.18	6.01-12.26	5.42-6.47
	Avg.	10.25	7.39	7.14	7.89	5.95
NO$_x$ out Anx.*	Range	0.35-0.53	4.95-6.49	0.03-0.8	0.08-1.04	0.32-0.58
	Avg.	0.44	5.77	0.31	0.42	0.45
%DeN in Anx.	Range	94.8-96.7	9.4-30.9	83.5-99.5	91.5-98.7	91.0-94.1
	Avg.	95.73	21.33	94.69	95.33	92.55

*** All values mg/l**

Eff. N Waste is the amount of influent nitrogen used for biomass growth.

Table B-10. Nit. Balance - System #2 (Day 160 to 319) & System #3 (Day 153 to 319)

System		**#2**	**#2**	**#2**	**#2**	**#3**
Sludge Age	**days**	**15**	**15**	**15**	**15**	**15**
Cu Dose	**mgCu/l**	**0.0**	**1.0**	**2.0**	**5.0**	**Control**
Days of Study	Range	160-173	173-225	225-253	253-319	153-319
Total Days		13	52	28	66	166
Steady State Days	Range	160-173	193-224	228-252	270-319	200-319
N Available for Nitrif.*	Range	33.08-40.5	39.5-43.2	35.8-47.0	40.4-45.4	38.7-47.2
	Avg.	38.19	41.08	42.89	43.65	42.79
Total N Nitrified*	Range	28.54-39.8	34.4-43.2	10.2-46.0	18.0-43.7	25.0-47.2
	Avg.	36.46	40.14	30.01	32.34	38.0
Percent Nitrif.	Range	86.3-99.3	92.7-100	28.4-98.5	44.6-100	64.5-100
	Avg.	95.14	97.71	67.87	74.12	88.75
N Available for Denitr.*	Range	33.5-42.0	38.14-43.41	11.1-46.0	18.1-43.8	25.8-47.6
	Avg.	38.8	40.42	30.76	32.45	38.35
Total N Denitrified*	Range	26.7-34.7	17.9-30.12	4.63-29.5	13.8-27.2	18.9-38.3
	Avg.	31.29	23.82	18.51	21.55	31.47
Percent Denitrif.	Range	78.5-83.3	47.0-74.0	25.9-74.1	53.9-84.2	53.6-92.0
	Avg.	80.62	58.69	59.64	67.3	82.16
Eff. N Waste*	Range	5.03-5.52	4.44-5.30	3.36-10.7	5.27-7.00	4.98-8.05
	Avg.	5.27	4.81	5.44	5.97	6.44
Eff. N Sum*	Range	15.9-20.4	17.9-30.3	25.1-50.1	24.7-40.7	16.7-37.1
	Avg.	17.77	25.31	35.18	32.36	22.31
Eff. TKN*	Range	2.14-7.54	2.14-5.40	2.14-29.7	2.65-28.7	1.35-18.7
	Avg.	4.22	3.22	15.42	14.64	6.87
Eff. NH_3*	Range	0.0-4.28	0.0-2.53	0.0-25.2	0.0-22.4	0.0-14.2
	Avg.	1.44	0.68	12.09	10.98	3.91
Eff. NO_2*	Range	1.06-1.54	0.0-2.48	.14-9.18	0.0-6.84	0.0-8.26
	Avg.	1.19	1.05	3.19	1.31	3.24
Eff. NO_3*	Range	6.36-8.68	10.4-19.8	3.75-21.3	2.85-17.8	.72-16.9
	Avg.	7.09	16.23	11.14	10.44	5.75
Anx. NO_2*	Range	0.0-1.06	0.0-0.62	0.0-1.86	0.0-7.15	0.0-1.53
	Avg.	0.52	0.14	.43	3.37	0.28
Anx. NO_3*	Range	.05-.09	0.19-11.0	.12-6.19	0.0-1.17	.01-1.19
	Avg.	.07	6.29	2.35	0.29	0.16
NO_x in Anx.*	Range	5.84-7.55	7.84-15.85	3.63-19.45	2.14-15.53	2.54-13.0
	Avg.	6.44	12.71	9.97	8.45	5.84
NO_x out Anx.*	Range	0.07-0.73	0.19-11.01	0.12-6.19	0.17-5.37	0.01-1.57
	Avg.	0.38	6.38	2.61	2.31	0.33
%DeN in Anx.	Range	87.5-99.1	25.4-97.6	53.2-99.1	4.70-96.9	75.7-99.9
	Avg.	93.8	56.34	73.39	71.37	93.56

*** All values mg/l.**

Eff. N Waste is the amount of influent nitrogen used for biomass growth.

Table B-11. Nitrification and Denitrification in System #1

DATE	day	#1N$_a$N mg/l	#1TNN mg/l	#1%N	#1N$_a$DeN mg/l	#1TNDeN mg/l	#1%DeN
11/24/89	7	48.60	43.97	90.5	44.78	34.34	76.7
11/27/89	10	49.37	49.14	99.5	49.95	39.18	78.4
11/30/89	13	47.54	47.54	100	48.35	37.91	78.4
12/04/89	17	45.94	45.94	100	46.75	36.31	77.7
12/07/89	20	45.71	43.18	94.5	43.99	32.69	74.3
12/11/89	24	46.76	46.76	100	47.57	35.86	75.4
12/13/89	26	49.07	49.07	100	49.88	37.32	74.8
12/14/89	27	48.81	48.81	100	49.62	37.73	76.0
12/16/89	29	49.65	49.65	100	50.46	39.43	78.1
12/19/89	32	50.00	50.00	100	50.81	41.57	81.8
12/22/89	35	49.98	47.62	95.3	48.43	40.96	84.6
12/24/89	37	49.60	49.43	99.7	50.24	41.09	81.8
12/26/89	39	49.22	49.22	100	50.03	39.76	79.5
12/29/89	42	49.43	49.43	100	50.24	40.53	80.7
1/02/90	46	50.19	49.96	99.5	50.77	40.91	80.6
1/05/90	49	49.59	49.37	99.6	50.18	42.23	84.2
1/09/90	53	37.69	37.57	99.7	41.92	32.28	77.0
1/12/90	56	36.26	36.26	100	42.83	33.52	78.3
1/15/90	59	43.12	41.77	96.9	43.84	34.20	78.0
1/18/90	62	35.70	35.70	100	37.53	28.94	77.1
1/21/90	65	37.83	37.83	100	39.41	30.54	77.5
1/24/90	68	46.72	46.72	100	48.61	38.40	79.0
1/27/90	71	40.01	39.98	99.9	46.83	28.79	61.5
1/30/90	74	40.20	40.20	100	40.51	29.32	72.4
2/02/90	77	39.06	39.06	100	39.72	29.05	73.1
2/05/90	80	41.58	41.58	100	42.46	33.93	79.9
2/08/90	83	39.55	39.55	100	39.97	31.17	78.0
2/11/90	86	36.04	35.99	99.9	42.65	33.95	79.6
2/14/90	89	42.26	42.13	99.7	42.21	29.55	70.0
2/17/90	92	41.34	39.21	94.8	40.62	32.30	79.5
2/20/90	95	42.93	42.85	99.8	43.79	33.64	76.8
2/23/90	98	42.03	42.03	100	42.04	29.79	70.9
2/26/90	101	41.97	32.79	78.1	32.80	27.18	82.9
3/01/90	104	41.31	26.77	64.8	27.27	21.42	78.5
3/04/90	107	40.92	25.84	63.1	26.08	22.27	85.4
3/07/90	110	38.15	17.52	45.9	17.70	14.38	81.2
3/10/90	113	41.35	20.45	49.5	21.91	19.32	88.2
3/14/90	117	42.30	19.00	44.9	19.01	14.21	74.8
3/17/90	120	40.64	17.40	42.8	17.67	15.44	87.4
3/20/90	123	36.86	19.99	54.2	23.81	18.81	79.0
3/23/90	126	39.59	27.05	68.3	27.59	23.11	83.8
3/26/90	129	46.40	45.61	98.3	45.74	37.67	82.4
3/29/90	132	44.16	44.06	99.8	44.16	34.25	77.6
4/01/90	135	43.27	43.27	100	43.72	28.62	65.5
4/04/90	138	42.48	42.48	100	43.52	32.82	75.4
4/07/90	141	43.22	43.22	100	44.01	35.51	80.7
4/10/90	144	42.87	42.87	100	43.23	33.41	77.3
4/13/90	147	40.86	40.86	100	43.23	30.06	69.5
4/16/90	150	42.19	42.19	100	42.91	32.77	76.4
4/20/90	154	37.74	36.79	97.5	38.15	27.26	71.5
4/23/90	157	34.43	34.43	100	38.24	29.37	76.8
4/26/90	160	33.66	33.63	99.9	38.54	28.43	73.8
5/01/90	165	38.69	38.69	100	39.70	31.40	79.1
5/04/90	168	39.26	36.39	92.7	37.86	31.04	82.0
5/08/90	172	39.73	35.58	89.6	37.81	30.37	80.3
5/09/90	173	40.05	37.12	92.7	39.24	32.46	82.7
5/11/90	175	41.19	27.92	67.8	29.93	24.91	83.2
5/15/90	179	40.86	24.71	60.5	27.12	20.16	74.3
5/18/90	182	40.87	26.06	63.8	28.66	22.90	79.9
5/22/90	186	41.43	27.87	67.3	32.32	24.41	75.5
5/25/90	189	42.48	42.34	99.7	42.65	29.97	70.3
5/29/90	193	41.06	39.44	96.1	39.88	29.57	74.1
6/01/90	196	40.43	40.22	99.5	40.37	28.13	69.7
6/05/90	200	40.97	40.81	99.6	41.58	31.11	74.8
6/19/90	214	39.95	38.07	95.3	38.09	27.07	71.1

6/22/90	217	41.09	41.05	99.9	41.23	23.26	56.4
6/26/90	221	42.53	39.49	92.9	39.71	29.64	74.6
6/29/90	224	45.02	44.94	99.8	45.12	25.01	55.4
6/30/90	225	45.00	45.00	100	45.05	34.37	76.3
7/03/90	228	44.02	42.52	96.6	43.40	34.91	80.4
7/06/90	231	45.57	40.04	87.9	40.05	30.93	77.2
7/10/90	235	42.96	32.36	75.3	33.24	28.12	84.6
7/13/90	238	41.68	30.60	73.4	31.40	25.77	82.1
7/17/90	242	44.53	30.80	69.2	34.27	27.45	80.1
7/20/90	245	44.50	33.28	74.8	33.28	27.00	81.1
7/24/90	249	45.66	45.30	99.2	45.30	27.94	61.7
7/27/90	252	45.59	45.46	99.7	45.46	33.89	74.5
7/31/90	256	45.26	43.95	97.1	43.95	32.73	74.5
8/03/90	259	45.08	44.53	98.8	45.01	37.42	83.1
8/07/90	263	41.53	18.74	45.1	18.86	18.46	97.9
8/08/90	264	38.77	24.22	62.5	24.28	21.82	89.9
8/10/90	266	42.29	26.92	63.7	26.92	24.93	92.6
8/14/90	270	43.44	27.70	63.8	27.71	25.01	90.3
8/17/90	273	44.17	26.28	59.5	26.29	24.27	92.3
8/21/90	277	43.02	27.13	63.1	27.14	23.53	86.7
8/24/90	280	44.94	41.86	93.1	41.92	36.94	88.1
8/28/90	284	42.82	40.39	94.3	40.44	36.19	89.5
8/31/90	287	43.27	41.20	95.2	41.24	36.85	89.4
9/11/90	298	42.22	40.20	95.2	40.21	31.48	78.3
9/14/90	301	42.66	40.91	95.9	40.93	34.43	84.1
9/15/90	302	42.94	41.39	96.4	41.41	34.37	83.0
9/16/90	303	43.16	41.15	95.3	41.18	34.13	82.9
9/17/90	304	43.37	41.32	95.3	41.36	32.05	77.5
9/19/90	306	45.34	43.77	96.5	43.97	36.98	84.1
9/21/90	308	45.35	42.74	94.2	42.92	35.73	83.2
9/22/90	309	45.26	40.26	89.0	40.44	33.26	82.2
9/25/90	312	45.03	34.48	76.6	34.67	27.81	80.2
9/29/90	316	42.64	24.51	57.5	24.88	19.53	78.5
10/02/90	319	43.66	23.60	54.1	23.97	18.55	77.4

Table B-12. Effluent Nitrogen from System #1

DATE	day	#1TN$_{eff}$ mg/l	#1N$_{w}$ mg/l	#1TKN$_{eff}$ mg/l	#1NH$_{3eff}$ mg/l	#1NO$_{2eff}$ mg/l	#1NO$_{3eff}$ mg/l
11/24/89	7	26.67	8.51	7.72*	4.63	0*	10.44*
11/27/89	10	22.20	7.74	3.09*	0	0.93	10.44
11/30/89	13	20.87	7.34	3.09*	0	0*	10.44*
12/04/89	17	22.47	8.94	3.09*	0	0*	10.44*
12/07/89	20	25.94	8.51	5.30*	2.21	1.28	10.85
12/11/89	24	22.26	7.46	3.09*	0	0*	11.71*
12/13/89	26	22.84	7.19	3.09*	0	0	12.56
12/14/89	27	22.43	7.45	3.09*	0	0	11.89
12/16/89	29	20.73	6.61	3.09	0	0	11.03
12/19/89	32	18.59	6.26	3.09*	0	0	9.24
12/22/89	35	19.54	6.28	5.24*	2.15	0.86	7.16
12/24/89	37	19.34	6.66	3.09*	0	0.68	8.91
12/26/89	39	20.40	7.04	3.09*	0	0	10.27
12/29/89	42	19.63	6.83	3.09*	0	0	9.71
1/02/90	46	19.62	6.07	3.09*	0	0.93	9.53
1/05/90	49	18.29	5.68	4.08	0	0.90	7.63
1/09/90	53	18.53	5.64	2.94	0	0.47	9.48
1/12/90	56	17.73	5.19	3.23*	0	0	9.31
1/15/90	59	18.95	5.51	3.51	1.24	0.44	9.49
1/18/90	62	18.14	6.38	3.17	0	0	8.59
1/21/90	65	22.40	6.74	6.79	0	0	8.87
1/24/90	68	17.79	5.88	1.70	0	0	10.21
1/27/90	71	25.05	6.36	0.57	0	0.12	18.00
1/30/90	74	20.31	6.52	2.60	0	0	11.19
2/02/90	77	19.46	6.58	2.21	0	0	10.67
2/05/90	80	17.40	6.72	2.15	0	0	8.53
2/08/90	83	17.75	6.77	2.18	0	0	8.80
2/11/90	86	17.09	5.80	2.46	0	0.21	8.62
2/14/90	89	21.19	5.85	2.35	0	0.51	12.48
2/17/90	92	20.29	5.92	6.05	2.13	0	8.32
2/20/90	95	19.78	7.25	2.18	0	0.31	10.04
2/23/90	98	21.96	5.57	4.14	0	0	12.25
2/26/90	101	23.93	5.80	12.38	9.13	0.21	5.54
3/01/90	104	29.90	6.01	17.81	14.45	0.35	5.73
3/04/90	107	29.05	6.74	18.31	15.01	0.29	3.71
3/07/90	110	35.50	7.32	24.64	20.55	0.34	3.20
3/10/90	113	31.75	2.60	26.38	20.83	0.29	2.48
3/14/90	117	36.03	1.38	29.85	23.30	0	4.80
3/17/90	120	34.67	5.39	27.05	23.24	0	2.23
3/20/90	123	32.12	5.20	21.45	16.69	0.73	4.74
3/23/90	126	26.16	4.93	16.18	12.32	0.87	4.18
3/26/90	129	18.22	5.29	2.80	0	3.18	6.95
3/29/90	132	17.18	5.20	1.80	0	0.42	9.76
4/01/90	135	22.09	4.80	2.19	0	0	15.10
4/04/90	138	17.69	4.85	2.14	0	0	10.70
4/07/90	141	15.43	4.90	2.03	0	0	8.50
4/10/90	144	16.48	4.75	1.91	0	0	9.82
4/13/90	147	19.92	4.89	1.86	0	0	13.17
4/16/90	150	16.86	4.81	1.91	0	0	10.14
4/20/90	154	20.44	5.87	3.55	0.90	0.21	10.81
4/23/90	157	16.31	5.36	2.08	0	0	8.87
4/26/90	160	18.29	5.74	2.36	0	0.14	10.05
5/01/90	165	15.70	5.82	1.58	0	0	8.30
5/04/90	168	17.99	5.99	5.18	2.87	0	6.82
5/08/90	172	19.87	5.46	6.70	4.05	0.42	7.29
5/09/90	173	17.59	4.64	6.17*	2.93	0	6.78
5/11/90	175	25.27	2.99	17.00	13.17	0.42	4.86
5/15/90	179	29.92	3.37	19.59	16.15	0	6.96
5/18/90	182	27.12	3.09	17.95	14.69	0.49	5.59
5/22/90	186	28.05	3.37	16.77	13.56	0	7.91
5/25/90	189	19.69	3.61	3.04	0	0.55	12.49
5/29/90	193	19.44	3.74	4.84	1.41	0.85	10.01
6/01/90	196	19.35	3.80	2.76	0	0.84	11.95
6/05/90	200	16.69	3.89	1.91	0	0.64	10.25
6/19/90	214	20.82	4.71	4.73	1.74	0.55	10.83

6/22/90	217	25.21	4.83	2.31	0	0.16	17.91
6/26/90	221	20.68	4.58	5.74	2.93	0.46	9.90
6/29/90	224	26.51	3.66	2.53	0	0.32	20.00
6/30/90	225	16.62	3.66	2.28*	0	0	10.68
7/03/90	228	15.74	3.65	3.49	1.46	0.18	8.42
7/06/90	231	20.74	3.95	7.49	5.46	0.28	9.02
7/10/90	235	23.99	4.53	14.13	10.52	0.32	5.01
7/13/90	238	25.36	4.75	14.69	10.97	0.46	5.46
7/17/90	242	28.53	4.54	17.17	13.73	0	6.82
7/20/90	245	26.28	4.80	14.86	11.09	0.52	6.10
7/24/90	249	25.66	4.43	2.93	0	1.45	16.85
7/27/90	252	18.54	4.45	2.19	0	0.51	11.39
7/31/90	256	20.89	4.66	4.22	1.01	1.22	10.79
8/03/90	259	16.39	5.06	2.31	0	2.20	6.82
8/07/90	263	34.44	6.59	27.01	22.62	0.67	0.17
8/08/90	264	33.34	9.85	18.01*	13.39	4.66	0.82
8/10/90	266	30.76	6.84	19.14	14.3	4.29	0.49
8/14/90	270	30.66	5.86	18.35	14.3	5.77	0.68
8/17/90	273	31.96	5.41	21.61	16.77	4.50	0.44
8/21/90	277	33.36	6.00	18.29	13.79	8.39	0.68
8/24/90	280	22.02	6.50	2.53	0	12.32	0.67
8/28/90	284	19.92	6.70	2.65	0	9.73	0.84
8/31/90	287	18.39	5.75	2.87	0	8.27	1.50
9/11/90	298	23.72	6.97	2.76	0	8.09	5.90
9/14/90	301	20.39	6.86	2.48	0	7.01	4.04
9/15/90	302	20.09	6.53	2.48*	0	6.22	4.86
9/16/90	303	21.07	6.20	2.59*	0	8.04	4.24
9/17/90	304	23.16	5.87	2.65	0	8.20	6.44
9/19/90	306	20.05	6.10	2.87*	0	6.29	4.79
9/21/90	308	22.57	6.32	3.60	0.51	8.39	4.26
9/22/90	309	25.14	6.08	5.90*	2.70	9.21	3.95
9/25/90	312	30.07	5.96	11.76	8.44	8.46	3.89
9/29/90	316	36.59	6.55	21.89	17.05	4.31	3.84
10/02/90	319	37.72	6.49	24.14	19.42	2.58	4.51

* Estimated Value.

Table B-13. Anoxic Chamber Nitrite, Nitrate, Phosphate, & Cloride and Effluent Phosphate & Cloride from System #1

DATE	day	#1NO_{2anx} mg/l	#1NO_{3anx} mg/l	#1PO_{4anx} mg/l	#1CL_{anx} mg/l	#1$P0_{4eff}$ mg/l	#1CL_{eff} mg/l
11/27/89	10	0.06	0.50	11.9	192	10.9	199
12/07/89	20	0	0.41	11.0	195	10.9	195
12/16/89	29	0	0.20	11.4	191	10.5	193
12/19/89	32	0	0.11	12.9	200	11.5	193
12/22/89	35	0	0.32	9.8	179	10.5	193
12/24/89	37	0	0.15	12.0	192	11.5	192
12/26/89	39	0	0.05	12.2	191	12.3	195
12/29/89	42	0	0.15	11.9	214	11.3	196
1/02/90	46	0	0.22	11.3	195	11.2	194
1/05/90	49	0	0.07	10.7	177	11.0	179
1/09/90	53	0	0.10	11.1	186	10.8	181
1/12/90	56	0.11	0.32	10.4	180	10.4	183
1/15/90	59	0	0.03	10.6	177	10.1	178
1/18/90	62	0	0.21	10.6	178	10.2	183
1/21/90	65	0	0.14	10.6	185	10.0	175
1/24/90	68	0	0.06	11.2	182	10.7	179
1/27/90	71	0	0.01	10.5	172	10.6	174
1/30/90	74	0	0.02	10.1	163	9.7	168
2/02/90	77	0	0.03	11.0	161	10.2	164
2/05/90	80	0	0.02	13.5	162	12.2	165
2/08/90	83	0.29	0.48	12.8	162	12.6	163
2/11/90	86	0	0.05	11.9	161	11.3	164
2/14/90	89	0.14	0.05	12.3	160	12.0	162
2/17/90	92	0.15	0.13	11.7	199	12.0	199
2/20/90	95	0.18	0.20	10.6	198	10.6	199
2/23/90	98	0.36	0.27	11.3	158	11.3	158
2/26/90	101	0	0.10	10.5	156	10.7	158
3/01/90	104	0.31	0.06	10.7	157	10.5	158
3/04/90	107	0.30	0.07	12.9	159	12.1	161
3/07/90	110	0	0.12	13.3	160	12.1	156
3/10/90	113	0	0.03	12.7	153	12.0	154
3/14/90	117	0	0.03	12.5	198	11.8	198
3/17/90	120	0	0.04	12.0	198	11.3	198
3/20/90	123	0	0.03	10.4	154	9.8	154
3/23/90	126	0	0.02	10.8	154	10.2	154
3/26/90	129	0	0.09	10.9	154	10.3	154
3/29/90	132	0	0.08	10.7	157	10.2	155
4/01/90	135	0	0.73	8.5	165	8.0	163
4/04/90	138	0.23	0.36	8.3	163	8.5	164
4/07/90	141	0	0.07	10.1	164	10.2	163
4/10/90	144	0.51	0.38	9.7	164	9.7	165
4/13/90	147	0.73	0.72	10.2	165	9.8	164
4/16/90	150	0	0.27	9.7	161	8.8	162
4/20/90	154	0.37	0.15	9.2	144	10.3	146
4/23/90	157	0	0.03	10.8	141	9.6	142
4/26/90	160	0.48	0.07	11.8	145	9.6	147
5/01/90	165	0	0.06	12.4	153	10.0	151
5/04/90	168	0.51	0.07	10.7	167	11.3	160
5/08/90	172	0	0.05	12.5	158	10.5	159
5/11/90	175	0	0.03	10.3	160	10.0	160
5/15/90	179	0	0.07	11.0	172	9.6	166
5/18/90	182	0	0.02	9.9	166	9.7	162
5/22/90	186	0	0.08	7.0	173	6.5	168
5/25/90	189	0	0.23	9.6	170	9.4	170
5/29/90	193	0	0.09	9.7	175	9.2	171
6/01/90	196	0	0.09	9.7	173	9.0	171
6/05/90	200	0	0.03	9.3	172	8.8	167
6/19/90	214	0	0.06	9.0	155	6.8	156
6/22/90	217	0.41	0.18	9.8	157	8.6	159
6/26/90	221	0.15	0.14	7.7	172	7.1	172

6/29/90	224	0.20	0.36	9.1	173	8.5	174
7/03/90	228	0	0.23	10.6	172	10.6	172
7/06/90	231	0	0.21	9.7	172	9.6	176
7/10/90	235	0	0.27	8.0	177	5.4	177
7/13/90	238	0	0.49	12.4	179	10.4	176
7/17/90	242	0	0.04	7.6	190	6.3	191
7/20/90	245	0	0.03	9.9	192	8.8	190
7/24/90	249	0	0.13	9.9	186	8.9	181
7/27/90	252	0.51	0.04	9.3	184	8.2	184
7/31/90	256	0	0.05	11.6	188	11.2	186
8/03/90	259	1.88	0.06	10.3	185	9.4	183
8/07/90	263	2.72	0.33	10.8	203	11.5	197
8/08/90	264	2.25	0.41	10.4	198	7.4	193
8/10/90	266	1.56	0.20	10.7	203	8.4	197
8/14/90	270	1.32	0.12	13.8	205	10.2	196
8/17/90	273	0	0.07	11.1	190	6.9	165
8/21/90	277	5.34	0.38	12.4	210	9.2	205
8/24/90	280	0	0.08	11.4	205	9.2	195
8/28/90	284	1.26	0.13	12.3	189	8.8	185
8/31/90	287	0.49	0.10	12.1	183	9.0	178
9/11/90	298	2.11	0.06	10.3	186	8.2	180
9/14/90	301	0	0.06	11.7	191	7.5	180
9/15/90	302	2.07	0.03	9.4	186	7.5	181
9/16/90	303	2.69	0.01	8.7	187	7.4	183
9/17/90	304	2.75	0.19	8.6	187	6.9	182
9/19/90	306	1.74	0.05	12.5	200	9.5	192
9/21/90	308	3.18	0.03	13.0	204	10.0	197
9/22/90	309	4.80	0.04	12.5	208	9.9	202
9/25/90	312	6.70	0.13	10.0	207	9.1	205
9/29/90	316	2.34	0.19	12.4	221	8.7	214
10/02/90	319	3.39	0.22	11.4	216	8.1	210

Table B-14. Nitrification and Denitrification in System #2

DATE	day	#2N$_a$N mg/l	#2TNN mg/l	#2%N	#2N$_a$DeN mg/l	#2TNDeN mg/l	#2%DeN
11/24/89	7	45.84	45.70	99.7	46.51	34.37	73.9
11/27/89	10	47.33	47.19	99.7	48.00	35.86	74.7
11/30/89	13	48.03	48.03	100	48.84	36.24	74.2
12/04/89	17	47.02	47.02	100	47.83	34.57	72.3
12/07/89	20	45.48	45.48	100	46.29	32.36	69.9
12/11/89	24	46.57	46.57	100	47.38	33.50	70.7
12/13/89	26	49.07	49.07	100	49.88	36.05	72.3
12/14/89	27	49.02	49.02	100	49.83	36.95	74.2
12/16/89	29	49.93	49.93	100	50.74	38.19	75.3
12/19/89	32	50.89	50.89	100	51.70	37.24	72.0
12/22/89	35	50.26	45.29	90.1	46.10	35.75	77.5
12/24/89	37	44.19	35.48	80.3	36.29	30.88	85.1
12/26/89	39	44.02	28.37	64.4	29.18	21.65	74.2
12/29/89	42	45.02	28.21	62.7	29.02	20.41	70.3
1/02/90	46	39.86	16.32	40.9	17.13	11.22	65.5
1/05/90	49	46.03	17.79	38.6	18.60	14.23	76.5
1/09/90	53	31.06	4.82	15.5	9.17	2.76	30.1
1/12/90	56	28.51	3.55	12.5	10.12	5.50	54.3
1/15/90	59	36.64	9.06	24.7	11.13	9.92	89.1
1/18/90	62	32.24	14.44	44.8	16.27	13.35	82.1
1/21/90	65	36.68	24.21	66.0	25.79	22.80	88.4
1/24/90	68	40.66	37.14	91.3	39.03	34.66	88.8
1/27/90	71	40.14	37.24	92.8	44.09	39.04	88.5
1/30/90	74	39.88	36.37	91.2	36.68	30.41	82.9
2/02/90	77	42.44	40.28	94.9	40.94	35.85	87.6
2/05/90	80	43.46	42.11	96.9	42.99	38.24	89.0
2/08/90	83	39.81	38.75	97.3	39.17	32.65	83.4
2/11/90	86	38.86	37.92	97.6	44.58	38.28	85.9
2/14/90	89	41.98	41.74	99.4	41.82	32.17	76.9
2/17/90	92	39.69	39.69	100	41.10	31.25	76.0
2/20/90	95	42.54	42.44	99.8	43.38	32.19	74.2
2/23/90	98	42.79	42.79	100	42.80	30.24	70.7
2/26/90	101	42.26	42.17	99.8	42.18	31.03	73.6
3/01/90	104	41.50	41.33	99.6	41.83	28.60	68.4
3/04/90	107	41.29	27.52	66.7	27.76	23.91	86.1
3/07/90	110	38.17	15.52	40.7	15.70	11.91	75.9
3/10/90	113	35.74	17.74	49.6	19.20	11.45	59.6
3/14/90	117	38.77	16.84	43.4	16.85	8.72	51.8
3/17/90	120	41.69	21.53	51.6	21.80	19.53	89.6
3/20/90	123	38.44	19.33	50.3	23.15	19.85	85.7
3/23/90	126	39.43	27.81	70.5	28.35	22.20	78.3
3/26/90	129	48.49	41.68	86.0	41.81	35.16	84.1
3/29/90	132	44.19	44.08	99.8	44.18	35.83	81.1
4/01/90	135	42.97	42.40	98.7	42.85	34.37	80.2
4/04/90	138	42.39	41.61	98.2	42.65	27.43	64.3
4/07/90	141	43.52	43.51	100	44.30	36.56	82.5
4/10/90	144	42.31	42.31	100	42.67	30.53	71.5
4/13/90	147	40.07	39.61	98.9	41.98	25.45	60.6
4/16/90	150	41.68	37.77	90.6	38.49	25.43	66.1
4/20/90	154	37.75	30.31	80.3	31.67	23.73	74.9
4/23/90	157	34.08	27.39	80.4	31.20	25.36	81.3
4/26/90	160	33.08	28.54	86.3	33.45	26.71	79.9
5/01/90	165	38.69	38.41	99.3	39.42	31.62	80.2
5/04/90	168	39.23	36.01	91.8	37.48	30.48	81.3
5/08/90	172	40.05	39.78	99.3	42.01	32.95	78.4
5/09/90	173	39.92	39.54	99.0	41.66	34.70	83.3
5/11/90	175	39.78	34.93	87.8	36.94	28.74	77.8
5/15/90	179	40.12	40.12	100	42.53	30.85	72.5
5/18/90	182	40.12	38.85	96.8	41.45	31.38	75.7
5/22/90	186	40.47	40.47	100	44.92	32.33	72.0
5/25/90	189	41.74	41.18	98.7	41.49	26.78	64.5

5/29/90	193	40.59	39.97	98.5	40.41	21.14	52.3
6/01/90	196	39.47	38.92	98.6	39.07	18.54	47.5
6/05/90	200	40.30	37.37	92.7	38.14	17.92	47.0
6/19/90	214	40.21	40.21	100	40.23	29.79	74.0
6/22/90	217	40.62	40.58	99.9	40.76	26.35	64.6
6/26/90	221	43.19	43.19	100	43.41	30.12	69.4
6/29/90	224	43.20	40.73	94.3	40.91	22.89	56.0
6/30/90	225	43.22	43.18	99.9	43.23	23.07	53.4
7/03/90	228	42.28	29.98	70.9	30.86	22.66	73.4
7/06/90	231	44.09	21.82	49.5	21.83	16.17	74.1
7/10/90	235	35.83	10.17	28.4	11.05	4.63	41.9
7/13/90	238	37.36	14.85	39.7	15.65	11.41	72.9
7/17/90	242	44.11	28.04	63.6	31.51	8.17	25.9
7/20/90	245	46.28	43.71	94.4	43.71	29.05	66.5
7/24/90	249	47.00	46.03	97.9	46.03	29.47	64.0
7/27/90	252	46.18	45.50	98.5	45.50	26.54	58.3
7/31/90	256	46.23	45.58	98.6	45.58	32.40	71.1
8/03/90	259	44.45	43.40	97.6	43.88	27.06	61.7
8/07/90	263	44.68	44.03	98.5	44.15	31.43	71.2
8/10/90	266	44.98	44.29	98.5	44.29	33.64	76.0
8/14/90	270	43.55	33.65	77.3	33.66	26.61	79.1
8/17/90	273	43.76	25.81	59.0	25.82	21.59	83.6
8/21/90	277	40.44	18.04	44.6	18.05	15.20	84.2
8/24/90	280	44.13	34.51	78.2	34.57	26.18	75.7
8/28/90	284	43.76	42.29	96.6	42.34	22.83	53.9
8/31/90	287	43.14	41.43	96.0	41.47	24.68	59.5
9/11/90	298	43.74	43.74	100	43.75	27.22	62.2
9/14/90	301	43.10	38.15	88.5	38.17	24.50	64.2
9/15/90	302	43.33	39.28	90.7	39.30	25.77	65.6
9/16/90	303	42.76	36.57	85.5	36.60	23.69	64.7
9/17/90	304	42.51	34.63	81.5	34.67	21.42	61.8
9/19/90	306	44.89	31.16	69.4	31.36	22.71	72.4
9/21/90	308	45.39	29.46	64.9	29.64	20.32	68.6
9/22/90	309	65.63	48.41	73.8	48.59	37.93	78.1
9/25/90	312	43.78	22.79	52.1	22.98	13.80	60.1
9/29/90	316	44.22	25.11	56.8	25.48	14.94	58.6
10/02/90	319	45.08	25.96	57.6	26.33	18.10	68.7

Table B-15. Effluent Nitrogen from System #2

DATE	day	#2TN$_{eff}$ mg/l	#2N$_{w}$ mg/l	#2TKN$_{eff}$ mg/l	#2NH$_{3eff}$ mg/l	#2NO$_{2eff}$ mg/l	#2NO$_{3eff}$ mg/l
11/24/89	7	26.87	11.05	3.31*	0	0.57*	11.94*
11/27/89	10	25.38	9.56	3.31*	0	0.57	11.94
11/30/89	13	22.54	6.63	3.31*	0	0*	12.60*
12/04/89	17	24.21	7.64	3.31*	0	0*	13.26*
12/07/89	20	25.76	8.52	3.31*	0	0	13.93
12/11/89	24	24.62	7.43	3.31*	0	0*	13.88*
12/13/89	26	24.11	6.97	3.31*	0	0	13.83
12/14/89	27	23.21	7.02	3.31*	0	0	12.88
12/16/89	29	21.97	6.11	3.31	0	0	12.55
12/19/89	32	22.92	5.15	3.31*	0	0	14.46
12/22/89	35	26.21	5.78	7.16*	3.85	4.50	8.77
12/24/89	37	30.87	5.95	16.93*	7.72	3.98	4.01
12/26/89	39	41.31	6.12	23.11*	13.90	7.00	5.08
12/29/89	42	43.70	5.12	23.55*	14.34	9.88	5.15
1/02/90	46	52.89	10.28	30.28*	21.07	9.87	2.46
1/05/90	49	49.02	4.11	35.52	26.31	7.73	1.66
1/09/90	53	51.48	3.56	35.63	23.98	9.06	3.23
1/12/90	56	48.41	4.74	34.73	23.30	6.64	2.30
1/15/90	59	44.11	1.93	39.25	26.92	2.65	0.28
1/18/90	62	36.33	2.38	26.81	16.18	6.50	0.64
1/21/90	65	33.26	2.12	23.08	10.52	7.79	0.27
1/24/90	68	26.07	1.88	12.44	0.68	11.36	0.39
1/27/90	71	19.39	2.61	4.19	0	11.59	1.00
1/30/90	74	24.84	7.06	2.38	0	14.05	1.35
2/02/90	77	16.12	2.98	2.43	0	8.64	2.07
2/05/90	80	15.25	4.16	2.83	0	5.40	2.86
2/08/90	83	17.97	5.89	2.80	0	4.26	5.02
2/11/90	86	14.19	3.09	2.35	0	3.78	4.97
2/14/90	89	18.76	6.24	2.24	0	0.97	9.31
2/17/90	92	21.34	7.79	3.70	0	0	9.85
2/20/90	95	21.27	7.52	2.30	0	0.41	11.04
2/23/90	98	21.51	6.43	2.52	0	0	12.56
2/26/90	101	20.15	6.02	2.74	0	0.38	11.01
3/01/90	104	22.86	5.32	3.86	0	0.69	12.99
3/04/90	107	27.47	5.86	17.47	13.66	0.45	3.69
3/07/90	110	38.14	6.13	27.72	22.46	0.77	3.52
3/10/90	113	39.81	5.25	26.32	17.81	0.76	7.48
3/14/90	117	42.66	5.02	27.66	21.22	2.86	7.12
3/17/90	120	30.58	3.67	24.64	20.16	0	2.27
3/20/90	123	31.08	4.18	23.13	18.93	0.73	3.04
3/23/90	126	27.22	4.47	15.79	11.31	1.24	5.72
3/26/90	129	20.33	4.77	7.50	6.27	2.18	5.88
3/29/90	132	15.61	4.89	2.08	0	0.44	8.20
4/01/90	135	17.26	4.81	2.48	0	2.30	7.67
4/04/90	138	24.33	4.94	2.14	0	3.13	14.12
4/07/90	141	14.4	4.94	1.69	0	0.05	7.72
4/10/90	144	19.36	5.08	2.14	0	0	12.14
4/13/90	147	24.73	4.95	2.93	0.34	0.49	16.36
4/16/90	150	24.42	4.75	6.25	3.77	0.56	12.86
4/20/90	154	24.08	5.92	9.91	7.32	0.47	7.78
4/23/90	157	20.51	5.37	9.00	6.58	0.46	5.68
4/26/90	160	20.38	5.42	7.54	4.28	1.06	6.36
5/01/90	165	15.93	5.26	2.14	0	1.12	7.41
5/04/90	168	19.02	5.52	5.74	2.93	1.17	6.59
5/08/90	172	17.55	5.03	2.76	0	1.08	8.68
5/09/90	173	15.97	5.11	2.90*	0	1.54	6.42
5/11/90	175	21.74	5.19	7.60	4.56	1.16	7.79
5/15/90	179	19.23	5.19	2.36	0	0	11.68
5/18/90	182	18.95	4.74	3.32	0.96	1.26	9.63
5/22/90	186	20.13	4.84	2.70	0	0	12.59
5/25/90	189	23.56	4.97	2.42	0	2.26	13.91

5/29/90	193	28.52	4.66	2.98	0	2.48	18.40
6/01/90	196	29.48	4.59	2.93	0	2.19	19.77
6/05/90	200	30.26	4.44	4.56	2.53	1.61	19.65
6/19/90	214	17.88	5.30	2.14	0	0	10.44
6/22/90	217	22.13	5.30	2.31	0	0.18	14.34
6/26/90	221	20.02	4.54	2.19	0	0	13.29
6/29/90	224	28.86	4.86	5.40	2.25	0.90	17.70
6/30/90	225	27.98	4.93	2.79*	0	0.15	20.11
7/03/90	228	27.97	5.00	14.69	12.27	0.14	8.14
7/06/90	231	35.55	4.64	24.99	22.17	0.40	5.52
7/10/90	235	48.15	10.71	29.72	25.16	2.01	5.71
7/13/90	238	40.09	7.38	27.58	22.17	1.38	3.75
7/17/90	242	50.12	4.85	18.18	14.63	5.77	21.32
7/20/90	245	27.69	3.36	3.71	0.28	9.18	11.44
7/24/90	249	25.11	3.66	2.36	0	3.90	15.19
7/27/90	252	26.78	3.91	2.14	0	2.72	18.01
7/31/90	256	21.51	4.42	2.65	0.17	1.94	12.50
8/03/90	259	27.55	5.41	2.59	0	4.19	15.36
8/07/90	263	22.24	5.75	2.08	0	2.60	11.81
8/10/90	266	20.98	6.40	2.87	0.28	1.63	10.08
8/14/90	270	27.10	6.65	12.83	9.68	0.87	6.75
8/17/90	273	32.84	7.00	21.61	17.95	0	4.23
8/21/90	277	38.33	6.78	28.70	22.4	0	2.85
8/24/90	280	29.47	6.63	11.82	8.61	4.04	6.98
8/28/90	284	31.29	5.59	3.10	0.28	4.76	17.84
8/31/90	287	29.99	6.10	2.65	0	6.84	14.40
9/11/90	298	24.74	5.56	2.65	0	0	16.53
9/14/90	301	27.52	5.86	7.99	4.95	0	13.67
9/15/90	302	26.20	5.67	7.00*	4.05	0	13.53
9/16/90	303	28.29	5.47	9.91*	6.19	0	12.91
9/17/90	304	30.51	5.27	11.99	7.88	0	13.25
9/19/90	306	31.80	5.75	17.40*	13.73	0	8.65
9/21/90	308	34.62	6.22	19.08	15.93	0	9.32
9/22/90	309	16.79	6.13	21.13*	17.22	0	10.66
9/25/90	312	40.70	5.86	25.66	20.99	0	9.18
9/29/90	316	39.96	5.48	23.13	18.80	1.25	10.10
10/02/90	319	38.92	5.51	22.29	18.01	4.46	6.66

* Estimated Value.

Table B-16. Anoxic Chamber Nitrite, Nitrate, Phosphate, & Cloride and Effluent Phosphate & Cloride from System #2

DATE	day	#2NO$_{2anx}$ mg/l	#2NO$_{3anx}$ mg/l	#2PO$_{4anx}$ mg/l	#2CL$_{anx}$ mg/l	#2P0$_{4eff}$ mg/l	#2CL$_{eff}$ mg/l
11/27/89	10	0	0.07	10.9	193	10.8	197
12/07/89	20	0	0.53	11.2	203	11.3	196
12/16/89	29	0	0.35	10.6	189	10.1	196
12/19/89	32	0.64	0.83	11.6	191	11.3	195
12/22/89	35	2.27	3.17	9.5	191	9.6	197
12/24/89	37	1.18	1.18	10.3	187	10.2	193
12/26/89	39	4.28	2.38	10.9	190	11.1	194
12/29/89	42	5.76	3.03	10.6	215	10.3	208
1/02/90	46	7.12	1.61	10.2	194	9.5	197
1/05/90	49	5.8	1.31	9.9	199	9.3	197
1/09/90	53	7.65	3.25	10.6	187	8.2	197
1/12/90	56	5.18	2.04	9.5	179	9.0	182
1/15/90	59	0.85	0.13	9.3	177	8.8	178
1/18/90	62	3.83	0.57	9.2	174	9.2	180
1/21/90	65	2.73	0.11	8.9	183	8.7	183
1/24/90	68	4.22	0.15	9.9	176	9.4	177
1/27/90	71	3.63	0.34	9.8	177	9.9	172
1/30/90	74	5.07	0.23	9.3	181	9.8	168
2/02/90	77	2.39	0.28	10.3	161	9.4	163
2/05/90	80	0	0.08	12.1	165	11.2	161
2/08/90	83	0.75	0.45	11.0	159	11.4	163
2/11/90	86	0.29	0.07	11.7	161	10.9	163
2/14/90	89	0.48	0.12	12.0	159	11.0	163
2/17/90	92	0	0.08	11.1	199	11.4	199
2/20/90	95	0	0.10	10.0	198	10.7	199
2/23/90	98	0.29	0.17	11.0	158	11.0	159
2/26/90	101	0	0.29	10.4	158	10.5	157
3/01/90	104	0.29	0.63	10.6	157	10.9	157
3/04/90	107	0.36	0.28	12.3	157	12.2	160
3/07/90	110	0	0.25	13.2	158	11.8	155
3/10/90	113	0	0.03	12.8	155	11.8	154
3/14/90	117	0	0.17	12.6	198	11.9	199
3/17/90	120	0	0.05	11.4	198	10.8	198
3/20/90	123	0	0.04	9.9	154	9.5	153
3/23/90	126	0	0.04	10.2	153	9.9	153
3/26/90	129	0	0.05	10.3	152	10.3	153
3/29/90	132	0	0.08	10.4	158	10.1	155
4/01/90	135	0.21	0.07	8.7	163	8.4	163
4/04/90	138	0.49	0.75	8.4	166	8.5	164
4/07/90	141	0	0.36	10.3	162	10.5	163
4/10/90	144	0.92	2.02	10.0	168	10.0	167
4/13/90	147	1.38	2.94	9.8	163	9.7	164
4/16/90	150	0.22	4.77	9.8	164	9.0	163
4/20/90	154	0.44	1.26	8.5	143	9.3	146
4/23/90	157	0.39	0.09	11.0	141	10.1	141
4/26/90	160	0.86	0.06	11.5	148	9.3	149
5/01/90	165	0.70	0.05	12.2	150	10.0	151
5/04/90	168	1.06	0.09	10.8	173	11.5	163
5/08/90	172	0	0.07	14.7	160	10.6	160
5/11/90	175	0	0.07	10.7	161	9.9	159
5/15/90	179	1.03	0.56	10.9	160	9.6	157
5/18/90	182	1.00	0.16	9.7	165	9.8	155
5/22/90	186	0	2.45	8.7	166	8.9	165
5/25/90	189	0	3.90	9.4	169	9.1	170
5/29/90	193	0	9.81	8.9	173	8.7	169
6/01/90	196	0	11.01	9.1	172	8.6	170
6/05/90	200	0	10.9	9.1	173	8.4	170
6/19/90	214	0	0.19	9.7	158	10.0	159
6/22/90	217	0.11	0.65	9.2	162	9.3	158
6/26/90	221	0.62	1.39	9.8	172	8.3	170

6/29/90	224	0.28	10.07	10.5	170	8.4	173
7/03/90	228	0.22	1.65	11.5	173	10.4	175
7/06/90	231	0.32	1.10	12.1	184	10.3	180
7/10/90	235	0.65	1.41	8.4	184	7.2	184
7/13/90	238	0.37	0.40	12.2	189	11.0	179
7/17/90	242	1.86	1.80	10.2	191	8.8	181
7/20/90	245	0	0.12	8.8	189	8.1	184
7/24/90	249	0	6.15	8.4	183	6.7	182
7/27/90	252	0	6.19	7.8	185	6.4	182
7/31/90	256	1.19	0.67	10.2	186	9.5	181
8/03/90	259	3.68	12.01	6.3	189	8.4	182
8/07/90	263	0	0.24	9.8	191	8.3	185
8/10/90	266	0	0.15	8.9	195	7.6	188
8/14/90	270	0	0.17	10.9	200	8.9	192
8/17/90	273	0	0.19	9.5	191	7.7	186
8/21/90	277	2.11	0.77	10.4	215	8.7	210
8/24/90	280	1.42	0.72	10.2	209	9.4	199
8/28/90	284	7.15	1.08	12.6	188	9.3	183
8/31/90	287	6.27	1.17	11.3	181	9.6	176
9/11/90	298	4.84	0.23	9.2	187	7.9	181
9/14/90	301	2.31	0.05	9.4	187	8.2	184
9/15/90	302	4.55	0.03	8.4	191	7.6	184
9/16/90	303	5.27	0.09	8.1	194	7.2	197
9/17/90	304	3.74	0.03	7.3	194	6.6	190
9/19/90	306	1.45	0	11.7	211	9.9	201
9/21/90	308	3.45	0.03	11.2	211	10.1	207
9/22/90	309	4.54	0.21	10.3	219	9.9	208
9/25/90	312	4.58	0.04	9.8	220	9.6	217
9/29/90	316	1.54	0.07	10.9	230	9.7	216
10/02/90	319	4.13	0.04	11.4	221	9.6	209

Table B-17. Nitrification and Denitrification in System #3

DATE	day	#3N$_a$N mg/l	#3TNN mg/l	#3%N	#3N$_a$DeN mg/l	#3TNDeN mg/l	#3%DeN
4/23/90	157	36.76	18.68	50.8	22.49	20.64	91.8
4/26/90	160	32.78	20.90	63.8	25.81	20.77	80.5
5/01/90	165	37.81	27.34	72.3	28.35	23.02	81.2
5/04/90	168	37.72	27.08	71.8	28.55	17.45	61.1
5/08/90	172	39.33	26.52	67.4	28.75	22.85	79.5
5/11/90	175	36.46	23.52	64.5	25.53	19.71	77.2
5/15/90	179	37.84	23.82	62.9	26.23	20.25	77.2
5/18/90	182	38.10	27.65	72.6	30.25	21.06	69.6
5/22/90	186	38.94	28.87	74.1	33.32	26.56	79.7
5/25/90	189	40.60	33.18	81.7	33.49	30.11	89.9
5/29/90	193	39.96	37.74	94.4	38.18	34.40	90.1
6/01/90	196	38.76	36.37	93.8	36.52	32.35	88.6
6/05/90	200	39.17	37.11	94.7	37.88	34.14	90.1
6/19/90	214	39.43	36.92	93.6	36.94	19.82	53.7
6/22/90	217	39.01	30.88	79.2	31.06	24.89	80.1
6/26/90	221	40.78	34.54	84.7	34.76	28.05	80.7
6/29/90	224	42.54	38.60	90.7	38.78	30.72	79.2
6/30/90	225	48.38	44.47	91.9	44.52	36.11	81.1
7/03/90	228	41.82	30.54	73.0	31.42	28.64	91.2
7/06/90	231	43.37	35.29	81.4	35.30	28.11	79.6
7/10/90	235	39.97	30.03	75.1	30.91	26.38	85.3
7/13/90	238	38.74	25.00	64.5	25.80	21.77	84.4
7/17/90	242	40.94	26.70	65.2	30.17	18.90	62.6
7/20/90	245	42.33	28.46	67.2	28.46	25.23	88.7
7/24/90	249	43.01	32.36	75.2	32.36	29.25	90.4
7/27/90	252	41.64	32.77	78.7	32.77	29.47	89.9
7/31/90	256	44.40	38.11	85.8	38.11	35.06	92.0
8/03/90	259	42.43	37.82	89.1	38.30	35.00	91.4
8/07/90	263	42.42	38.32	90.3	38.44	35.21	91.6
8/10/90	266	44.59	42.63	95.6	42.63	38.28	89.8
8/14/90	270	43.50	41.68	95.8	41.69	36.76	88.2
8/17/90	273	43.43	39.98	92.1	39.99	35.20	88.0
8/21/90	277	42.66	40.60	95.2	40.61	34.13	84.0
8/24/90	280	44.15	42.29	95.8	42.35	37.32	88.1
8/28/90	284	43.20	42.21	97.7	42.26	34.63	81.9
8/31/90	287	42.35	42.06	99.3	42.10	33.38	79.3
9/11/90	298	43.01	42.74	99.4	42.75	32.44	75.9
9/14/90	301	42.20	41.74	98.9	41.76	32.49	77.8
9/15/90	302	42.69	42.35	99.2	42.37	32.12	75.8
9/16/90	303	42.97	41.75	97.2	41.78	33.17	79.4
9/17/90	304	43.45	43.10	99.2	43.14	32.94	76.4
9/19/90	306	45.58	44.71	98.1	44.91	35.83	79.8
9/21/90	308	45.76	39.41	86.1	39.59	32.79	82.8
9/22/90	309	45.72	43.78	95.8	43.96	35.79	81.4
9/25/90	312	45.90	41.88	91.2	42.07	32.49	77.2
9/29/90	316	44.29	38.47	86.9	38.84	29.24	75.3
10/02/90	319	47.22	47.22	100	47.59	36.31	76.3

Table B-18. Effluent Nitrogen from System #3

DATE	day	#3TN$_{eff}$ mg/l	#3N$_w$ mg/l	#3TKN$_{eff}$ mg/l	#3NH$_{3eff}$ mg/l	#3NO$_{2eff}$ mg/l	#3NO$_{3eff}$ mg/l
4/23/90	157	25.16	1.40	21.72	18.01	0.30	1.74
4/26/90	160	25.99	5.21	15.59	11.82	0.24	4.95
5/01/90	165	24.46	6.03	12.49	10.24	0.94	5.00
5/04/90	168	32.49	6.63	13.28	10.07	2.28	10.30
5/08/90	172	28.36	6.15	14.46	12.10	2.85	4.90
5/11/90	175	31.55	6.32	17.39	12.16	3.12	4.72
5/15/90	179	32.01	6.56	15.93	12.66	5.44	4.08
5/18/90	182	30.98	5.85	12.33	9.06	5.55	7.25
5/22/90	186	25.90	6.20	12.94	10.07	0	6.76
5/25/90	189	22.29	6.11	7.99	5.57	7.40	0.79
5/29/90	193	17.83	6.08	2.19	0	8.90	0.66
6/01/90	196	18.61	6.26	1.97	0	9.55	0.83
6/05/90	200	16.70	6.25	1.35	0	8.26	0.84
6/19/90	214	28.17	5.80	4.73	2.31	0.79	16.85
6/22/90	217	23.75	6.07	11.14	7.99	0.57	5.97
6/26/90	221	22.80	5.88	9.06	5.8	1.78	6.08
6/29/90	224	21.67	5.80	6.19	3.32	2.49	7.19
6/30/90	225	15.83	5.88	5.72*	3.32	2.37	7.58
7/03/90	228	22.44	5.96	12.89	10.97	1.25	2.34
7/06/90	231	24.49	6.32	9.29	7.43	2.61	6.27
7/10/90	235	26.19	7.08	13.62	9.57	1.47	4.02
7/13/90	238	29.64	7.30	17.56	13.45	1.16	3.62
7/17/90	242	37.08	7.07	18.74	14.24	0	11.27
7/20/90	245	29.34	6.74	16.94	12.94	3.74	1.92
7/24/90	249	25.60	6.74	12.78	9.51	4.58	1.50
7/27/90	252	25.16	6.59	11.37	7.37	6.00	1.20
7/31/90	256	20.57	6.54	6.92	4.73	6.26	0.85
8/03/90	259	20.89	7.32	5.46	2.76	7.39	0.72
8/07/90	263	20.29	7.11	5.29	2.31	7.17	0.72
8/10/90	266	18.83	7.35	2.03	0	7.84	1.61
8/14/90	270	19.52	8.05	1.80	0	7.29	2.38
8/17/90	273	21.77	7.90	4.95	1.86	6.35	2.57
8/21/90	277	21.26	7.99	3.77	0.90	4.65	4.85
8/24/90	280	19.69	7.74	2.08	0	7.44	2.43
8/28/90	284	19.18	6.66	2.31	0	3.97	6.24
8/31/90	287	19.02	7.35	2.19	0	1.18	8.30
9/11/90	298	19.95	6.01	2.93	0	1.07	9.94
9/14/90	301	20.27	6.25	3.55	0	1.86	8.61
9/15/90	302	20.39	5.96	3.30*	0	1.35	9.78
9/16/90	303	19.50	5.68	4.09*	0.79	1.72	8.01
9/17/90	304	19.55	5.40	3.04	0	1.39	9.72
9/19/90	306	19.08	5.43	3.92*	0.62	1.00	8.73
9/21/90	308	22.41	5.45	9.74	6.19	0.66	6.56
9/22/90	309	19.33	5.33	5.18*	1.69	0.99	7.83
9/25/90	312	22.41	4.98	7.20	3.77	1.01	9.22
9/29/90	316	25.84	5.23	9.91	5.40	1.70	9.00
10/02/90	319	18.93	5.40	2.25	0	0	11.28

* Estimated Value.

Table B-19. Anoxic Chamber Nitrite, Nitrate, Phosphate, & Cloride and Effluent Phosphate & Cloride from System #3

DATE	day	#3NO$_{2anx}$ mg/l	#3NO$_{3anx}$ mg/l	#3PO$_{4anx}$ mg/l	#3CL$_{anx}$ mg/l	#3P0$_{4eff}$ mg/l	#3CL$_{eff}$ mg/l
4/23/90	157	0	0.04	11.3	141	8.9	144
4/26/90	160	0	0.11	13.3	150	8.0	148
5/01/90	165	0	0.05	13.0	154	9.2	151
5/04/90	168	0	0.03	13.1	183	11.1	172
5/08/90	172	0	0.05	13.9	163	10.3	159
5/11/90	175	0	0.01	13.1	168	10.7	163
5/15/90	179	0	0.05	12.6	171	9.8	163
5/18/90	182	0	0	12.5	169	10.1	159
5/22/90	186	0	0.01	8.5	179	6.9	171
5/25/90	189	0	0.01	11.5	173	9.0	172
5/29/90	193	0	0.02	9.9	177	8.4	169
6/01/90	196	0	0.01	10.1	173	9.0	170
6/05/90	200	0	0.01	9.7	172	9.0	169
6/19/90	214	0.32	0.10	9.4	158	7.6	156
6/22/90	217	0.90	0.15	9.7	158	9.7	158
6/26/90	221	0.22	0.19	7.9	171	6.6	172
6/29/90	224	0.63	1.19	10.0	173	8.3	174
7/03/90	228	0.18	0.16	11.8	173	9.7	173
7/06/90	231	0	0.11	12.3	178	9.2	174
7/10/90	235	0	0.20	11.4	183	6.5	174
7/13/90	238	0	0.06	14.0	182	9.0	176
7/17/90	242	0	0.11	8.1	198	6.2	191
7/20/90	245	0	0.03	12.9	204	7.6	192
7/24/90	249	0	0.02	9.8	184	7.7	184
7/27/90	252	0.46	0.07	7.6	185	6.8	185
7/31/90	256	0	0.02	16.1	189	10.1	183
8/03/90	259	1.53	0.05	12.5	186	9.8	182
8/07/90	263	1.14	0.04	5.2	188	4.8	185
8/10/90	266	1.13	0.14	11.2	190	9.6	185
8/14/90	270	1.00	0.16	13.4	188	11.5	186
8/17/90	273	0	0.12	6.6	183	5.5	175
8/21/90	277	0.88	0.55	11.9	196	10.8	190
8/24/90	280	0	0.38	11.8	199	11.0	189
8/28/90	284	0	0.07	12.9	182	9.2	180
8/31/90	287	0	0.06	13.7	176	12.0	172
9/11/90	298	0	0.08	12.0	184	9.8	174
9/14/90	301	0	0.08	9.6	182	9.0	175
9/15/90	302	0	0.10	9.6	189	8.7	176
9/16/90	303	0	0.07	9.0	189	8.8	180
9/17/90	304	0	0.02	8.3	187	8.4	177
9/19/90	306	0	0.01	12.1	206	10.7	192
9/21/90	308	0	0.03	13.1	206	11.8	200
9/22/90	309	0	0.21	12.6	204	11.3	194
9/25/90	312	0	0.04	11.1	209	11.1	200
9/29/90	316	0	0.06	9.9	213	9.2	204
10/02/90	319	0	0.03	10.6	205	8.8	198

Table B-20. Mixed Liquor in System #1

Date	MLVSS$_{avg}$ mg/l	MLVSS$_{anx}$ mg/l	MLSS$_{anx}$ mg/l	%MLVSS$_{anx}$	MLVSS$_{aer}$ mg/l	MLSS$_{aer}$ mg/l	%MLVSS$_{aer}$
11/24/89	873	840	1110	75.7	890	1180	75.4
11/27/89	793	860	970	88.7	760	840	90.5
11/30/89	753	800	890	89.9	730	850	85.9
12/02/89	903	850	950	89.5	930	1080	86.1
12/04/89	917	790	960	82.3	980	1180	83.1
12/07/89	873	680	790	86.1	970	1140	85.1
12/11/89	765	805	935	86.1	745	855	87.1
12/13/89	737	740	840	88.1	735	835	88.0
12/14/89	763	820	920	89.1	735	830	88.6
12/16/89	678	715	825	86.7	660	770	85.7
12/19/89	642	679	790	85.9	624	725	86.1
12/22/89	645	995	1130	88.1	470	530	88.7
12/26/89	722	894	1005	89.0	636	715	89.0
12/29/89	700	810	910	89.0	645	725	89.0
1/02/90	622	665	725	91.7	600	640	93.8
1/05/90	582	630	700	90.0	558	620	90.0
1/09/90	579	576	640	90.0	581	645	90.1
1/12/90	533	635	705	90.1	482	535	90.1
1/15/90	566	815	905	90.1	441	490	90.0
1/18/90	654	783	870	90.0	590	655	90.1
1/21/90	692	885	975	90.8	595	650	91.5
1/24/90	603	720	790	91.1	545	605	90.1
1/27/90	653	896	995	90.1	531	590	90.0
1/30/90	669	747	830	90.0	630	700	90.0
2/02/90	675	755	840	89.9	635	715	88.8
2/05/90	690	930	1030	90.3	570	640	89.1
2/08/90	695	905	970	93.3	590	625	94.4
2/11/90	595	755	805	93.8	515	545	94.5
2/14/90	600	720	785	91.7	540	600	90.0
2/17/90	607	890	970	91.8	465	510	91.2
2/20/90	743	770	850	90.6	730	805	90.7
2/23/90	572	675	695	97.1	520	565	92.0
2/26/90	595	545	595	91.6	620	695	89.2
3/01/90	617	610	720	84.7	620	715	86.7
3/04/90	692	725	830	87.3	675	790	85.4
3/07/90	750	770	865	89.0	740	845	87.6
3/10/90	797	770	900	85.6	810	960	84.4
3/14/90	893	910	1050	86.7	885	1020	86.8
3/17/90	1037	1040	1185	87.8	1035	1195	86.6
3/20/90	1000	980	1170	83.8	1010	1205	83.8
3/23/90	948	905	1055	85.8	970	1120	86.6
3/26/90	1017	1000	1165	85.8	1025	1200	85.4
3/29/90	998	985	1150	85.7	1005	1190	84.5
4/01/90	925	815	965	84.5	980	1175	83.4
4/04/90	935	855	1035	82.6	975	1205	80.9
4/07/90	942	975	1170	83.3	925	1120	82.6
4/10/90	912	835	965	86.5	950	1115	85.2
4/13/90	940	930	1075	86.5	945	1115	84.8
4/16/90	927	930	1075	86.5	925	1085	85.3
4/20/90	1130	1030	1190	86.6	1180	1370	86.1
4/23/90	1032	1045	1215	86.0	1025	1215	84.4
4/26/90	1103	1150	1325	86.8	1080	1230	87.8
5/01/90	1118	1115	1320	84.5	1120	1325	84.5
5/04/90	1153	1090	1290	84.5	1185	1400	84.6
5/08/90	1050	970	1145	84.7	1090	1305	83.5
5/11/90	1088	995	1155	86.1	1135	1315	86.3
5/15/90	1157	920	1060	86.8	1275	1485	85.9
5/18/90	1188	1195	1360	87.9	1185	1370	86.5
5/22/90	1298	1215	1420	85.6	1340	1595	84.0
5/25/90	1388	1025	1200	85.4	1570	1840	85.3
5/29/90	1437	1520	1785	85.2	1395	1640	85.1

6/01/90	1460	1360	1590	85.5	1510	1780	84.8
6/05/90	1492	1105	1295	85.3	1685	1990	84.7
6/19/90	1813	1000	1280	78.1	2220	2895	76.7
6/22/90	1858	1735	2205	78.7	1920	2465	77.9
6/26/90	1757	1660	2165	76.7	1805	2375	76.0
6/29/90	1410	1480	1910	77.5	1375	1775	77.5
7/03/90	1402	1425	1815	78.5	1390	1845	75.3
7/06/90	1517	1500	1900	78.9	1525	1965	77.6
7/10/90	1745	1735	2145	80.9	1750	2185	80.1
7/13/90	1825	1845	2255	81.8	1815	2255	80.5
7/17/90	1752	1755	2240	78.3	1750	2255	77.6
7/20/90	1848	1985	2545	78.0	1780	2295	77.6
7/24/90	1697	1820	2350	77.4	1635	2115	77.3
7/27/90	1707	1640	2150	76.3	1740	2300	75.7
7/31/90	1793	1720	2305	74.6	1830	2475	73.9
8/03/90	1950	1620	2150	75.3	2115	2850	74.2
8/07/90	2530	2430	3460	70.2	2580	3610	71.5
8/08/90	2330	2410	3420	70.5	2290	3230	70.9
8/10/90	2557	2670	3870	69.0	2500	3590	69.6
8/14/90	2257	2150	3160	68.0	2310	3390	68.1
8/17/90	2087	2020	2970	68.0	2120	3080	68.8
8/21/90	2083	1950	2890	67.5	2150	3160	68.0
8/24/90	2143	2110	3090	68.3	2160	3200	67.5
8/28/90	2080	1860	2820	66.0	2190	3280	66.8
8/31/90	2167	2040	2990	68.2	2230	3300	67.6
9/11/90	2313	2300	3380	68.0	2320	3460	67.1
9/14/90	2377	2350	3500	67.1	2390	3550	67.3
9/17/90	2260	2220	3350	66.3	2280	3450	66.1
9/21/90	2430	2310	3380	68.3	2490	3690	67.5
9/25/90	2300	2180	3190	68.3	2360	3480	67.8
9/29/90	2517	2610	3910	66.8	2470	3710	66.6
10/02/90	2500	2400	3540	67.8	2550	3790	67.3

Table B-21. Eff. SS, Sludge Age, & Vol. Wasted in System #1

DATE	day	#1VSS$_{eff}$ mg/l	#1TSS$_{eff}$ mg/l	#1%VSS$_{eff}$ mg/l	#1θ$_{act}$ mg/l	#1Q$_{wact}$ l/day
11/24/89	7	6.70	11.86	56.5	8	0.520
11/27/89	10	10.33	10.33	100	8	0.491
11/30/89	13	5.67	6.38	88.9	8	0.521
12/02/89	15	9.32	11.86	78.6	8	0.506
12/04/89	17	4.16	5.12	81.3	8	0.538
12/07/89	20	3.74	4.37	85.6	8	0.539
12/11/89	24	2.71	3.39	79.9	8	0.543
12/13/89	26	2.41	2.41	100	8	0.545
12/14/89	27	2.76	2.76	100	8	0.543
12/16/89	29	4.23	5.21	81.2	8	0.528
12/19/89	32	4.47	5.20	86.0	8	0.524
12/22/89	35	13.36	14.92	89.5	8	0.447
12/26/89	39	5.99	6.73	89.0	8	0.517
12/29/89	42	2.55	2.87	88.9	8	0.543
1/02/90	46	1.71	1.71	100	8	0.548
1/05/90	49	0.92	1.02	90.2	8	0.554
1/09/90	53	1.95	2.17	89.9	8	0.544
1/12/90	56	1.73	1.92	90.1	8	0.545
1/15/90	59	2.12	2.35	90.2	8	0.542
1/18/90	62	1.65	1.83	90.2	8	0.549
1/21/90	65	2.57	2.57	100	8	0.542
1/24/90	68	3.44	3.44	100	8	0.531
1/27/90	71	2.75	3.06	89.9	8	0.539
1/30/90	74	8.59	9.54	90.0	8	0.492
2/02/90	77	2.55	2.76	92.4	8	0.542
2/05/90	80	2.67	2.67	100	8	0.541
2/08/90	83	5.98	6.15	97.2	8	0.515
2/11/90	86	1.38	1.38	100	8	0.550
2/14/90	89	2.14	2.46	87.0	8	0.543
2/17/90	92	1.64	1.64	100	8	0.548
2/20/90	95	4.82	5.29	91.1	8	0.527
2/23/90	98	6.66	6.66	100	8	0.498
2/26/90	101	3.60	3.60	100	8	0.529
3/01/90	104	3.43	3.90	87.9	8	0.532
3/04/90	107	3.20	3.47	92.2	8	0.537
3/07/90	110	2.86	3.18	89.9	8	0.542
3/10/90	113	3.97	4.10	96.8	23.9	0.159
3/14/90	117	8.40	9.60	87.5	50.5	0.033
3/17/90	120	11.99	13.45	89.1	15	0.233
3/20/90	123	20.24	23.81	85.0	15	0.182
3/23/90	126	13.46	15.38	87.5	15	0.218
3/26/90	129	9.00	9.80	91.8	15	0.249
3/29/90	132	5.62	5.62	100	15	0.268
4/01/90	135	7.33	9.01	81.4	15	0.254
4/04/90	138	3.84	5.06	75.9	15	0.276
4/07/90	141	3.20	3.30	97.0	15	0.281
4/10/90	144	2.94	3.14	93.6	15	0.282
4/13/90	147	4.62	5.38	85.9	15	0.272
4/16/90	150	4.93	6.13	80.4	15	0.269
4/20/90	154	5.85	7.00	83.6	15	0.270
4/23/90	157	5.15	6.62	77.8	15	0.271
4/26/90	160	5.20	5.87	88.6	15	0.273
5/01/90	165	5.88	7.13	82.5	15	0.270
5/04/90	168	3.78	4.89	77.3	15	0.281
5/08/90	172	5.89	7.21	81.7	15	0.268
5/11/90	175	2.85	2.95	96.6	28.4	0.143
5/15/90	179	6.89	6.89	100	26.8	0.133
5/18/90	182	1.82	1.82	100	30	0.141
5/22/90	186	2.20	2.72	80.9	30	0.140
5/25/90	189	3.81	4.23	90.1	30	0.134
5/29/90	193	10.55	11.81	89.3	29.9	0.107

6/01/90	196	5.77	6.01	96.0	30	0.127
6/05/90	200	4.69	5.19	90.4	29.9	0.132
6/19/90	214	5.20	6.67	78.0	30	0.133
6/22/90	217	22.00	28.80	76.4	30	0.080
6/26/90	221	8.45	11.27	75.0	29.9	0.122
6/29/90	224	9.8	12.40	79.0	30	0.109
7/03/90	228	11.00	13.40	82.1	29.9	0.104
7/06/90	231	7.50	9.33	80.4	30	0.121
7/10/90	235	11.20	13.40	83.6	30	0.112
7/13/90	238	5.94	6.52	91.1	30.0	0.131
7/17/90	242	10.60	13.80	76.8	30.1	0.114
7/20/90	245	12.15	14.92	81.4	30.1	0.111
7/24/90	249	11.37	13.74	82.8	29.9	0.111
7/27/90	252	10.00	12.20	82.0	29.9	0.116
7/31/90	256	10.67	12.93	82.5	30.0	0.115
8/03/90	259	7.20	9.87	72.9	30.1	0.128
8/07/90	263	12.20	16.40	74.4	29.9	0.122
8/08/90	264	79.73	137.84	57.8	18.4	0.040
8/10/90	266	56.56	84.43	67.0	29.2	0.022
8/14/90	270	38.18	68.18	56.0	30.1	0.049
8/17/90	273	37.00	70.00	52.9	30.1	0.044
8/21/90	277	44.83	85.06	52.7	27.1	0.038
8/24/90	280	52.44	84.15	62.3	25.7	0.029
8/28/90	284	51.56	103.13	50.0	24.2	0.038
8/31/90	287	51.39	90.28	56.9	29.4	0.011
9/11/90	298	52.70	82.43	63.9	25.9	0.038
9/14/90	301	51.28	85.90	59.7	27.0	0.038
9/17/90	304	45.33	82.67	54.8	30.1	0.030
9/21/90	308	42.86	66.23	64.7	30.0	0.045
9/25/90	312	51.35	72.97	70.4	30.1	0.016
9/29/90	316	36.56	52.69	69.4	30.0	0.064
10/02/90	319	27.00	35.00	77.1	30.0	0.086

Table B-22. **Mixed Liquor in System #2**

DATE	MLVSS$_{avg}$ mg/l	MLVSS$_{anx}$ mg/l	MLSS$_{anx}$ mg/l	%MLVSS$_{anx}$	MLVSS$_{aer}$ mg/l	MLSS$_{aer}$ mg/l	%MLVSS$_{aer}$
11/24/89	1133	1060	1340	79.1	1170	1490	78.5
11/27/89	980	660	740	89.2	1140	1290	88.4
11/30/89	680	520	550	94.5	760	860	88.4
12/02/89	840	700	810	86.4	910	1030	88.3
12/04/89	783	970	1170	82.9	690	870	79.3
12/07/89	873	720	840	85.7	950	1090	87.2
12/11/89	762	725	825	87.9	780	890	87.6
12/13/89	715	645	720	89.6	750	845	88.8
12/14/89	720	650	740	87.8	755	865	87.3
12/16/89	627	610	710	85.9	635	740	85.8
12/19/89	529	391	455	85.9	598	695	86.0
12/22/89	557	560	630	88.9	555	620	89.5
12/26/89	604	645	725	89.0	583	655	89.0
12/29/89	546	525	590	89.0	556	625	89.0
1/02/90	427	410	460	89.1	435	480	90.6
1/05/90	245	230	255	90.2	252	280	90.0
1/09/90	209	203	225	90.2	212	235	90.2
1/12/90	174	153	170	90.0	185	205	90.2
1/15/90	149	113	125	90.4	167	185	90.3
1/18/90	164	113	125	90.4	189	210	90.0
1/21/90	149	140	157	89.2	153	190	80.5
1/24/90	173	150	150	100	185	220	84.1
1/27/90	308	230	255	90.2	347	385	90.1
1/30/90	330	324	360	90.0	333	370	90.0
2/02/90	308	325	375	86.7	300	360	83.3
2/05/90	302	345	380	90.8	280	315	88.9
2/08/90	320	330	350	94.3	315	330	95.5
2/11/90	408	425	455	93.4	400	425	94.1
2/14/90	640	610	685	89.1	655	730	89.7
2/17/90	798	745	835	89.2	825	915	90.2
2/20/90	772	735	820	89.6	790	875	90.3
2/23/90	659	550	580	94.8	714	760	93.9
2/26/90	617	590	670	88.1	630	710	88.7
3/01/90	545	415	475	87.4	610	700	87.1
3/04/90	602	365	420	86.9	720	825	87.3
3/07/90	628	375	430	87.2	755	885	85.3
3/10/90	592	525	625	84.0	625	735	85.0
3/14/90	722	605	715	84.6	780	925	84.3
3/17/90	705	625	705	88.7	745	865	86.1
3/20/90	805	775	930	83.3	820	955	85.9
3/23/90	860	650	755	86.1	965	1125	85.8
3/26/90	917	850	965	88.1	950	1105	86.0
3/29/90	942	945	1085	87.1	940	1085	86.6
4/01/90	927	510	575	88.7	1135	1335	85.0
4/04/90	950	770	915	84.2	1040	1270	81.9
4/07/90	950	740	890	83.1	1055	1275	82.7
4/10/90	975	845	1030	82.0	1040	1240	83.9
4/13/90	952	795	980	81.1	1030	1255	82.1
4/16/90	913	720	875	82.3	1010	1245	81.1
4/20/90	1138	985	1285	76.7	1215	1615	75.2
4/23/90	1033	890	1205	73.9	1105	1470	75.2
4/26/90	1040	880	1195	73.6	1120	1490	75.2
5/01/90	1013	870	1175	74.0	1085	1450	74.8
5/04/90	1063	870	1125	77.3	1160	1530	75.8
5/08/90	968	775	1000	77.5	1065	1370	77.7
5/11/90	997	810	1060	76.4	1090	1405	77.6
5/15/90	998	855	1135	75.3	1070	1410	75.9
5/18/90	913	780	1130	69.0	980	1400	70.0
5/22/90	932	825	1245	66.3	985	1495	65.9
5/25/90	957	800	1225	65.3	1035	1575	65.7
5/29/90	895	745	1140	65.4	970	1505	64.5

6/01/90	882	745	1140	65.4	950	1475	64.4
6/05/90	853	750	1125	66.7	905	1390	65.1
6/19/90	1020	900	1350	66.7	1080	1660	65.1
6/22/90	1020	950	1415	67.1	1055	1615	65.3
6/26/90	872	785	1200	65.4	915	1430	64.0
6/29/90	933	800	1190	67.2	1000	1495	66.9
7/03/90	962	815	1140	71.5	1035	1455	71.1
7/06/90	893	870	1190	73.1	905	1270	71.3
7/10/90	800	770	1005	76.6	815	1090	74.8
7/13/90	757	730	910	80.2	770	960	80.2
7/17/90	708	645	845	76.3	740	980	75.5
7/20/90	647	560	770	72.7	690	930	74.2
7/24/90	703	660	875	75.4	725	985	73.6
7/27/90	752	735	1020	72.1	760	1150	66.1
7/31/90	850	790	1120	70.5	880	1280	68.8
8/03/90	1040	980	1320	74.2	1070	1450	73.8
8/07/90	1107	980	1450	67.6	1170	1770	66.1
8/10/90	1230	1210	1780	68.0	1240	1860	66.7
8/14/90	1280	1220	1750	69.7	1310	1940	67.5
8/17/90	1347	1200	1730	69.4	1420	2040	69.6
8/21/90	1303	1170	1840	63.6	1370	2160	63.4
8/24/90	1273	1120	1700	65.9	1350	2040	66.2
8/28/90	1077	930	1420	65.5	1150	1790	64.2
8/31/90	1173	1180	1720	68.6	1170	1750	66.9
9/11/90	1070	970	1350	71.9	1120	1620	69.1
9/14/90	1127	1040	1480	70.3	1170	1720	68.0
9/17/90	1013	1000	1430	69.9	1020	1510	67.5
9/21/90	1197	1070	1530	69.9	1260	1800	70.0
9/25/90	1127	1100	1510	72.8	1140	1590	71.7
9/29/90	1053	940	1320	71.2	1110	1590	69.8
10/02/90	1060	960	1260	76.2	1110	1500	74.0

Table B-23. Effluent TSS, Sludge Age, & Volume Wasted in System #2

DATE	day	#2VSS$_{eff}$ mg/l	#2TSS$_{eff}$ mg/l	#2%VSS$_{eff}$ mg/l	#2θ_{act} mg/l	#2Q$_{wact}$ l/day
11/24/89	7	2.58	5.58	46.2	8	0.550
11/27/89	10	7.33	7.33	100	8	0.522
11/30/89	13	11.33	11.33	100	8	0.470
12/02/89	15	2.88	3.70	77.8	8	0.544
12/04/89	17	0.64	1.59	40.3	8	0.558
12/07/89	20	1.56	2.22	70.3	8	0.553
12/11/89	24	2.35	2.88	81.6	8	0.546
12/13/89	26	2.72	2.72	100	8	0.542
12/14/89	27	5.01	5.39	92.9	8	0.524
12/16/89	29	3.14	3.77	83.3	8	0.535
12/19/89	32	7.20	8.37	86.0	8	0.487
12/22/89	35	32.00	36.00	88.9	7.5	0.270
12/26/89	39	52.71	59.22	89.0	7.7	0.067
12/29/89	42	43.61	49.00	89.0	8.3	0.067
1/02/90	46	95.12	100.0	95.1	3.2	0.067
1/05/90	49	37.20	41.33	90.0	4.6	0.067
1/09/90	53	32.27	35.86	90.0	4.6	0.067
1/12/90	56	44.15	49.06	90.0	2.9	0.067
1/15/90	59	17.10	19.00	90.0	6.0	0.067
1/18/90	62	21.30	23.67	90.0	5.4	0.067
1/21/90	65	19.13	22.02	86.9	5.5	0.060
1/24/90	68	16.80	18.97	88.6	7.2	0.050
1/27/90	71	22.72	25.24	90.0	9.2	0.050
1/30/90	74	65.70	73.00	90.0	3.6	0.050
2/02/90	77	26.27	29.95	87.7	8.1	0.050
2/05/90	80	37.78	42.22	89.5	5.7	0.050
2/08/90	83	54.39	57.31	94.9	4.2	0.050
2/11/90	86	27.60	29.60	93.2	10.3	0.033
2/14/90	89	52.17	61.74	84.5	8	0.080
2/17/90	92	15.52	16.55	93.8	8	0.455
2/20/90	95	4.17	5.15	81.0	8	0.533
2/23/90	98	4.91	5.41	90.8	8	0.522
2/26/90	101	6.50	7.00	92.9	8	0.505
3/01/90	104	2.97	3.69	80.5	8	0.533
3/04/90	107	3.77	4.14	91.1	8	0.528
3/07/90	110	8.40	9.60	87.5	8	0.489
3/10/90	113	48.21	53.57	90.0	8.8	0.025
3/14/90	117	31.03	34.48	90.0	11.2	0.150
3/17/90	120	2.37	2.37	100	15	0.281
3/20/90	123	2.38	2.38	100	15	0.283
3/23/90	126	1.33	1.33	100	15	0.291
3/26/90	129	1.49	1.49	100	15	0.291
3/29/90	132	2.89	2.89	100	15	0.282
4/01/90	135	1.10	1.41	78.0	15	0.293
4/04/90	138	0.81	0.81	100	15	0.295
4/07/90	141	1.01	1.01	100	15	0.294
4/10/90	144	1.43	1.43	100	15	0.292
4/13/90	147	1.80	2.00	90.0	15	0.289
4/16/90	150	2.20	2.70	81.5	15	0.286
4/20/90	154	3.02	3.62	83.4	15	0.285
4/23/90	157	5.74	8.35	68.7	15	0.268
4/26/90	160	3.16	3.88	81.4	15	0.283
5/01/90	165	2.25	3.13	71.9	15	0.287
5/04/90	168	1.40	2.30	60.9	15	0.292
5/08/90	172	1.27	1.38	92.0	15	0.292
5/11/90	175	4.73	4.73	100	15	0.273
5/15/90	179	5.72	7.15	80.0	15	0.267
5/18/90	182	2.51	3.85	65.2	15	0.284
5/22/90	186	9.00	12.80	70.3	15	0.244
5/25/90	189	6.00	8.93	67.2	15	0.264
5/29/90	193	11.20	16.20	69.1	15	0.228

6/01/90	196	9.20	13.20	69.7	15	0.240
6/05/90	200	16.44	23.63	69.6	15	0.188
6/19/90	214	12.50	16.16	77.4	15	0.229
6/22/90	217	11.60	15.40	75.3	15	0.234
6/26/90	221	16.28	23.26	70.0	15	0.192
6/29/90	224	17.88	24.83	72.0	15	0.189
7/03/90	228	5.68	6.79	83.7	15	0.266
7/06/90	231	22.00	30.40	72.4	15	0.156
7/10/90	235	93.55	122.58	76.3	5.8	0.080
7/13/90	238	65.38	78.85	82.9	8	0.048
7/17/90	242	42.67	49.33	86.5	11.4	0.036
7/20/90	245	27.46	34.51	79.6	15	0.047
7/24/90	249	19.20	24.00	80.0	15	0.140
7/27/90	252	20.40	29.20	69.9	15	0.141
7/31/90	256	29.66	40.69	72.9	15	0.094
8/03/90	259	28.05	41.46	67.7	15	0.142
8/07/90	263	13.60	33.60	40.5	15	0.229
8/10/90	266	12.40	34.40	36.0	15	0.242
8/14/90	270	13.92	27.53	50.6	15	0.237
8/17/90	273	13.55	21.94	61.8	15	0.242
8/21/90	277	14.67	26.63	55.1	15	0.235
8/24/90	280	17.67	33.00	53.5	15	0.220
8/28/90	284	23.60	50.80	46.5	15	0.172
8/31/90	287	20.80	42.40	49.1	15	0.197
9/11/90	298	31.33	52.41	59.8	15	0.128
9/14/90	301	23.81	42.26	56.3	15	0.177
9/17/90	304	21.88	39.06	56.0	15	0.174
9/21/90	308	11.24	17.42	64.5	15	0.246
9/25/90	312	12.73	18.63	68.3	15	0.235
9/29/90	316	13.93	18.93	73.6	15	0.224
10/02/90	319	12.13	16.54	73.3	15	0.234

Table B-24. Mixed Liquor in System #3

DATE	$MLVSS_{avg}$ mg/l	$MLVSS_{anx}$ mg/l	$MLSS_{anx}$ mg/l	$\%MLVSS_{anx}$	$MLVSS_{aer}$ mg/l	$MLSS_{aer}$ mg/l	$\%MLVSS_{aer}$
4/23/90	655	545	660	82.6	710	850	83.5
4/26/90	1003	900	1015	88.7	1055	1205	87.6
5/01/90	1160	1030	1215	84.8	1225	1445	84.8
5/04/90	1273	1110	1325	83.8	1355	1600	84.7
5/08/90	1183	1080	1285	84.0	1235	1460	84.6
5/11/90	1215	1125	1315	85.6	1260	1460	86.3
5/15/90	1260	1210	1390	87.1	1285	1480	86.8
5/18/90	1125	985	1155	85.3	1195	1420	84.2
5/22/90	1192	1045	1225	85.3	1265	1475	85.8
5/25/90	1175	1035	1210	85.5	1245	1460	85.3
5/29/90	1170	1030	1190	86.6	1240	1440	86.1
6/01/90	1203	1070	1265	84.6	1270	1490	85.2
6/05/90	1202	1075	1270	84.6	1265	1495	84.6
6/19/90	1115	1065	1485	71.7	1140	1615	70.6
6/22/90	1167	1080	1420	76.1	1210	1640	73.8
6/26/90	1132	1095	1490	73.5	1150	1585	72.6
6/29/90	1113	1110	1600	69.4	1115	1365	81.7
7/03/90	1145	1105	1465	75.4	1165	1560	74.7
7/06/90	1213	1150	1485	77.4	1245	1680	74.1
7/10/90	1360	1430	1810	79.0	1325	1730	76.6
7/13/90	1407	1300	1655	78.5	1460	1895	77.0
7/17/90	1358	1345	1780	75.6	1365	1825	74.8
7/20/90	1295	1175	1530	76.8	1355	1805	75.1
7/24/90	1297	1310	1775	73.8	1290	1755	73.5
7/27/90	1267	1360	1780	76.4	1220	1655	73.7
7/31/90	1257	1250	1610	77.6	1260	1675	75.2
8/03/90	1407	1440	1820	79.1	1390	1790	77.7
8/07/90	1367	1260	1710	73.7	1420	1940	73.2
8/10/90	1413	1300	1760	73.9	1470	2010	73.1
8/14/90	1547	1460	1960	74.5	1590	2100	75.7
8/17/90	1517	1390	1980	70.2	1580	2200	71.8
8/21/90	1537	1470	1930	76.2	1570	2100	74.8
8/24/90	1487	1360	1790	76.0	1550	2050	75.6
8/28/90	1280	1200	1610	74.5	1320	1780	74.2
8/31/90	1413	1340	1790	74.9	1450	1920	75.5
9/11/90	1157	1070	1320	81.1	1200	1470	81.6
9/14/90	1203	1190	1550	76.8	1210	1580	76.6
9/17/90	1040	980	1290	76.0	1070	1450	73.8
9/21/90	1047	960	1200	80.0	1090	1420	76.8
9/25/90	957	890	1120	79.5	990	1240	79.8
9/29/90	1007	800	960	83.3	1110	1360	81.6
10/02/90	1040	1020	1190	85.7	1050	1260	83.3

Table B-25. Effluent TSS, Sludge Age, & Volume Wasted in System #3

DATE	day	#3VSS$_{eff}$ mg/l	#3TSS$_{eff}$ mg/l	#3%VSS$_{eff}$ mg/l	#3Θ_{act} mg/l	#3Q$_{wact}$ l/day
4/23/90	157	13.48	17.25	78.1	36.4	0.000
4/26/90	160	14.00	19.60	71.4	15	0.219
5/01/90	165	20.00	25.60	78.1	15	0.200
5/04/90	168	22.00	28.40	77.5	15	0.200
5/08/90	172	22.40	26.40	84.8	15	0.190
5/11/90	175	20.40	23.60	86.4	15	0.203
5/15/90	179	18.40	22.40	82.1	15	0.216
5/18/90	182	19.60	22.80	86.0	15	0.199
5/22/90	186	16.78	19.08	87.9	15	0.219
5/25/90	189	24.40	28.00	87.1	15	0.179
5/29/90	193	15.71	16.79	93.6	15	0.222
6/01/90	196	7.60	8.20	92.7	15	0.264
6/05/90	200	7.80	8.20	95.1	15	0.263
6/19/90	214	9.51	11.27	84.4	15	0.251
6/22/90	217	9.02	11.64	77.5	15	0.256
6/26/90	221	9.80	13.20	74.2	15	0.250
6/29/90	224	7.47	9.33	80.1	15	0.262
7/03/90	228	13.40	16.60	80.7	15	0.233
7/06/90	231	9.80	12.20	80.3	15	0.254
7/10/90	235	18.40	23.60	78.0	15	0.222
7/13/90	238	11.88	12.87	92.3	15	0.251
7/17/90	242	12.57	15.50	81.1	15	0.247
7/20/90	245	26.80	34.00	78.8	15	0.180
7/24/90	249	18.40	23.20	79.3	15	0.218
7/27/90	252	30.80	40.80	75.5	15	0.158
7/31/90	256	20.00	25.60	78.1	15	0.208
8/03/90	259	32.12	39.42	81.5	15	0.167
8/07/90	263	20.80	26.00	80.0	15	0.212
8/10/90	266	32.70	44.65	73.2	15	0.165
8/14/90	270	54.79	71.92	76.2	15	0.091
8/17/90	273	27.27	37.01	73.7	15	0.196
8/21/90	277	32.50	39.38	82.5	15	0.177
8/24/90	280	44.58	56.63	78.7	15	0.124
8/28/90	284	20.40	27.60	73.9	15	0.208
8/31/90	287	19.60	25.20	77.8	15	0.220
9/11/90	298	35.33	46.67	75.7	15	0.120
9/14/90	301	11.00	13.60	80.9	15	0.247
9/17/90	304	15.03	21.33	70.5	15	0.216
9/21/90	308	9.15	12.15	75.3	15	0.250
9/25/90	312	10.96	13.20	83.0	15	0.234
9/29/90	316	12.50	14.72	84.9	15	0.228
10/02/90	319	28.00	32.80	85.4	15	0.142

Table B-26. COD in Systems #1 & #2

DATE	day	COD$_{in}$ mg/l	#1COD$_{eff}$ mg/l	#1COD$_{anx}$ mg/l	#2COD$_{eff}$ mg/l	#2COD$_{anx}$ mg/l
12/16/89	29	76.5	65.1	118.0	66.7	105.8
12/19/89	32		68.6	111.8	87.3	
12/22/89	35		71.2	108.4	96.0	115.9
12/26/89	39		77.0	109.8	101.6	142.5
12/29/89	42		74.5	112.6	105.9	152.3
1/02/90	46		90.7	92.3	140.6	142.3
1/05/90	49		61.6	104.0	143.1	168.0
1/07/90	51	67.6				
1/09/90	53	70.7	63.3	92.9	141.4	168.5
1/12/90	56		57.0	78.0	118.5	153.0
1/15/90	59		40.1	66.3	114.3	125.7
1/18/90	62		58.3	90.0	135.4	124.3
1/21/90	65	62.3	60.6	102.1		153.6
1/24/90	68	65.6	63.1	87.2	152.0	130.4
1/27/90	71		56.1	87.9	93.6	106.6
1/30/90	74	60.1	55.2	83.2	97.2	104.6
2/02/90	77	64.9	55.1	81.1	73.0	94.1
2/05/90	80	63.6	55.6	93.4	66.0	120.8
2/08/90	83	59.7	55.7	94.4	69.4	88.7
2/14/90	89	55.7	51.6	100.8	55.7	93.6
2/17/90	92	51.9	63.1	82.2	61.4	83.9
2/20/90	95	62.9	61.2	91.8	69.7	87.5
2/23/90	98	68.5	61.8	86.8	53.4	78.5
2/26/90	101	60.0	56.8	98.1	61.6	84.3
3/01/90	104	59.4	47.2	108.2	52.9	84.6
3/04/90	107	53.1	47.2	117.9	42.1	108.6
3/07/90	110	42.0	36.9	117.5	29.4	117.5
3/10/90	113	47.4	45.8	112.0	50.7	101.4
3/14/90	117	59.1	59.1	142.8		139.5
3/17/90	120	72.0	56.4	115.3	52.3	101.4
3/20/90	123	64.9	46.2	91.6	46.2	86.8
3/23/90	126	47.5	51.7		54.2	124.2
3/26/90	129	54.2	50.9	81.2	53.3	83.7
3/29/90	132	54.1	48.5	84.8	52.5	77.6
4/01/90	135	54.2	55.8	64.0	56.6	87.0
4/04/90	138	48.5	50.1	55.9	50.1	56.7
4/07/90	141	52.6	44.4	73.2	47.7	70.7
4/10/90	144	58.2	52.5	72.7	56.6	84.0
4/13/90	147	54.5	52.1	85.4	54.5	103.3
4/16/90	150	54.3	49.4	95.5	57.6	102.9
4/20/90	154	51.9	46.2	57.6	51.1	66.5
4/23/90	157	53.8	49.7	82.3	60.3	89.6
4/26/90	160	54.4	53.6	105.6	48.7	93.4
5/01/90	165	54.7	49.0	103.7	52.2	104.5
5/04/90	168	50.1	50.1	68.7	49.3	
5/08/90	172	51.9	47.8	118.4	53.5	120.0
5/11/90	175	51.1	49.5	94.2	53.5	87.1
5/15/90	179	47.8	46.2	110.8	52.6	83.7
5/18/90	182	50.8	53.2	108.7	58.7	92.8
5/22/90	186		53.1	82.7	53.9	
5/25/90	189	58.2	56.6	80.8	57.4	80.8
5/29/90	193	55.8	51.0	81.3	59.8	84.5
6/01/90	196	62.8	56.4	83.4	56.4	96.2
6/05/90	200	54.0	58.0	82.6	59.6	79.5
6/19/90	214	78.3	60.3	83.8	58.7	78.3
6/22/90	217	59.5	59.5	76.7	68.9	79.1
6/26/90	221	63.9	57.5	70.3	59.1	83.9
6/29/90	224	65.0	59.4	74.5	64.2	91.9
7/03/90	228	58.6	59.4	85.5	61.8	112.5
7/06/90	231	60.1	62.5	87.0	62.5	120.2
7/10/90	235	63.6	61.2	116.0	60.4	148.2

7/13/90	238	63.1	86.3	124.6	66.3	170.1
7/17/90	242	67.8	68.6	110.8	69.4	132.4
7/20/90	245	56.4	59.8	76.6	96.8	126.3
7/24/90	249	69.5	67.9	110.9	72.0	92.7
7/27/90	252	72.0	73.7	85.2	67.9	95.2
7/31/90	256	61.7	69.8	104.8	63.4	95.0
8/03/90	259	59.4	64.3	109.8	65.9	68.3
8/07/90	263	66.4		159.2	65.6	94.4
8/10/90	266	69.3	81.3	160.3	75.7	104.7
8/14/90	270	61.6	96.0	164.8	66.4	117.6
8/17/90	273	61.8	85.5	156.0	67.3	133.1
8/21/90	277	61.8	95.2	139.1	68.3	131.8
8/24/90	280	68.1	91.9	122.3	76.3	105.8
8/28/90	284	68.0	86.4	177.6	80.0	163.2
8/31/90	287	68.7	86.3	111.8	81.5	131.0
9/11/90	298	58.4	82.1	137.4	65.5	97.9
9/14/90	301	62.7	73.7	107.5	62.7	87.8
9/17/90	304	67.5	85.8	101.7	71.5	82.6
9/21/90	308	65.6	84.6	142.3	64.1	130.5
9/25/90	312	59.7	80.9	137.5	69.1	120.2
9/29/90	316	63.2	75.0	140.5	65.5	150.0
10/02/90	319	55.5	69.1	139.9	75.6	184.1

Table B-27. **COD in System #3**

DATE	day	COD_{in} mg/l	#3COD_{eff} mg/l	#3COD_{anx} mg/l
4/23/90	157	53.8	60.3	106.8
4/26/90	160	54.4	51.2	101.5
5/01/90	165	54.7	52.2	121.6
5/04/90	168	50.1	52.5	122.8
5/08/90	172	51.9	47.8	136.2
5/11/90	175	51.1	46.3	109.4
5/15/90	179	47.8	42.3	112.4
5/18/90	182	50.8	52.4	119.8
5/22/90	186		55.4	99.9
5/25/90	189	58.2	61.4	105.1
5/29/90	193	55.8	55.0	89.3
6/01/90	196	62.8	71.5	115.2
6/05/90	200	54.0	62.0	93.0
6/19/90	214	78.3	61.9	94.7
6/22/90	217	59.5	57.2	90.8
6/26/90	221	63.9	59.1	100.6
6/29/90	224	65.0	61.0	95.8
7/03/90	228	58.6	58.6	110.9
7/06/90	231	60.1	56.1	109.9
7/10/90	235	63.6	61.2	145.0
7/13/90	238	63.1	66.3	154.9
7/17/90	242	67.8	76.5	134.0
7/20/90	245	56.4	64.0	138.9
7/24/90	249	69.5	83.6	96.8
7/27/90	252	72.0	77.0	96.0
7/31/90	256	61.7	65.0	96.6
8/03/90	259	59.4	65.1	95.2
8/07/90	263	66.4	69.6	120.8
8/10/90	266	69.3	70.9	112.8
8/14/90	270	61.6	69.6	116.8
8/17/90	273	61.8	61.0	115.6
8/21/90	277	61.8	60.2	104.1
8/24/90	280	68.1	70.6	108.3
8/28/90	284	68.0	72.0	158.4
8/31/90	287	68.7	67.9	105.4
9/11/90	298	58.4	64.7	101.1
9/14/90	301	62.7	66.7	86.3
9/17/90	304	67.5	71.5	101.7
9/21/90	308	65.6	65.6	124.2
9/25/90	312	59.7	67.6	97.4
9/29/90	316	63.2	70.3	90.8
10/02/90	319	55.5	61.9	126.2

Table B-28. Influent Methanol & Phosphate-P Feed and the associated Theoretic Oxygen Demand

DATE	DAY	$THOD_{in}$ mg/l	$METHANOL_{in}$ mg/l	PO_{4in}-P mg/l
11/16/89	0	360	240	13
11/24/89	7	350	230	12
11/27/89	10	350	230	12
11/28/89	11	360	240	12
12/07/89	20	340	220	12
12/16/89	29	280	190	9.8
12/19/89	32	310	210	11
12/20/89	33	260	170	9.0
12/21/89	34	360	240	13
12/27/89	40	310	210	11
1/05/90	49	320	210	11
2/06/90	81	300	200	11
2/07/90	82	330	220	12
2/12/90	87	340	220	12
2/13/90	88	340	220	12
2/19/90	94	260	180	9.2
2/22/90	97	330	220	12
2/27/90	102	360	240	12
3/16/90	119	300	200	10
3/18/90	121	250	170	8.8
3/19/90	122	260	180	9.2
3/23/90	126	260	170	9.0
3/26/90	129	260	170	9.0
3/30/90	133	270	180	9.5
4/1/90	135	300	200	11
4/02/90	136	260	170	8.9
4/03/90	137	250	160	8.6
4/07/90	141	270	180	9.3
4/20/90	154	330	220	12
4/21/90	155	260	170	9.0
5/05/90	169	270	180	9.5
5/08/90	172	410	270	14
5/09/90	173	340	230	12
5/10/90	174	330	220	11
5/12/90	176	260	170	8.9
5/13/90	177	260	170	9.1
5/23/90	187	270	180	9.4
5/28/90	192	270	180	9.6
7/01/90	226	270	180	9.4
7/02/90	227	380	250	13
7/03/90	228	360	240	13
7/04/90	229	350	230	12
7/12/90	237	370	250	13
7/15/90	240	260	180	9.2
7/16/90	241	280	190	9.7
7/25/90	250	300	200	10
7/28/90	253	270	180	9.5
7/29/90	254	330	220	11
7/30/90	255	380	250	13
8/05/90	261	340	230	12
8/07/90	263	360	240	13
8/21/90	277	390	260	13
8/29/90	285	400	270	14
9/05/90	295	410	280	15
9/11/90	298	390	260	13
9/17/90	304	400	270	14
10/2/90	319	360	240	13

APPENDIX C

METALS

Table C-1. Soluble and Total Copper in System #2

System		**#2**	**#2**	**#2**	**#2**	**#2**
MCRT	**days**	**8**	**15**	**15**	**15**	**15**
Cu Dose	**mgCu/L**	**2.5**	**1.0**	**1.0**	**2.0**	**5.0**
Days of Study	Range	29-57	141-160	173-225	225-253	253-319
Total Days		28	19	52	28	66
Steady State Days	Range	39-46	157-160	193-224	228-252	270-319
Anx. Sol.	Range	0.68-0.89	0.15-0.17	0.15-0.19	0.21-0.33	0.54-1.18
Copper•	Avg.	0.79	0.16	0.17	0.29	0.80
Aer. Sol.	Range	0.71-0.96	0.16-0.17	0.15-0.18	0.22-0.34	0.50-0.94
Copper•	Avg.	0.83	0.17	0.17	0.28	0.73
System Avg.	Range	0.70-0.94	0.16-0.17	0.15-0.18	0.22-0.33	0.52-1.02
Soluble Cu•	Avg.	0.82	0.16	0.17	0.28	0.75
Eff. Sol.	Range			0.15-0.21	0.22-0.32	0.49-.93
Copper•	Avg.			0.17	0.27	0.70
Anx. Total	Range	5.2-6.4	5.0-5.1	6.0-7.8	6.29-12.6	39.6-53.3
Copper•	Avg.	5.65	5.06	7.09	8.44	46.55
Aer. Total	Range	6.1-6.2	5.4-6.0	7.7-9.2	6.63-12.8	43.2-59.1
Copper•	Avg.	6.11	5.69	8.71	8.81	52.40
System Avg.	Range	5.8-6.2	5.3-5.7	7.2-8.7	6.52-12.7	42.4-56.7
Total Cu•	Avg.	5.96	5.48	8.17	8.69	50.45
Eff. Total	Range	1.1-1.9	0.18-0.18	0.26-0.38	0.34-1.12	1.4-2.8
Copper•	Avg.	1.38	0.18	0.30	0.66	1.96
Inf. Total	Range	1.7-5.3••	1.0-3.5••	0.31-1.28	0.96-1.71	3.14-5.8
Copper•	Avg.	2.73••	2.22••	0.75	1.28	4.3
	Est. Avg.	2.09	0.75			

• mg/L

•• These values reflect inaccurate sampling techniques and were not representive of the influent.

Table C-2. Ratio of Soluble & Total Cu to MLVSS in System #2

System		#2	#2	#2	#2	#2
Sludge Age	days	8	15	15	15	15
Copper Dose	mgCu/L	2.5	1.0	1.0	2.0	5.0
Days of Study	Range	29-57	141-160	173-225	225-253	253-319
Total Days		28	19	52	28	66
Steady State Days	Range	39-46	157-160	193-225	228-253	270-319
System	Range	46-51	9.6-9.7	9.8-11.7	23-24	48-54
Loading**	Avg.	48.6	9.65	10.9	23.5	51.8
Anx. Sol.	Range	10.5-21.8	1.71-1.80	1.63-2.49	2.58-5.64	4.61-12.6
Cu/MLVSS*	Avg.	15.8	1.80	2.09	4.13	7.62
Aer. Sol.	Range	12.2-22.1	1.47-1.53	1.44-2.02	2.14-4.30	4.30-8.5
Cu/MLVSS*	Avg.	16.3	1.50	1.71	3.58	6.15
System Avg.	Range	11.6-22.0	1.54-1.63	1.53-2.16	2.26-4.5	4.55-9.6
Sol. Cu/MLVSS*	Avg.	16.1	1.59	1.82	3.75	6.59
Anx. Total	Range	83.0-156	56.6-57.6	80.5-97.0	86.2-172	330-555
Cu/MLVSS*	Avg.	113	57.1	87.5	119	440
Aer. Total	Range	106-141	48.8-53.6	85.1-94.3	82.8-168	330-532
Cu/MLVSS*	Avg.	118	51.2	88.9	112	439
System Avg.	Range	97.6-145	51.0-54.7	84.0-95.1	84.2-169	331-535
Tot. Cu/MLVSS*	Avg.	116	52.9	88.5	114	439
Anx. Sol.	Range	9.34-19.4	1.26-1.39	1.10-1.66	1.8-4.1	2.93-9.3
Cu/MLSS*	Avg.	14.1	1.33	1.38	3.09	5.37
Aer. Sol.	Range	10.9-20.0	1.10-1.15	.94-1.32	1.5-3.2	2.82-6.3
Cu/MLSS*	Avg.	14.6	1.13	1.11	2.64	4.23
System Avg.	Range	10.3-19.8	1.15-1.22	1.00-1.42	1.61-3.35	2.89-7.2
Sol. Cu/MLSS*	Avg.	14.4	1.18	1.19	2.77	4.57
Anx. Total	Range	73.8-139	41.8-42.4	53.7-63.5	62.6-124	229-423
Cu/MLSS*	Avg.	100	42.1	58.0	88.5	307
Aer. Total	Range	94.0-127	36.7-40.3	55.4-60.3	58.9-111	223-389
Cu/MLSS*	Avg.	106	38.5	57.8	81.2	300
System Avg.	Range	86.9-131	38.1-40.9	55.0-61.3	60.0-115	226-399
Tot. Cu/MLSS*	Avg.	104	39.5	57.8	83.4	302

* All the above ratios are multiplied by 10,000.

** Units are Cumg/day/MLVSSmg/system multiplied by 10,000.

Table C-3. Soluble & Total Copper in System #1

System Sludge Age (days) Copper Dose (mgCu/L)		#1 30 2.0	#1 30 5.0
Days of Study	Range	245-253	253-319
Total Days Spiked		8	66
Days Used	Range	252	270-319
Anoxic Soluble	Range		0.40-0.66
Copper*	Average	0.20	0.55
Aerobic Soluble	Range		0.36-0.61
Copper*	Average	0.20	0.50
System Average	Range		0.39-0.62
Soluble Copper*	Average	0.20	0.51
Effluent Soluble	Range		0.36-0.60
Copper*	Average	0.18	0.48
Anoxic Chamber	Range		51.0-116.9
Total Copper*	Average	8.16	79.92
Aerobic Chamber	Range		55.3-118.8
Total Copper*	Average	8.98	83.58
System Average	Range		53.9-116.7
Total Copper*	Average	8.71	82.36
Effluent Total	Range	0.20-0.24	1.6-3.37
Copper*	Average	0.22	2.63
Influent Total	Range	1.33-1.57	3.5-5.3
Copper*	Average	1.45	4.4

* All values mg/L.

Table C-4. Ratio of Soluble & Total Cu to MLVSS in System #1

System Sludge Age (days) Copper Dose (mgCu/L)		#1 30 2.0	#1 30 5.0
Days of Study	Range	245-253	253-319
Total Days Spiked		8	66
Days Used	Range	253	270-319
System Loading**	Range		23.3-25.5
	Average	11.39	24.10
Anoxic Soluble Copper/MLVSS*	Range		2.13-2.97
	Average	1.19	2.49
Aerobic Soluble Copper/MLVSS*	Range		1.61-2.89
	Average	1.13	2.15
System Average Sol. CU/MLVSS*	Range		1.79-2.84
	Average	1.15	2.26
Anoxic Total Copper/MLVSS*	Range		237-468
	Average	49.7	360
Aerobic Total Copper/MLVSS*	Range		240-466
	Average	51.6	359
System Average Total Cu/MLVSS*	Range		239-467
	Average	51.0	359
Anoxic Soluble Copper/MLSS*	Range		1.41-1.97
	Average	0.91	1.68
Aerobic Soluble Copper/MLSS*	Range		1.09-1.99
	Average	0.86	1.45
System Average Sol. CU/MLSS*	Range		1.21-1.95
	Average	0.87	1.53
Anoxic Total Copper/MLSS*	Range		161-318
	Average	37.9	243
Aerobic Total Copper/MLSS*	Range		163-313
	Average	39.1	242
System Average Total Cu/MLSS*	Range		163-315
	Average	38.7	242

* All the above ratios are multiplied by 10,000.
** Units are Cumg/day/MLVSSmg/system multiplied by 10,000.

Table C-5. Total Copper Measured in System #2

DATE	DAY	#2 Cu_{totin} mg/L	#2 Cu_{totanx} mg/L	#2 Cu_{totaer} mg/L	#2 Cu_{totavg} ml/L	#2 Cu_{toteff} mg/L
12/16/90	29	0.04	0.25	0.30	0.3	0.02
12/19/90	32	1.69	3.01	2.84	2.9	0.46
12/22/90	35	1.67	4.77	4.56	4.6	0.73
12/26/90	39	3.00	5.36	6.16	5.9	1.13
12/29/90	42	2.14	5.18	6.06	5.8	1.17
1/02/90	46	2.35	6.40	6.11	6.2	1.86
1/05/90	49	2.58	6.29	4.64	5.2	1.58
1/09/90	53	5.29	4.23	4.62	4.5	1.55
1/12/90	56	3.09	4.72	5.34	5.1	1.87
1/15/90	59	0.07	3.40	4.03	3.8	0.75
1/18/90	62	0.09	3.03	1.89	2.3	0.36
1/21/90	65	0.06	1.26	1.80	1.6	0.34
1/24/90	68	0.04	1.97	1.31	1.5	0.25
1/27/90	71	0.36	1.18	1.68	1.5	0.23
1/30/90	74	0.05	1.57	1.74	1.7	0.41
2/02/90	77	0.07	1.28	1.40	1.4	0.22
2/05/90	80	0.05	0.98	1.15	1.1	0.20
2/08/90	83	0.05	0.56	0.76	0.7	0.18
4/07/90	141	1.02	0.42	0.50	0.5	0.03
4/10/90	144	2.48	1.38	1.71	1.6	0.11
4/13/90	147	3.51	2.76	2.90	2.9	0.15
4/16/90	150	2.58	1.96	4.00	3.3	0.17
4/20/90	154	1.74	4.46	6.05	5.5	0.17
4/23/90	157	2.56	5.04	5.39	5.3	0.18
4/26/90	160	1.62	5.07	6.00	5.7	0.18
5/01/90	165	0.01	3.33	4.25	3.9	0.12
5/04/90	168	0.01	2.55	3.56	3.2	0.10
5/08/90	172	0.01	1.79	3.02	2.6	0.07
5/11/90	175	5.73	2.66	3.77	3.4	0.14
5/15/90	179	5.65	4.48	5.23	5.0	0.18
5/18/90	182	1.52	5.21	6.22	5.9	0.18
5/22/90	186	0.76	6.45	7.33	7.0	0.24
5/25/90	189	0.61	6.97	8.42	7.9	0.20
5/29/90	193	1.13	6.40	9.01	8.1	0.28
6/01/90	196	1.28	6.61	8.67	8.0	0.26
6/05/90	200	0.62	6.04	7.73	7.2	0.33
6/19/90	214	0.46	7.68	9.19	8.7	0.26
6/22/90	217	0.53	7.85	9.04	8.6	0.26
6/26/90	221	1.03	7.62	8.62	8.3	0.32
6/29/90	224	0.31	7.41	8.73	8.3	0.38
7/03/90	228	1.29	7.14	8.57	8.1	0.34
7/06/90	231	0.96	8.31	8.44	8.4	0.45
7/10/90	235	1.24	7.38	7.31	7.3	1.12
7/13/90	238	1.34	6.29	6.63	6.5	0.89
7/17/90	242	1.23	7.00	7.78	7.5	0.67
7/20/90	245	1.09	8.07	8.19	8.2	0.54
7/24/90	249	1.71	10.67	10.81	10.8	0.61
7/27/90	252	1.38	12.63	12.76	12.7	0.66
7/31/90	256	3.14	20.42	21.52	21.1	1.28
8/03/90	259	3.77	25.94	28.94	27.9	1.49
8/07/90	263	4.60	35.94	39.24	38.1	2.10
8/10/90	266	4.85	37.42	40.35	39.4	1.97
8/14/90	270	3.60	40.88	43.19	42.4	1.77
8/17/90	273	4.37	39.6	47.2	44.7	1.51
8/21/90	277	4.31	48.5	52.8	51.4	1.49
8/24/90	280	4.47	43.9	55.2	51.4	1.59
8/28/90	284	4.00	42.9	53.4	49.9	2.56
8/31/90	287	4.18	51.9	49.6	50.4	2.4
9/11/90	298	4.3	42.7	49.1	47.0	2.8
9/14/90	301	3.9	43.0	51.6	48.7	2.6
9/17/90	304	4.2	46.6	47.5	47.2	2.6

9/21/90	308	4.83	49.0	57.1	54.4	1.4
9/25/90	312	5.79	52.9	57.0	55.6	1.6
9/29/90	316	4.1	49.9	59.1	56.0	1.5
10/02/90	319	4.9	53.3	58.4	56.7	1.6

Table C-6. Soluble Copper Measured in System #2

DATE	DAY	#2 Cu$_{solanx}$ mg/L	#2 Cu$_{solaer}$ mg/L	#2 Cu$_{solavg}$ mg/L	#2 Cu$_{soleff}$ mg/L
12/16/90	29	0	0	0	
12/19/90	32	0.32	0.25	0.27	
12/22/90	35	0.53	0.49	0.51	
12/26/90	39	0.68	0.71	0.7	
12/29/90	42	0.79	0.81	0.8	
1/02/90	46	0.89	0.96	0.94	
1/05/90	49	0.10	1.20	1.13	
1/09/90	53	0.81	0.92	0.88	
1/12/90	56	0.97	0.94	0.95	
1/15/90	59	0.43	0.49	0.47	
1/18/90	62	0.23	0.27	0.26	
1/21/90	65	0.19	0.23	0.22	
1/24/90	68	0.16	0.18	0.17	
1/27/90	71	0.15	0.17	0.16	
1/30/90	74	0.16	0.17	0.16	
2/02/90	77	0.14	0.15	0.14	
2/05/90	80	0.10	0.10	0.10	
2/08/90	83	0.08	0.12	0.10	
4/07/90	141	0.02	0.02	0.02	
4/10/90	144	0.12	0.10	0.11	
4/13/90	147	0.16	0.15	0.16	
4/16/90	150	0.18	0.15	0.16	
4/20/90	154	0.17	0.17	0.17	
4/23/90	157	0.15	0.16	0.16	
4/26/90	160	0.17	0.17	0.17	
5/01/90	165	0.13	0.13	0.13	
5/04/90	168	0.10	0.12	0.11	
5/08/90	172	0.08	0.08	0.08	
5/11/90	175	0.15	0.14	0.14	
5/15/90	179	0.17	0.18	0.17	
5/18/90	182	0.16	0.16	0.16	
5/22/90	186	0.15	0.16	0.16	
5/25/90	189	0.15	0.15	0.15	0.14
5/29/90	193	0.19	0.17	0.18	0.17
6/01/90	196	0.17	0.16	0.16	0.16
6/05/90	200	0.19	0.18	0.18	0.19
6/19/90	214	0.16	0.16	0.16	0.15
6/22/90	217	0.16	0.16	0.16	0.16
6/26/90	221	0.15	0.15	0.15	0.15
6/29/90	224	0.17	0.18	0.18	0.21
7/03/90	228	0.21	0.22	0.22	0.22
7/06/90	231	0.23	0.23	0.23	0.22
7/10/90	235	0.33	0.34	0.33	0.32
7/13/90	238	0.28	0.29	0.29	0.28
7/17/90	242	0.33	0.31	0.31	0.31
7/20/90	245	0.32	0.26	0.28	0.23
7/24/90	249	0.32	0.31	0.32	0.30
7/27/90	252	0.29	0.30	0.29	0.29
7/31/90	256	0.53	0.48	0.5	0.44
8/03/90	259	0.89	0.62	0.71	0.53
8/07/90	263	0.53	0.48	0.5	0.47
8/10/90	266	0.57	0.50	0.52	0.46
8/14/90	270	0.60	0.67	0.64	0.56
8/17/90	273	0.67	0.72	0.71	0.71
8/21/90	277	0.54	0.62	0.59	0.68
8/24/90	280	0.59	0.58	0.58	0.54
8/28/90	284	0.56	0.50	0.52	0.49
8/31/90	287	0.64	0.55	0.58	0.54
9/11/90	298	0.68	0.66	0.67	0.64
9/14/90	301	0.84	0.74	0.77	0.69
9/17/90	304	0.92	0.85	0.87	0.79

9/21/90	308	0.97	0.80	0.86	0.77
9/25/90	312	1.01	0.92	0.95	0.88
9/29/90	316	1.18	0.93	1.01	0.85
10/02/90	319	1.17	0.94	1.02	0.93

Table C-7. **Total Copper Measured in System #1**

DATE	DAY	#1 Cu_{totin} mg/l	#1 Cu_{totanx} mg/l	#1 Cu_{totaer} mg/l	#1 Cu_{totavg} ml/l	#1 Cu_{toteff} mg/l
7/20/90	245	0.014	0.42	0.36	0.4	0.01
7/24/90	249	1.57	5.41	5.20	5.3	0.20
7/27/90	252	1.33	8.16	8.98	8.7	0.24
7/31/90	256	3.46	20.23	21.19	20.9	0.47
8/03/90	259	3.83	26.98	32.08	30.4	0.54
8/07/90	263	4.72	46.96	50.86	49.6	1.33
8/08/90	264	4.34	43.51	45.34	44.7	4.0
8/10/90	266	4.23	52.09	53.59	53.1	1.98
8/14/90	270	4.01	51.02	55.34	53.9	2.07
8/17/90	273	4.76	56.2	57.4	57.0	2.69
8/21/90	277	4.31	55.3	61.6	59.5	2.88
8/24/90	280	4.38	62.2	62.47	62.4	2.56
8/28/90	284	3.96	60.58	70.3	67.1	3.37
8/31/90	287	4.4	66.2	72.5	70.4	2.9
9/11/90	298	4.4	86.4	88.3	87.7	3.0
9/14/90	301	4.4	89.7	91.0	90.6	3.1
9/17/90	304	4.0	91.6	95.1	93.9	3.2
9/21/90	308	4.9	94.8	98.8	97.5	2.3
9/25/90	312	5.3	95.6	102.9	100.5	2.4
9/29/90	316	4.0	116.9	112	113.6	2.1
10/02/90	319	5.0	112.4	118.8	116.7	1.6

Table C-8. Soluble Copper Measured in System #1

DATE	DAY	#1 Cu$_{solanx}$ mg/l	#1 Cu$_{solaer}$ mg/l	#1 Cu$_{solavg}$ mg/l	#1 Cu$_{soleff}$ mg/l
7/20/90	245	0.02	0.02	0.02	0.02
7/24/90	249	0.14	0.16	0.15	0.13
7/27/90	252	0.20	0.20	0.2	0.18
7/31/90	256	0.36	0.36	0.36	0.35
8/03/90	259	0.45	0.44	0.44	0.41
8/07/90	263	1.50	2.42	2.11	1.04
8/08/90	264	0.73		0.73	0.68
8/10/90	266	0.63	0.63	0.63	0.60
8/14/90	270	0.59	0.53	0.55	0.52
8/17/90	273	0.56	0.61	0.59	0.56
8/21/90	277	0.50	0.49	0.49	0.47
8/24/90	280	0.47	0.39	0.41	0.36
8/28/90	284	0.40	0.39	0.39	0.36
8/31/90	287	0.44	0.36	0.39	0.37
9/11/90	298	0.57	0.46	0.5	0.49
9/14/90	301	0.50	0.49	0.49	0.46
9/17/90	304	0.66	0.51	0.56	0.49
9/21/90	308	0.56	0.5	0.52	0.47
9/25/90	312	0.59	0.53	0.55	0.49
9/29/90	316	0.62	0.61	0.61	0.54
10/02/90	319	0.65	0.61	0.62	0.6

Table C-9 Loading of Total Copper per Day per Total MLVSS in System #2, Multiplied by 10,000

DATE	DAY	#2CU$_{in}$ Added mg/day	#2Cu$_{totin}$ Measured mg/day	#2Cu$_{avg.in}$ Measured mg/day	#2MLVSS$_{avg}$ mg/system	Cu$_{in}$/MLVSS Added mg/day/mg /system	Cu$_{avgin}$/MLVSS Measured mg/day/mg /system
12/16/90	29	0	0.26	0.26	2822	0	0.92
12/19/90	32	15	10.16	12.54	2381	63.00	52.67
12/22/90	35	15	10.03	12.54	2507	59.83	50.02
12/26/90	39	15	17.98	12.54	2718	55.19	46.14
12/29/90	42	15	12.85	12.54	2457	61.05	51.04
1/02/90	46	15	14.07	12.54	1922	78.04	65.24
1/05/90	49	15	15.49	12.54	1098	136.61	114.21
1/09/90	53	15	31.75	12.54	941	159.4	133.26
1/12/90	56	15	18.55	12.54	783	191.57	160.15
1/15/90	59	0	0.42	0.42	671	0	6.26
1/18/90	62	0	0.55	0.55	738	0	7.45
1/21/90	65	0	0.38	0.38	671	0	5.66
1/24/90	68	0	0.22	0.22	779	0	2.82
1/27/90	71	0	2.17	2.17	1382	0	15.7
1/30/90	74	0	0.31	0.31	1485	0	2.09
2/02/90	77	0	0.43	0.43	1386	0	3.10
2/05/90	80	0	0.28	0.28	1359	0	2.06
2/08/90	83	0	0.32	0.32	1440	0	2.22
4/07/90	141	0	6.1	0	4275	0	0
4/10/90	144	6	14.87	4.5	4388	13.67	10.26
4/13/90	147	6	21.09	4.5	4284	14.01	10.5
4/16/90	150	6	15.47	4.5	4109	14.6	10.95
4/20/90	154	6	10.46	4.5	5121	11.72	8.79
4/23/90	157	6	15.38	4.5	4649	12.91	9.68
4/26/90	160	6	9.7	4.5	4680	12.82	9.62
5/01/90	165	0	0.08	0.08	4559	0	0.18
5/04/90	168	0	0.05	0.05	4784	0	0.10
5/08/90	172	0	0.05	0.05	4356	0	0.11
5/11/90	175	6	34.39	4.5	4487	13.37	10.03
5/15/90	179	6	33.88	4.5	4491	13.36	10.02
5/18/90	182	6	9.11	4.5	4109	14.6	10.95
5/22/90	186	6	4.57	4.5	4194	14.31	10.73
5/25/90	189	6	3.65	4.5	4307	13.93	10.45
5/29/90	193	6	6.79	4.5	4028	14.9	11.17
6/01/90	196	6	7.67	4.5	3969	15.12	11.34
6/05/90	200	6	3.73	4.5	3839	15.63	11.72
6/19/90	214	6	2.75	4.5	4590	13.07	9.8
6/22/90	217	6	3.17	4.5	4590	13.07	9.8
6/26/90	221	6	6.19	4.50	3924	15.29	11.47
6/29/90	224	6	1.84	4.50	4199	14.29	10.72
7/03/90	228	12	7.72	7.68	4329	27.72	17.74
7/06/90	231	12	5.76	7.68	4019	29.86	19.11
7/10/90	235	12	7.42	7.68	3600	33.33	21.33
7/13/90	238	12	8.01	7.68	3407	35.22	22.54
7/17/90	242	12	7.4	7.68	3186	37.66	24.11
7/20/90	245	12	6.55	7.68	2912	41.21	26.37
7/24/90	249	12	10.26	7.68	3164	37.93	24.27
7/27/90	252	12	8.29	7.68	3384	35.46	22.7
7/31/90	256	30	18.86	25.8	3825	78.43	67.45
8/03/90	259	30	22.64	25.8	4680	64.1	55.13
8/07/90	263	30	27.6	25.8	4982	60.22	51.79
8/08/90	264	30	28.08	25.8	5261	57.02	49.04
8/10/90	266	30	29.09	25.8	5535	54.20	46.61
8/14/90	270	30	21.58	25.8	5760	52.08	44.79
8/17/90	273	30	26.22	25.8	6062	49.49	42.56
8/21/90	277	30	25.86	25.8	5864	51.16	44.00

8/24/90	280	30	26.82	25.8	5729	52.37	45.03
8/28/90	284	30	24.00	25.8	4847	61.89	53.23
8/31/90	287	30	25.08	25.8	5279	56.83	48.87
9/11/90	298	30	25.8	25.8	4815	62.31	53.58
9/14/90	301	30	23.4	25.8	5072	59.15	50.87
9/17/90	304	30	25.2	25.8	4559	65.8	56.59
9/21/90	308	30	28.98	25.8	5387	55.69	47.89
9/25/90	312	30	34.74	25.8	5072	59.15	50.87
9/29/90	316	30	24.6	25.8	4739	63.3	54.44
10/02/90	319	30	29.4	25.8	4770	62.89	54.09

Table C-10. Ratios of Accumulated Soluble and Total Copper per MLVSS, Multiplied by 10,000, in System #2

DATE	DAY	#2Cu$_{solanx}$ /MLVSS	#2Cu$_{solaer}$ /MLVSS	#2Cu$_{solavg}$ /MLVSS	#2Cu$_{totanx}$ /MLVSS	#2Cu$_{totaer}$ /MLVSS	#2Cu$_{totavg}$ /MLVSS
12/16/90	29	0	0	0	4.13	4.66	4.49
12/19/90	32	8.18	4.22	5.19	76.87	47.52	54.76
12/22/90	35	9.54	8.86	9.09	85.21	82.09	83.14
12/26/90	39	10.49	12.25	11.62	83.01	105.6	97.55
12/29/90	42	15.08	14.56	14.73	98.72	109.02	105.72
1/02/90	46	21.76	22.09	21.98	156	140.51	145.47
1/05/90	49	43.36	47.66	46.31	274.16	184.29	212.41
1/09/90	53	40.1	43.26	42.24	208.79	218.25	215.19
1/12/90	56	63.2	51.11	54.66	308.76	289.65	295.25
1/15/90	59	38.58	29.61	31.87	301.87	242.16	257.24
1/18/90	62	20.8	14.07	15.62	269.51	99.89	138.8
1/21/90	65	13.79	15.13	14.71	90.29	117.13	108.72
1/24/90	68	10.47	9.68	9.9	131.2	70.7	88.15
1/27/90	71	6.67	4.79	5.26	51.24	48.37	49.08
1/30/90	74	4.81	5.02	4.95	48.52	52.25	51.03
2/02/90	77	4.37	4.87	4.69	39.38	46.67	44.11
2/05/90	80	2.81	3.71	3.37	28.41	41.0	36.2
2/08/90	83	2.42	3.71	3.27	16.97	24.13	21.67
4/07/90	141	0.31	0.19	0.22	5.68	4.78	5.01
4/10/90	144	1.36	0.99	1.1	16.28	16.46	16.41
4/13/90	147	2.05	1.48	1.64	34.77	28.12	29.97
4/16/90	150	2.46	1.52	1.77	27.17	39.64	36.36
4/20/90	154	1.74	1.36	1.47	45.24	49.78	48.47
4/23/90	157	1.71	1.47	1.54	56.61	48.76	51.01
4/26/90	160	1.89	1.53	1.63	57.64	53.57	54.72
5/01/90	165	1.47	1.24	1.3	38.25	39.15	38.89
5/04/90	168	1.16	1.02	1.06	29.29	30.72	30.33
5/08/90	172	1.06	0.71	0.81	23.12	28.39	26.99
5/11/90	175	1.8	1.3	1.44	32.89	34.57	34.11
5/15/90	179	1.94	1.64	1.73	52.44	48.86	49.88
5/18/90	182	1.99	1.62	1.73	66.85	63.47	64.43
5/22/90	186	1.87	1.58	1.67	78.16	74.44	75.53
5/25/90	189	1.85	1.41	1.53	87.08	81.35	82.95
5/29/90	193	2.48	1.78	1.98	85.91	92.93	90.98
6/01/90	196	2.23	1.73	1.87	88.75	91.22	90.53
6/05/90	200	2.49	2.02	2.16	80.48	85.44	83.98
6/19/90	214	1.73	1.44	1.53	85.31	85.09	85.16
6/22/90	217	1.63	1.54	1.57	82.59	85.67	84.71
6/26/90	221	1.95	1.65	1.74	97.02	94.25	95.08
6/29/90	224	2.11	1.81	1.9	92.65	87.32	88.84
7/03/90	228	2.58	2.14	2.26	87.56	82.84	84.17
7/06/90	231	2.69	2.55	2.6	95.47	93.22	93.95
7/10/90	235	4.29	4.12	4.17	95.84	89.67	91.65
7/13/90	238	3.86	3.75	3.79	86.22	86.05	86.11
7/17/90	242	5.07	4.14	4.42	108.47	105.19	106.18
7/20/90	245	5.64	3.78	4.32	144.05	118.72	126.04
7/24/90	249	4.88	4.3	4.48	161.64	149.13	153.04
7/27/90	252	4.00	3.88	3.92	171.86	167.89	169.19
7/31/90	256	6.72	5.44	5.84	258.43	244.5	248.82
8/03/90	259	9.1	5.77	6.81	264.69	270.47	268.65
8/07/90	263	5.45	4.09	4.49	366.73	335.38	344.64
8/10/90	266	4.67	4.03	4.24	309.21	325.4	320.09
8/14/90	270	4.9	5.1	5.04	335.08	329.69	331.41
8/17/90	273	5.62	5.1	5.25	330	332.39	331.68
8/21/90	277	4.61	4.52	4.54	414.53	385.4	394.12
8/24/90	280	5.26	4.3	4.58	391.96	408.89	403.93
8/28/90	284	6.01	4.38	4.85	461.29	464.35	463.47
8/31/90	287	5.4	4.7	4.93	439.83	423.93	429.26
9/11/90	298	7.01	5.89	6.23	440.21	438.39	438.94
9/14/90	301	8.08	6.32	6.86	413.46	441.03	432.54

9/17/90	304	9.2	8.33	8.62	466	465.69	465.79
9/21/90	308	9.07	6.35	7.16	457.94	453.17	454.6
9/25/90	312	9.18	8.07	8.43	480.91	500	493.79
9/29/90	316	12.55	8.38	9.62	530.85	532.43	531.96
10/02/90	319	12.19	8.47	9.59	555.21	526.13	534.91

Table C-11. Ratios of Accumulated Soluble and Total Copper per MLSS, Multiplied by 10,000, in System #2

DATE	DAY	#2Cu$_{solanx}$ /MLSS	#2Cu$_{solaer}$ /MLSS	#2Cu$_{solavg}$ /MLSS	#2Cu$_{totanx}$ /MLSS	#2Cu$_{totaer}$ /MLSS	#2Cu$_{totavg}$ /MLSS
12/16/89	29	0	0	0	4	4	4
12/19/89	32	7.03	3.63	4.39	66	41	47
12/22/89	35	8.48	7.94	8.19	76	73	74
12/26/89	39	9.34	10.9	10.32	74	94	87
12/29/89	42	13.42	12.96	13.05	88	97	95
1/02/90	46	19.39	20.02	19.87	139	127	131
1/05/90	49	39.02	42.89	41.54	247	166	191
1/09/90	53	36.09	38.94	37.93	188	196	194
1/12/90	56	56.88	46.0	49.22	278	261	264
1/15/90	59	34.72	26.65	28.48	272	218	230
1/18/90	62	18.72	12.67	14.29	243	90	126
1/21/90	65	12.29	12.21	12.29	81	95	89
1/24/90	68	10.47	8.14	8.63	131	59	76
1/27/90	71	6.00	4.31	4.68	46	44	44
1/30/90	74	4.33	4.51	4.36	44	47	46
2/02/90	77	3.79	4.06	3.84	34	39	38
2/05/90	80	2.55	3.3	2.97	26	36	33
2/08/90	83	2.29	3.55	2.97	16	23	21
4/07/90	141	0.26	0.16	0.17	5	4	4
4/10/90	144	1.12	0.83	0.94	13	14	14
4/13/90	147	1.66	1.21	1.38	28	23	25
4/16/90	150	2.02	1.24	1.43	22	32	29
4/20/90	154	1.33	1.02	1.13	35	37	37
4/23/90	157	1.26	1.1	1.16	42	37	38
4/26/90	160	1.39	1.15	1.22	42	40	41
5/01/90	165	1.09	0.92	0.96	28	29	29
5/04/90	168	0.90	0.77	0.79	23	23	23
5/08/90	172	0.82	0.55	0.64	18	22	21
5/11/90	175	1.38	1.01	1.09	25	27	26
5/15/90	179	1.46	1.25	1.29	40	37	38
5/18/90	182	1.37	1.14	1.22	46	44	45
5/22/90	186	1.24	1.04	1.13	52	49	50
5/25/90	189	1.21	0.93	1.03	57	53	54
5/29/90	193	1.62	1.15	1.3	56	60	59
6/01/90	196	1.46	1.11	1.17	58	59	59
6/05/90	200	1.66	1.32	1.38	54	56	55
6/19/90	214	1.16	0.94	1.03	57	55	56
6/22/90	217	1.10	1.00	1.03	55	56	56
6/26/90	221	1.28	1.06	1.11	63	60	61
6/29/90	224	1.42	1.21	1.29	62	58	60
7/03/90	228	1.84	1.52	1.63	63	59	60
7/06/90	231	1.97	1.82	1.85	70	66	68
7/10/90	235	3.28	3.08	3.11	73	67	69
7/13/90	238	3.10	3.01	3.08	69	69	69
7/17/90	242	3.87	3.12	3.32	83	79	80
7/20/90	245	4.10	2.81	3.19	105	88	94
7/24/90	249	3.68	3.17	3.38	122	110	114
7/27/90	252	2.88	2.57	2.62	124	111	115
7/31/90	256	4.74	3.74	4.07	182	168	172
8/03/90	259	6.76	4.26	5.05	197	200	198
8/07/90	263	3.68	2.71	3.01	248	222	229
8/10/90	266	3.17	2.69	2.84	210	217	215
8/14/90	270	3.42	3.44	3.41	234	223	226
8/17/90	273	3.90	3.55	3.67	229	231	231
8/21/90	277	2.93	2.87	2.87	264	244	250
8/24/90	280	3.46	2.84	3.01	258	271	267
8/28/90	284	3.94	2.82	3.12	302	298	299
8/31/90	287	3.70	3.14	3.33	302	283	290
9/11/90	298	5.04	4.07	4.38	316	303	307
9/14/90	301	5.68	4.3	4.7	291	300	297

9/17/90	304	6.43	5.63	5.87	326	315	318
9/21/90	308	6.34	4.44	5.03	320	317	318
9/25/90	312	6.69	5.79	6.08	350	358	356
9/29/90	316	8.94	5.85	6.73	378	372	373
10/02/90	319	9.29	6.27	7.18	423	389	399

Table C-12. Loading of Total Copper per Day per Total MLVSS in System #1, Multiplied by 10,000

DATE	DAY	#1CU$_{in}$ Added mg/day	#1Cu$_{totin}$ Measured mg/day	#1Cu$_{avg.in}$ Measured mg/day	#1MLVSS$_{avg}$ mg/system	Cu$_{in}$/MLVSS Added mg/day/mg /system	Cu$_{avgin}$/MLVSS Measured mg/day/mg /system
7/20/90	245	0	0.04	0.04	8316	0	0.05
7/24/90	249	12	9.44	8.7	7637	15.71	11.39
7/27/90	252	12	7.97	8.7	7682	15.62	11.33
7/31/90	256	30	20.76	26.4	8069	37.18	32.72
8/03/90	259	30	23.0	26.4	8775	34.19	30.09
8/07/90	263	30	28.33	26.4	11385	26.35	23.19
8/08/90	264	30	26.03	26.4	10485	28.61	25.18
8/10/90	266	30	25.36	26.4	11507	26.07	22.94
8/14/90	270	30	24.07	26.4	10157	29.54	25.99
8/17/90	273	30	28.56	26.4	9392	31.94	28.11
8/21/90	277	30	25.86	26.4	9374	32.00	28.16
8/24/90	280	30	26.28	26.4	9644	31.11	27.37
8/28/90	284	30	23.76	26.4	9360	32.05	28.21
8/31/90	287	30	26.4	26.4	9752	30.76	27.07
9/11/90	298	30	26.4	26.4	10409	28.82	25.36
9/14/90	301	30	26.4	26.4	10697	28.05	24.68
9/17/90	304	30	24.0	26.4	10170	29.50	25.96
9/21/90	308	30	29.4	26.4	10935	27.43	24.14
9/25/90	312	30	31.8	26.4	10350	28.99	25.51
9/29/90	316	30	24.0	26.4	11327	26.49	23.31
10/02/90	319	30	30.0	26.4	11250	26.67	23.47

Table C-13. Ratios of Accumulated Soluble and Total Copper per MLVSS, Multiplied by 10,000, in System #1

DATE	DAY	#1Cu$_{solanx}$ /MLVSS	#1Cu$_{solaer}$ /MLVSS	#1Cu$_{solavg}$ /MLVSS	#1Cu$_{totanx}$ /MLVSS	#1Cu$_{totaer}$ /MLVSS	#1Cu$_{totavg}$ /MLVSS
7/20/90	245	0.09	0.11	0.1	2.11	2.04	2.07
7/24/90	249	0.74	0.95	0.87	29.71	31.8	31.06
7/27/90	252	1.19	1.13	1.15	49.73	51.63	51.02
7/31/90	256	2.11	1.97	2.02	117.63	115.8	116.39
8/03/90	259	2.77	2.09	2.28	166.54	151.68	155.79
8/07/90	263	6.16	9.4	8.36	193.25	197.13	195.89
8/08/90	264	3.04	3.19	3.13	180.54	197.99	191.97
8/10/90	266	2.37	2.5	2.46	195.09	214.36	207.65
8/14/90	270	2.74	2.3	2.44	237.3	239.57	238.85
8/17/90	273	2.75	2.89	2.84	278.22	270.75	273.16
8/21/90	277	2.56	2.26	2.35	283.59	286.51	285.6
8/24/90	280	2.22	1.79	1.93	294.79	289.21	291.04
8/28/90	284	2.13	1.76	1.87	325.7	321	322.4
8/31/90	287	2.16	1.61	1.78	324.51	325.11	324.92
9/11/90	298	2.48	1.98	2.15	375.65	380.6	378.96
9/14/90	301	2.13	2.05	2.08	381.7	380.75	381.07
9/17/90	304	2.97	2.24	2.48	412.61	417.11	415.63
9/21/90	308	2.42	2.01	2.14	410.39	396.79	401.1
9/25/90	312	2.71	2.25	2.39	438.53	436.02	436.81
9/29/90	316	2.38	2.47	2.44	447.89	453.44	451.52
10/02/90	319	2.71	2.39	2.49	468.33	465.88	466.67

Table C-14. Ratios of Accumulated Soluble and Total Copper per MLSS, Multiplied by 10,000, in System #1

DATE	DAY	#1Cu$_{solanx}$ /MLSS	#1Cu$_{solaer}$ /MLSS	#1Cu$_{solavg}$ /MLSS	#1Cu$_{totanx}$ /MLSS	#1Cu$_{totaer}$ /MLSS	#1Cu$_{totavg}$ /MLSS
7/20/90	245	0.07	0.08	0.08	2	2	2
7/24/90	249	0.57	0.73	0.68	23	25	24
7/27/90	252	0.91	0.86	0.89	38	39	39
7/31/90	256	1.57	1.46	1.49	88	86	86
8/03/90	259	2.09	1.55	1.68	125	113	116
8/07/90	263	4.32	6.71	5.93	136	141	139
8/08/90	264	2.14		2.22	127	140	136
8/10/90	266	1.64	1.74	1.71	135	149	144
8/14/90	270	1.86	1.57	1.66	161	163	163
8/17/90	273	1.87	1.99	1.94	189	186	187
8/21/90	277	1.73	1.54	1.60	191	195	194
8/24/90	280	1.51	1.21	1.30	201	195	197
8/28/90	284	1.41	1.17	1.25	215	214	215
8/31/90	287	1.47	1.09	1.22	221	220	220
9/11/90	298	1.69	1.33	1.46	256	255	255
9/14/90	301	1.43	1.38	1.39	256	256	256
9/17/90	304	1.97	1.48	1.64	273	276	275
9/21/90	308	1.66	1.36	1.45	280	268	272
9/25/90	312	1.85	1.52	1.63	300	296	297
9/29/90	316	1.59	1.64	1.62	299	302	301
10/02/90	319	1.84	1.61	1.67	318	313	315

Table C-15a. Copper Balance in System #2

DATE	DAY	#2Cu$_{totaer}$ mg/l	#2Cu$_{totanx}$ mg/l	#2Cu$_{totavg}$ mg/l	#2Cu$_{tot}$ mg/reactor	#2Cu$_{toteff}$ mg/l	#2Q$_w$ l/day
12/16/90	29	0.296	0.252	0.28	1.3	0.021	0
	30	0.93	1.2	1.02	4.6	0.166	0.528
	31	1.87	2.1	1.95	8.8	0.31	0.528
12/19/90	32	2.84	3.008	2.9	13.1	0.455	0.528
	33	3.4	3.6	3.47	15.6	0.547	0.431
	34	4.0	4.2	4.07	18.3	0.639	0.431
12/22/90	35	4.556	4.772	4.63	20.8	0.731	0.231
	36	5.0	4.95	4.98	22.4	0.83	0.27
	37	5.4	5.1	5.3	23.9	0.928	0.27
	38	5.8	5.25	5.62	25.3	1.027	0.27
12/26/90	39	6.156	5.356	5.89	26.5	1.125	0.2
	40	6.167	5.333	5.89	26.5	1.14	0
	41	6.133	5.267	5.84	26.3	1.154	0
12/29/90	42	6.064	5.184	5.77	26.0	1.169	0.2
	43	6.1	5.5	5.9	26.6	1.341	0
	44	6.1	5.8	6.0	27.0	1.513	0
	45	6.1	6.1	6.1	27.5	1.685	0
1/02/90	46	6.112	6.396	6.21	27.9	1.857	0.2
	47	5.6	6.367	5.86	26.4	1.763	0
	48	5.1	6.333	5.51	24.8	1.67	0
1/05/90	49	4.644	6.292	5.19	23.4	1.576	0.177
	50	4.6	5.775	4.99	22.5	1.57	0
	51	4.6	5.25	4.82	21.7	1.563	0
	52	4.6	4.725	4.64	20.9	1.557	0
1/09/90	53	4.616	4.228	4.49	20.2	1.55	0.2
	54	4.83	4.393	4.68	21.1	1.656	0
	55	5.066	4.559	4.9	22.1	1.763	0
1/12/90	56	5.344	4.724	5.14	23.1	1.869	0.2
	57	4.91	4.281	4.7	21.2	1.497	0
	58	4.47	3.839	4.26	19.2	1.124	0
1/15/90	59	4.032	3.396	3.82	17.2	0.752	0.2
	60	3.318	3.275	3.3	14.9	0.621	0
	61	2.603	3.153	2.79	12.6	0.491	0
1/18/90	62	1.888	3.032	2.27	10.2	0.36	0.2
	63	1.857	2.443	2.05	9.2	0.354	0
	64	1.827	1.853	1.84	8.3	0.347	0
1/21/90	65	1.796	1.264	1.62	7.3	0.341	0.18
	66	1.633	1.499	1.59	7.2	0.31	0
	67	1.471	1.733	1.56	7.0	0.279	0
1/24/90	68	1.308	1.968	1.53	6.9	0.248	0.15
	69	1.4307	1.704	1.52	6.8	0.242	0
	70	1.553	1.44	1.52	6.8	0.235	0
1/27/90	71	1.676	1.176	1.51	6.8	0.229	0.15
	72	1.697	1.308	1.57	7.1	0.289	0
	73	1.719	1.44	1.63	7.3	0.349	0
1/30/90	74	1.74	1.572	1.68	7.6	0.409	0.15
	75	1.627	1.475	1.58	7.1	0.347	0
	76	1.513	1.377	1.47	6.6	0.285	0
2/02/90	77	1.4	1.28	1.36	6.1	0.223	0.15
	78	1.316	1.18	1.27	5.7	0.215	0
	79	1.232	1.08	1.18	5.3	0.207	0
2/05/90	80	1.148	0.98	1.09	4.9	0.199	0
	81	1.0187	0.84	0.96	4.3	0.192	0
	82	0.889	0.7	0.83	3.7	0.184	0
2/08/90	83	0.76	0.56	0.69	3.1	0.177	0.15
4/07/90	141	0.504	0.42	0.48	2.2	0.034	0.276
	142	0.907	0.739	0.85	3.8	0.058	0.294
	143	1.309	1.057	1.23	5.5	0.081	0.294
4/10/90	144	1.712	1.376	1.6	7.2	0.105	0.294
	145	2.107	1.839	2.02	9.1	0.118	0.292
	146	2.501	2.301	2.43	10.9	0.132	0.292

4/13/90	147	2.896	2.764	2.85	12.8	0.145	0.292
	148	3.265	2.495	3.01	13.5	0.152	0.289
	149	3.635	2.225	3.17	14.3	0.16	0.289
4/16/90	150	4.004	1.956	3.32	14.9	0.167	0.289
	151	4.515	2.581	3.87	17.4	0.168	0.286
	152	5.026	3.206	4.42	19.9	0.169	0.286
	153	5.537	3.831	4.97	22.4	0.171	0.286
4/20/90	154	6.048	4.456	5.52	24.8	0.172	0.286
	155	5.828	4.65	5.44	24.5	0.176	0.285
	156	5.608	4.844	5.35	24.1	0.18	0.285
4/23/90	157	5.388	5.038	5.27	23.7	0.184	0.285
	158	5.592	5.049	5.41	24.3	0.181	0.268
	159	5.796	5.061	5.55	25.0	0.179	0.268
4/26/90	160	6.0	5.072	5.69	25.6	0.176	0.268
	161	5.65	4.723	5.34	24.0	0.165	0.283
	162	5.299	4.374	4.99	22.5	0.154	0.283
	163	4.949	4.026	4.64	20.9	0.144	0.283
	164	4.598	3.677	4.29	19.3	0.133	0.283
5/01/90	165	4.248	3.328	3.94	17.7	0.122	0.283
	166	4.02	3.068	3.7	16.7	0.113	0.287
	167	3.792	2.808	3.46	15.6	0.105	0.287
5/04/90	168	3.564	2.548	3.23	14.5	0.096	0.287
	169	3.429	2.359	3.07	13.8	0.089	0.292
	170	3.294	2.17	2.92	13.1	0.083	0.292
	171	3.159	1.981	2.77	12.5	0.076	0.292
5/08/90	172	3.024	1.792	2.61	11.7	0.069	0.292
	173	3.272	2.083	2.88	13.0	0.093	0.292
	174	3.52	2.373	3.14	14.1	0.117	0.292
5/11/90	175	3.768	2.664	3.4	15.3	0.141	0.292
	176	4.133	3.119	3.8	17.1	0.15	0.273
	177	4.498	3.574	4.19	18.9	0.159	0.273
	178	4.863	4.029	4.59	20.7	0.168	0.273
5/15/90	179	5.228	4.484	4.98	22.4	0.177	0.273
	180	5.559	4.727	5.28	23.8	0.179	0.267
	181	5.889	4.971	5.58	25.1	0.181	0.267
5/18/90	182	6.22	5.214	5.88	26.5	0.183	0.267
	183	6.498	5.523	6.17	27.8	0.196	0.264
	184	6.776	5.831	6.46	29.1	0.209	0.264
	185	7.054	6.14	6.75	30.4	0.222	0.264
5/22/90	186	7.332	6.448	7.04	31.7	0.235	0.264
	187	7.695	6.621	7.34	33.0	0.224	0.231
	188	8.057	6.793	7.64	34.4	0.213	0.231
5/25/90	189	8.42	6.966	7.94	35.7	0.202	0.24
	190	8.569	6.825	7.99	36.0	0.221	0.244
	191	8.717	6.683	8.04	36.2	0.24	0.244
	192	8.866	6.542	8.09	36.4	0.258	0.244
5/29/90	193	9.014	6.4	8.14	36.6	0.277	0.244
	194	8.898	6.471	8.09	36.4	0.271	0.21
	195	8.782	6.541	8.04	36.2	0.266	0.21
6/01/90	196	8.666	6.612	7.98	35.9	0.26	0.24
	197	8.433	6.468	7.78	35.0	0.276	0.223
	198	8.199	6.324	7.57	34.1	0.293	0.223
	199	7.966	6.18	7.37	33.2	0.309	0.223
6/05/90	200	7.732	6.036	7.17	32.3	0.325	0.24
	201	7.836	6.153	7.28	32.8	0.321	0.177
	202	7.94	6.271	7.38	33.2	0.316	0.177
	203	8.044	6.388	7.49	33.7	0.312	0.177
	204	8.149	6.505	7.6	34.2	0.308	0.177
	205	8.253	6.622	7.71	34.7	0.303	0.177
	206	8.357	6.74	7.82	35.2	0.299	0.177
	207	8.461	6.857	7.93	35.7	0.295	0.177
	208	8.565	6.974	8.03	36.1	0.29	0.177
	209	8.669	7.092	8.14	36.6	0.286	0.177
	210	8.773	7.209	8.25	37.1	0.281	0.177
	211	8.878	7.326	8.36	37.6	0.277	0.177
	212	8.982	7.443	8.47	38.1	0.273	0.177
	213	9.086	7.561	8.58	38.6	0.268	0.177

6/19/90	214	9.19	7.678	8.69	39.1	0.264	0.24
	215	9.139	7.734	8.67	39.0	0.262	0.216
	216	9.089	7.79	8.66	39.0	0.26	0.216
6/22/90	217	9.038	7.846	8.64	38.9	0.258	0.24
	218	8.935	7.789	8.55	38.5	0.273	0.227
	219	8.831	7.731	8.46	38.1	0.287	0.227
	220	8.728	7.674	8.38	37.7	0.302	0.227
6/26/90	221	8.624	7.616	8.29	37.3	0.316	0.24
	222	8.66	7.548	8.29	37.3	0.336	0.183
	223	8.696	7.48	8.29	37.3	0.356	0.183
6/29/90	224	8.732	7.412	8.29	37.3	0.376	0.24
	225	8.693	7.343	8.24	37.1	0.367	0.176
	226	8.653	7.274	8.19	36.9	0.359	0.176
	227	8.614	7.205	8.14	36.6	0.35	0.176
7/03/90	228	8.574	7.136	8.09	36.4	0.341	0.24
	229	8.528	7.526	8.19	36.9	0.377	0.266
	230	8.482	7.916	8.29	37.3	0.412	0.266
7/06/90	231	8.436	8.306	8.39	37.8	0.448	0.266
	232	8.154	8.075	8.13	36.6	0.636	0.154
	233	7.872	7.843	7.86	35.4	0.824	0.154
	234	7.59	7.612	7.6	34.2	1.012	0.154
7/10/90	235	7.308	7.38	7.33	33.0	1.12	0.23
	236	7.081	7.018	7.06	31.8	1.043	0
	237	6.853	6.656	6.79	30.6	0.965	0
7/13/90	238	6.626	6.294	6.52	29.3	0.888	0.145
	239	6.916	6.47	6.77	30.5	0.834	0
	240	7.205	6.645	7.02	31.6	0.779	0
	241	7.495	6.821	7.27	32.7	0.725	0
7/17/90	242	7.784	6.996	7.52	33.8	0.67	0.145
	243	7.92	7.353	7.73	34.8	0.625	0
	244	8.056	7.71	7.94	35.7	0.58	0
7/20/90	245	8.192	8.067	8.15	36.7	0.535	0.19
	246	8.847	8.717	8.8	39.6	0.553	0
	247	9.502	9.368	9.46	42.6	0.571	0
	248	10.157	10.018	10.11	45.5	0.589	0
7/24/90	249	10.812	10.668	10.76	48.4	0.607	0.165
	250	11.461	11.323	11.42	51.4	0.624	0.107
	251	12.111	11.977	12.07	54.3	0.64	0.136
7/27/90	252	12.76	12.632	12.72	57.2	0.657	0.155
	253	14.949	14.578	14.83	66.7	0.812	0.125
	254	17.138	16.524	16.93	76.2	0.967	0.14
	255	19.327	18.47	19.04	85.7	1.121	0.14
7/31/90	256	21.516	20.416	21.15	95.2	1.276	0.145
	257	23.991	22.257	23.41	105.3	1.347	0.37
	258	26.465	24.099	25.68	115.6	1.419	0.91
8/03/90	259	28.94	25.94	27.94	125.7	1.49	0.145
	260	31.515	28.44	30.49	137.2	1.642	0.131
	261	34.09	30.94	33.04	148.7	1.794	0.138
	262	36.665	33.44	35.59	160.2	1.945	0.138
8/07/90	263	39.24	35.94	38.14	171.6	2.097	0.14
8/08/90	264	39.61	36.432	38.55	173.5	2.053	0.217
	265	39.98	36.923	38.96	175.3	2.01	0.217
8/10/90	266	40.35	37.415	39.37	177.2	1.966	0.217
	267	41.06	38.281	40.13	180.6	1.917	0.24
	268	41.77	39.148	40.9	184.1	1.867	0.24
	269	42.48	40.014	41.66	187.5	1.818	0.24
8/14/90	270	43.19	40.88	42.42	190.9	1.768	0.24
	271	44.527	40.453	43.17	194.3	1.682	0.232
	272	45.863	40.027	43.92	197.6	1.596	0.232
8/17/90	273	47.2	39.6	44.67	201	1.51	0.232
	274	48.6	41.825	46.34	208.5	1.505	0.23
	275	50.0	44.05	48.02	216.1	1.5	0.23
	276	51.4	46.275	49.69	223.6	1.495	0.23
8/21/90	277	52.8	48.5	51.37	231.2	1.49	0.23
	278	53.6	46.967	51.39	231.3	1.523	0.224
	279	54.4	45.433	51.41	231.3	1.557	0.224
8/24/90	280	55.2	43.9	51.43	231.4	1.59	0.224

	281	54.75	43.65	51.05	229.7	1.833	0.207
	282	54.3	43.4	50.67	228	2.075	0.207
	283	53.85	43.15	50.28	226.3	2.318	0.207
8/28/90	284	53.4	42.9	49.9	224.6	2.56	0.202
	285	52.133	45.9	50.06	225.3	2.507	0.202
	286	50.867	48.9	50.21	225.9	2.453	0.202
8/31/90	287	49.6	51.9	50.37	226.7	2.4	0.202
	288	49.555	51.064	50.06	225.3	2.436	0.202
	289	49.509	50.227	49.75	223.9	2.73	0.202
	290	49.464	49.391	49.44	222.5	2.509	0.198
	291	49.418	48.555	49.13	221.1	2.545	0.198
	292	49.373	47.718	48.82	219.7	2.582	0.198
	293	49.327	46.882	48.51	218.3	2.618	0.198
	294	49.282	46.045	48.2	216.9	2.655	0.198
	295	49.236	45.209	47.89	215.5	2.691	0.198
	296	49.191	44.373	47.59	214.2	2.727	0.198
	297	49.145	43.536	47.28	212.8	2.764	0.198
9/11/90	298	49.1	42.7	46.97	211.4	2.8	0.215
	299	49.933	42.8	47.56	214	2.733	0.122
	300	50.767	42.9	48.14	216.6	2.667	0.122
9/14/90	301	51.6	43.0	48.73	219.3	2.6	0.122
	302	50.233	44.2	48.22	217	2.6	0.171
	303	48.867	45.4	47.71	214.7	2.6	0.171
9/17/90	304	47.5	46.6	47.2	212.4	2.6	0.173
	305	49.9	47.2	49.0	220.5	2.3	0.173
	306	52.3	47.8	50.8	228.6	2.0	0.173
	307	54.7	48.4	52.6	236.7	1.7	0.173
9/21/90	308	57.1	49.0	54.4	244.8	1.4	0.234
	309	57.075	49.975	54.71	246.2	1.45	0.234
	310	57.05	50.95	55.02	247.6	1.5	0.234
	311	57.025	51.925	55.33	249	1.55	0.234
9/25/90	312	57.0	52.9	55.63	250.3	1.6	0.232
	313	57.525	52.15	55.73	250.8	1.575	0.232
	314	58.05	51.4	55.83	251.2	1.55	0.232
	315	58.575	50.65	55.93	251.7	1.525	0.232
9/29/90	316	59.1	49.9	56.03	252.1	1.5	0.238
	317	58.867	51.033	56.26	253.2	1.533	0.213
	318	58.633	52.167	56.48	254.2	1.567	0.213
10/02/90	319	58.4	53.3	56.7	255.2	1.6	0

Table C-15b. Copper Balance in System #2

DATE	DAY	#2Cu_{in} Added mg/l	#2$Cu_{dencity}$ Added Theory mg/l	#2Cu_{tot} Added Theory mg/reactor	#2Cu_{in} Avg. Measured mg/l	#2Cu_{tot} Measured Theory mg/reactor	#2$Cu_{dencity}$ Measured Theory mg/l	#2TOTCU mg/reactor
12/16/90	29	0	0.28	1.27	0.044	1.27	0.28	1.3
	30	2.5	3.07	13.8	2.09	11.5	2.56	4.6
	31	2.5	5.4	24.3	2.09	20.0	4.44	8.8
12/19/90	32	2.5	7.33	33.0	2.09	26.9	5.98	13.1
	33	2.5	9.11	41.0	2.09	33.2	7.38	15.6
	34	2.5	10.64	47.9	2.09	38.5	8.56	18.3
12/22/90	35	2.5	12.4	55.8	2.09	44.5	9.89	20.8
	36	2.5	13.84	62.3	2.09	49.3	10.96	22.4
	37	2.5	15.09	67.9	2.09	53.3	11.84	23.9
	38	2.5	16.16	72.7	2.09	56.6	12.58	25.3
12/26/90	39	2.5	17.27	77.7	2.09	59.9	13.33	26.5
	40	2.5	19.09	85.9	2.09	65.6	14.6	26.5
	41	2.5	20.89	94.0	2.09	71.2	15.84	26.3
12/29/90	42	2.5	21.76	97.9	2.09	73.7	16.4	26.0
	43	2.5	23.31	104.9	2.09	78.2	17.4	26.6
	44	2.5	24.62	110.8	2.09	81.7	18.18	27.0
	45	2.5	25.71	115.7	2.09	84.1	18.71	27.5
1/02/90	46	2.5	25.51	114.8	2.09	82.2	18.29	27.9
	47	2.5	26.49	119.2	2.09	84.2	18.73	26.4
	48	2.5	27.6	124.2	2.09	86.7	19.29	24.8
1/05/90	49	2.5	27.8	125.1	2.09	86.6	19.29	23.4
	50	2.5	29.04	130.7	2.09	89.7	19.98	22.5
	51	2.5	30.29	136.3	2.09	92.9	20.69	21.7
	52	2.5	31.51	141.8	2.09	96.2	21.38	20.9
1/09/90	53	2.5	31.44	141.5	2.09	95.5	21.22	20.2
	54	2.5	32.58	146.6	2.09	98.1	21.8	21.1
	55	2.5	33.56	151.0	2.09	100.1	22.24	22.1
1/12/90	56	2.5	33.02	148.6	2.09	97.5	21.67	23.1
	57	2.5	34.36	154.6	2.09	101.1	22.47	21.2
	58	0	32.87	147.9	0.07	94.8	21.07	19.2
1/15/90	59	0	30.53	137.4	0.07	87.0	19.33	17.2
	60	0	29.71	133.7	0.07	83.7	18.6	14.9
	61	0	29.07	130.8	0.07	81.2	18.04	12.6
1/18/90	62	0	27.38	123.2	0.091	76.3	16.96	10.2
	63	0	26.91	121.1	0.091	74.7	16.6	9.2
	64	0	26.44	119	0.091	73.2	16.27	8.3
1/21/90	65	0	25.0	112.5	0.064	68.8	15.29	7.3
	66	0	24.58	110.6	0.064	67.3	14.96	7.2
	67	0	24.2	108.9	0.064	66.0	14.67	7.0
1/24/90	68	0	23.11	104	0.037	62.7	13.93	6.9
	69	0	22.78	102.5	0.037	61.5	13.67	6.8
	70	0	22.47	101.1	0.037	60.3	13.4	6.8
1/27/90	71	0	21.44	96.5	0.051	57.4	12.76	6.8
	72	0	21.07	94.8	0.051	56.0	12.44	7.1
	73	0	20.6	92.7	0.051	54.2	12.04	7.3
1/30/90	74	0	19.42	87.4	0.051	50.4	11.2	7.6
	75	0	18.96	85.3	0.051	48.6	10.8	7.1
	76	0	18.58	83.6	0.051	47.2	10.49	6.6
2/02/90	77	0	17.69	79.6	0.072	44.8	9.96	6.1
	78	0	17.4	78.3	0.072	43.9	9.76	5.7
	79	0	17.13	77.1	0.072	43.1	9.58	5.3
2/05/90	80	0	16.87	75.9	0.046	42.2	9.38	4.9
	81	0	16.6	74.7	0.046	41.3	9.18	4.3
	82	0	16.36	73.6	0.046	40.5	9.0	3.7
2/08/90	83	0	15.63	70.3	0.053	38.4	8.54	3.1
4/07/90	141	0	0.5	2.27	0	2.27	0.5	2.2
	142	1	1.67	7.5	0.75	6	1.33	3.8
	143	1	2.71	12.2	0.75	9.4	2.09	5.5
4/10/90	144	1	3.67	16.5	0.75	12.5	2.78	7.2

	145	1	4.56	20.5	0.75	15.3	3.4	9.1
	146	1	5.38	24.2	0.75	17.9	3.98	10.9
4/13/90	147	1	6.13	27.6	0.75	20.3	4.51	12.8
	148	1	6.84	30.8	0.75	22.5	5.0	13.5
	149	1	7.49	33.7	0.75	24.5	5.44	14.3
4/16/90	150	1	8.09	36.4	0.75	26.4	5.84	14.9
	151	1	8.67	39.0	0.75	28.2	6.22	17.4
	152	1	9.2	41.4	0.75	29.9	6.58	19.9
	153	1	9.71	43.7	0.75	31.4	6.91	22.4
4/20/90	154	1	10.18	45.8	0.75	32.9	7.22	24.8
	155	1	10.62	47.8	0.75	34.3	7.51	24.5
	156	1	11.02	49.6	0.75	35.6	7.78	24.1
4/23/90	157	1	11.4	51.3	0.75	36.8	8.02	23.7
	158	1	11.8	53.1	0.75	38.0	8.29	24.3
	159	1	12.18	54.8	0.75	39.2	8.53	25.0
4/26/90	160	1	12.53	56.4	0.75	40.3	8.78	25.6
	161	0	11.6	52.2	0.75	41.3	9.0	24.0
	162	0	10.73	48.3	0.013	38.2	8.29	22.5
	163	0	9.93	44.7	0.013	35.3	7.62	20.9
	164	0	9.2	41.4	0.013	32.6	7.02	19.3
5/01/90	165	0	8.51	38.3	0.013	30.1	6.47	17.7
	166	0	7.87	35.4	0.008	27.8	5.93	16.7
	167	0	7.27	32.7	0.008	25.7	5.44	15.6
5/04/90	168	0	6.71	30.2	0.008	23.8	5.0	14.5
	169	0	6.2	27.9	0.008	22.0	4.58	13.8
	170	0	5.73	25.8	0.008	20.3	4.2	13.1
	171	0	5.29	23.8	0.008	18.8	3.84	12.5
5/08/90	172	0	4.89	22.0	0.009	17.4	3.51	11.7
	173	0	4.49	20.2	0.009	16.0	3.18	13.0
	174	1	5.33	24.0	0.75	18.7	3.76	14.1
5/11/90	175	1	6.09	27.4	0.75	21.1	4.27	15.3
	176	1	6.82	30.7	0.75	23.4	4.76	17.1
	177	1	7.51	33.8	0.75	25.6	5.2	18.9
	178	1	8.13	36.6	0.75	27.6	5.62	20.7
5/15/90	179	1	8.71	39.2	0.75	29.4	6.0	22.4
	180	1	9.27	41.7	0.75	31.2	6.36	23.8
	181	1	9.8	44.1	0.75	32.9	6.69	25.1
5/18/90	182	1	10.29	46.3	0.75	34.5	7.0	26.5
	183	1	10.76	48.4	0.75	36.0	7.29	27.8
	184	1	11.12	50.0	0.75	35.6	7.92	29.1
	185	1	11.49	51.7	0.75	36.7	8.16	30.4
5/22/90	186	1	11.82	53.2	0.75	37.6	8.36	31.7
	187	1	12.24	55.1	0.75	38.8	8.62	33.0
	188	1	12.64	56.9	0.75	40.0	8.89	34.4
5/25/90	189	1	13.02	58.6	0.75	41.1	9.13	35.7
	190	1	13.36	60.1	0.75	42.0	9.36	36.0
	191	1	13.64	61.4	0.75	42.8	9.53	36.2
	192	1	13.89	62.5	0.75	43.5	9.69	36.4
5/29/90	193	1	14.11	63.5	0.75	44.0	9.8	36.6
	194	1	14.42	64.9	0.75	44.8	9.98	36.4
	195	1	14.73	66.3	0.75	45.6	10.16	36.2
6/01/90	196	1	14.93	67.2	0.75	46.1	10.27	35.9
	197	1	15.16	68.2	0.75	46.7	10.4	35.0
	198	1	15.36	69.1	0.75	47.2	10.51	34.1
	199	1	15.51	69.8	0.75	47.6	10.6	33.2
6/05/90	200	1	15.6	70.2	0.75	47.7	10.62	32.3
	201	1	15.89	71.5	0.75	48.4	10.78	32.8
	202	1	16.18	72.8	0.75	49.1	10.93	33.2
	203	1	16.47	74.1	0.75	49.8	11.09	33.7
	204	1	16.73	75.3	0.75	50.5	11.24	34.2
	205	1	17.0	76.5	0.75	51.2	11.4	34.7
	206	1	17.27	77.7	0.75	51.9	11.56	35.2
	207	1	17.53	78.9	0.75	52.6	11.71	35.7
	208	1	17.8	80.1	0.75	53.3	11.87	36.1
	209	1	18.04	81.2	0.75	54.0	12.02	36.6
	210	1	18.29	82.3	0.75	54.7	12.18	37.1
	211	1	18.53	83.4	0.75	55.4	12.33	37.6

	212	1	18.78	84.5	0.75	56.1	12.49	38.1
	213	1	19.02	85.6	0.75	56.8	12.64	38.6
6/19/90	214	1	19.0	85.5	0.75	56.7	12.64	39.1
	215	1	19.09	85.9	0.75	56.9	12.71	39.0
	216	1	19.16	86.2	0.75	57.1	12.78	39.0
6/22/90	217	1	19.13	86.1	0.75	57.0	12.78	38.9
	218	1	19.16	86.2	0.75	57.0	12.78	38.5
	219	1	19.16	86.2	0.75	56.9	12.78	38.1
	220	1	19.13	86.1	0.75	56.8	12.76	37.7
6/26/90	221	1	19.04	85.7	0.75	56.4	12.69	37.3
	222	1	19.16	86.2	0.75	56.6	12.73	37.3
	223	1	19.24	86.6	0.75	56.7	12.76	37.3
6/29/90	224	1	19.07	85.8	0.75	56.0	12.6	37.3
	225	1	19.18	86.3	0.75	56.1	12.64	37.1
	226	2	20.58	92.6	1.28	59.3	13.38	36.9
	227	2	21.93	98.7	1.28	62.5	14.09	36.6
7/03/90	228	2	22.93	103.2	1.28	64.7	14.6	36.4
	229	2	23.71	106.7	1.28	66.2	14.96	36.9
	230	2	24.4	109.8	1.28	67.5	15.24	37.3
7/06/90	231	2	25.02	112.6	1.28	68.5	15.49	37.8
	232	2	25.98	116.9	1.28	70.0	15.84	36.6
	233	2	26.67	120	1.28	70.4	15.96	35.4
	234	2	27.09	121.9	1.28	69.7	15.82	34.2
7/10/90	235	2	26.93	121.2	1.28	67.4	15.33	33.0
	236	2	28.2	126.9	1.28	68.8	15.64	31.8
	237	2	29.58	133.1	1.28	70.7	16.07	30.6
7/13/90	238	2	30.11	135.5	1.28	70.8	16.11	29.3
	239	2	31.67	142.5	1.28	73.5	16.71	30.5
	240	2	33.29	149.8	1.28	76.5	17.38	31.6
	241	2	35	157.5	1.28	79.8	18.11	32.7
7/17/90	242	2	35.64	160.4	1.28	80.9	18.38	33.8
	243	2	37.49	168.7	1.28	84.8	19.24	34.8
	244	2	39.38	177.2	1.28	89.0	20.18	35.7
7/20/90	245	2	39.67	178.5	1.28	89.7	20.36	36.7
	246	2	41.6	187.2	1.28	94.1	21.33	39.6
	247	2	43.51	195.8	1.28	98.4	22.29	42.6
	248	2	45.4	204.3	1.28	102.5	23.2	45.5
7/24/90	249	2	45.6	205.2	1.28	102.8	23.29	48.4
	250	2	46.36	208.6	1.28	104.3	23.62	51.4
	251	2	46.78	210.5	1.28	105	23.8	54.3
7/27/90	252	2	46.98	211.4	1.28	105.1	23.84	57.2
	253	2	47.27	212.7	1.28	105	23.84	66.7
	254	5	51.09	229.9	4.3	121.3	27.49	76.2
	255	5	54.6	245.7	4.3	136.2	30.82	85.7
7/31/90	256	5	57.73	259.8	4.3	149.6	33.82	95.2
	257	5	57.93	260.7	4.3	154.9	35.04	105.3
	258	5	52.36	235.6	4.3	143.7	32.71	115.6
8/03/90	259	5	55.29	248.8	4.3	155.6	35.4	125.7
	260	5	58.11	261.5	4.3	166.8	37.91	137.2
	261	5	60.58	272.6	4.3	176.5	40.11	148.7
	262	5	62.78	282.5	4.3	185.1	42.04	160.2
8/07/90	263	5	64.69	291.1	4.3	192.5	43.71	171.6
8/08/90	264	5	65.53	294.9	4.3	196.7	44.69	173.5
	265	5	66.4	298.8	4.3	201	45.69	175.3
8/10/90	266	5	67.29	302.8	4.3	205.3	46.69	177.2
	267	5	67.87	305.4	4.3	208.7	47.49	180.6
	268	5	68.47	308.1	4.3	212.2	48.31	184.1
	269	5	69.11	311	4.3	215.7	49.16	187.5
8/14/90	270	5	69.78	314	4.3	219.3	50.02	190.9
	271	5	70.62	317.8	4.3	223.6	51.02	194.3
	272	5	71.53	321.9	4.3	228.1	52.09	197.6
8/17/90	273	5	72.51	326.3	4.3	232.8	53.2	201
	274	5	73.47	330.6	4.3	237.4	54.29	208.5
	275	5	74.38	334.7	4.3	241.8	55.33	216.1
	276	5	75.24	338.6	4.3	246	56.33	223.6
8/21/90	277	5	76.09	342.4	4.3	250	57.31	231.2
	278	5	76.93	346.2	4.3	254	58.27	231.3

	279	5	77.71	349.7	4.3	257.6	59.13	231.3
8/24/90	280	5	78.4	352.8	4.3	260.8	59.93	231.4
	281	5	79.04	355.7	4.3	263.4	60.6	229.7
	282	5	79.36	357.1	4.3	264.6	60.93	228
	283	5	79.36	357.1	4.3	264.4	60.96	226.3
8/28/90	284	5	79.52	357.8	4.3	268.6	59.69	224.6
	285	5	79.4	357.3	4.3	267.9	59.53	225.3
	286	5	79.33	357	4.3	267.5	59.44	225.9
8/31/90	287	5	79.36	357.1	4.3	267.4	59.42	226.7
	288	5	79.31	356.9	4.3	267.1	59.36	225.3
	289	5	78.91	355.1	4.3	265.2	58.93	223.9
	290	5	78.87	354.9	4.3	264.8	58.84	222.5
	291	5	78.78	354.5	4.3	264.2	58.71	221.1
	292	5	78.64	353.9	4.3	263.4	58.53	219.7
	293	5	78.49	353.2	4.3	262.5	58.33	218.3
	294	5	78.29	352.3	4.3	261.4	58.09	216.9
	295	5	78.04	351.2	4.3	260.1	57.8	215.5
	296	5	77.78	350	4.3	258.7	57.49	214.2
	297	5	77.47	348.6	4.3	257.1	57.16	212.8
9/11/90	298	5	76.87	345.9	4.3	254.5	56.58	211.4
	299	5	77.84	350.3	4.3	257.3	57.2	214
	300	5	78.89	355	4.3	260.4	57.89	216.6
9/14/90	301	5	80.0	360	4.3	263.8	58.64	219.3
	302	5	80.24	361.1	4.3	264.4	58.78	217
	303	5	80.49	362.2	4.3	265	58.91	214.7
9/17/90	304	5	80.69	363.1	4.3	265.4	59	212.4
	305	5	81.24	365.6	4.3	267.5	59.47	220.5
	306	5	82.16	369.7	4.3	271.2	60.29	228.6
	307	5	83.42	375.4	4.3	276.5	61.47	236.7
9/21/90	308	5	83.93	377.7	4.3	279.7	62.18	244.8
	309	5	84.37	379.7	4.3	282.4	62.75	246.2
	310	5	84.71	381.2	4.3	284.7	63.27	247.6
	311	5	84.98	382.4	4.3	286.7	63.71	249
9/25/90	312	5	85.2	383.4	4.3	288.4	64.09	250.3
	313	5	85.44	384.5	4.3	290.2	64.49	250.8
	314	5	85.71	385.7	4.3	292	64.89	251.2
	315	5	86.0	387	4.3	293.9	65.31	251.7
9/29/90	316	5	86.18	387.8	4.3	295.4	65.64	252.1
	317	5	86.76	390.4	4.3	298.2	66.27	253.2
	318	5	87.27	392.7	4.3	300.7	66.82	254.2
10/02/90	319	5	91.81	413.2	4.3	316.9	70.41	255.2

Table C-16a. Copper Balance in System #1

DATE	DAY	#1Cu$_{totaer}$ mg/l	#1Cu$_{totanx}$ mg/l	#1Cu$_{totavg}$ mg/l	#1Cu$_{tot}$ mg/Reactor	#1Cu$_{toteff}$ mg/l	#1Q$_{w}$ l/day
7/20/90	245	0.364	0.418	0.38	1.7	0.014	0.24
	246	1.573	1.666	1.6	7.2	0.059	0.115
	247	2.782	2.913	2.83	12.7	0.105	0.115
	248	3.991	4.161	4.05	18.2	0.15	0.115
7/24/90	249	5.2	5.408	5.27	23.7	0.195	0.165
	250	6.461	6.324	6.42	28.9	0.211	0.65
	251	7.723	7.24	7.56	34	0.226	0.115
7/27/90	252	8.984	8.156	8.71	39.2	0.242	0.165
	253	12.036	11.175	11.75	52.9	0.3	0.063
	254	15.088	14.194	14.79	66.6	0.357	0.114
	255	18.14	17.213	17.83	80.2	0.415	0.114
7/31/90	256	21.192	20.232	20.87	93.9	0.472	0.19
	257	24.821	22.481	24.04	108.2	0.495	0.036
	258	28.451	24.731	27.21	122.4	0.517	0.113
8/03/90	259	32.08	26.98	30.38	136.7	0.54	0.165
	260	36.775	31.975	35.18	158.3	0.737	0.071
	261	41.47	36.97	39.97	179.9	0.933	0.118
	262	46.165	41.965	44.77	201.5	1.13	0.118
8/07/90	263	50.86	46.96	49.56	223	1.326	0.114
8/08/90	264	45.34	43.51	44.73	201.3	4	0.05
	265	49.465	47.8	48.91	220.1	2.99	0
8/10/90	266	53.59	52.09	53.09	238.9	1.979	0.09
	267	54.028	51.823	53.29	239.8	2.003	0
	268	54.465	51.555	53.5	240.8	2.027	0
	269	54.903	51.288	53.7	241.7	2.05	0
8/14/90	270	55.34	51.02	53.9	242.6	2.074	0.115
	271	56.027	52.747	54.93	247.2	2.279	0.048
	272	56.713	54.473	55.97	251.9	2.485	0.048
8/17/90	273	57.4	56.2	57	256.5	2.69	0.115
	274	58.45	55.975	57.63	259.3	2.737	0.043
	275	59.5	55.75	58.25	262.1	2.785	0.043
	276	60.55	55.525	58.88	265	2.832	0.043
8/21/90	277	61.6	55.3	59.5	267.8	2.879	0.115
	278	61.89	57.6	60.46	272.1	2.773	0
	279	62.18	59.9	61.42	276.4	2.666	0
8/24/90	280	62.47	62.2	62.38	280.7	2.56	0.115
	281	64.428	61.795	63.55	286	2.763	0
	282	66.385	61.39	64.72	291.2	2.965	0
	283	68.343	60.985	65.89	296.5	3.168	0
8/28/90	284	70.3	60.58	67.06	301.8	3.37	0.115
	285	71.033	62.453	68.17	306.8	3.213	0
	286	71.767	64.327	69.29	311.8	3.057	0
8/31/90	287	72.5	66.2	70.4	316.8	2.9	0.115
	288	73.936	68.036	71.97	323.9	2.909	0
	289	75.373	69.873	73.54	330.9	2.918	0
	290	76.809	71.709	75.11	338	2.927	0
	291	78.245	73.545	76.68	345.1	2.936	0
	292	79.682	75.382	78.25	352.1	2.945	0
	293	81.118	77.218	79.82	359.2	2.954	0
	294	82.555	79.055	81.39	366.3	2.963	0
	295	83.991	80.891	82.96	373.3	2.972	0
	296	85.427	82.727	84.53	380.4	2.981	0
	297	86.864	84.564	86.1	387.5	2.99	0
9/11/90	298	88.3	86.4	87.67	394.5	3	0.115
	299	89.2	87.5	88.63	398.8	3.033	0
	300	90.1	88.6	89.6	403.2	3.067	0
9/14/90	301	91	89.7	90.57	407.6	3.1	0.115
	302	92.367	90.333	91.69	412.6	3.133	0
	303	93.733	90.967	92.81	417.6	3.167	0
9/17/90	304	95.1	91.6	93.93	422.7	3.2	0
	305	96.025	92.4	94.82	426.7	2.975	0

	306	96.95	93.2	95.7	430.7	2.75	0
	307	97.875	94	96.58	434.6	2.525	0
9/21/90	308	98.8	94.8	97.47	438.6	2.3	0.044
	309	99.825	95	98.22	442	2.325	0.044
	310	100.85	95.2	98.97	445.4	2.35	0.044
	311	101.875	95.4	99.72	448.7	2.375	0.044
9/25/90	312	102.9	95.6	100.47	452.1	2.4	0.04
	313	105.175	100.925	103.76	466.9	2.325	0
	314	107.45	106.25	107.05	481.7	2.25	0.008
	315	109.725	111.575	110.34	496.5	2.175	0.016
9/29/90	316	112	116.9	113.63	511.3	2.1	0.04
	317	114.267	115.4	114.64	515.9	1.933	0.065
	318	116.533	113.9	115.66	520.5	1.767	0.065
10/02/90	319	118.8	112.4	116.67	525	1.6	0

Table C-16b. Copper Balance in System #1

DATE	DAY	#1Cu$_{in}$ Added mg/l	#1Cu$_{dencity}$ Added Theory mg/l	#1Cu$_{tot}$ Added Theory mg/reactor	#1Cu$_{in}$ Avg. Measured mg/l	#1Cu$_{tot}$ Measured Theory mg/reactor	#1Cu$_{dencity}$ Measured Theory mg/l	#1Cu$_{tot}$ mg/reactor
7/20/90	245	0	0.4	1.719	0.006	1.719	0.4	1.7
	246	2	2.9	13	1.45	9.8	2.2	7.2
	247	2	5.3	23.8	1.45	17.4	3.9	12.7
	248	2	7.6	34	1.45	24.6	5.5	18.2
7/24/90	249	2	9.6	43.3	1.45	31	6.9	23.7
	250	2	10.5	47.3	1.45	33.7	7.5	28.9
	251	2	12.6	56.5	1.45	40	8.9	34
7/27/90	252	2	14.4	64.7	1.45	45.6	10.1	39.2
	253	2	16.4	74	1.45	51.9	11.5	52.9
	254	5	22.1	99.4	4.4	74.3	16.5	66.6
	255	5	27.5	123.8	4.4	95.8	21.3	80.2
7/31/90	256	5	32.2	144.9	4.4	114.6	25.5	93.9
	257	5	37.9	170.6	4.4	137	30.4	108.2
	258	5	42.8	192.7	4.4	156.4	34.8	122.4
8/03/90	259	5	47.1	211.8	4.4	173.3	38.5	136.7
	260	5	51.9	233.7	4.4	192.3	42.7	158.3
	261	5	55.9	251.6	4.4	207.8	46.2	179.9
	262	5	59.5	267.9	4.4	221.7	49.3	201.5
8/07/90	263	5	62.9	282.9	4.4	234.4	52.1	223
8/08/90	264	5	63.5	285.9	4.4	234.4	52.1	201.3
	265	5	66.2	298	4.4	242.9	54	220.1
8/10/90	266	5	68.9	310.1	4.4	252.6	56.1	238.9
	267	5	72.9	328.1	4.4	267	59.3	239.8
	268	5	76.9	345.9	4.4	281.2	62.5	240.8
	269	5	80.8	363.6	4.4	295.3	65.6	241.7
8/14/90	270	5	82.6	371.9	4.4	301.8	67.1	242.6
	271	5	85.4	384.2	4.4	311.3	69.2	247.2
	272	5	87.8	395.2	4.4	319.5	71	251.9
8/17/90	273	5	88.7	399.2	4.4	321.8	71.5	256.5
	274	5	90.9	409	4.4	328.8	73.1	259.3
	275	5	93	418.4	4.4	335.4	74.5	262.1
	276	5	95	427.4	4.4	341.7	75.9	265
8/21/90	277	5	95.4	429.5	4.4	342.4	76.1	267.8
	278	5	98.4	442.9	4.4	352.2	78.3	272.1
	279	5	101.5	456.9	4.4	362.6	80.6	276.4
8/24/90	280	5	102.2	460.1	4.4	364.6	81	280.7
	281	5	105.2	473.5	4.4	374.4	83.2	286
	282	5	107.9	485.7	4.4	383	85.1	291.2
	283	5	110.4	496.7	4.4	390.4	86.8	296.5
8/28/90	284	5	109.8	494.3	4.4	387	86	301.8
	285	5	112.2	505	4.4	394.1	87.6	306.8
	286	5	114.8	516.7	4.4	402.2	89.4	311.8
8/31/90	287	5	114.8	516.4	4.4	401.3	89.2	316.8
	288	5	117.5	528.9	4.4	410.2	91.2	323.9
	289	5	120.3	541.4	4.4	419.1	93.1	330.9
	290	5	123.1	553.8	4.4	427.9	95.1	338
	291	5	125.8	566.2	4.4	436.7	97	345.1
	292	5	128.6	578.5	4.4	445.4	99	352.1
	293	5	131.3	590.8	4.4	454.1	100.9	359.2
	294	5	134	603	4.4	462.7	102.8	366.3
	295	5	136.7	615.2	4.4	471.3	104.7	373.3
	296	5	139.4	627.3	4.4	479.8	106.6	380.4
	297	5	142.1	639.4	4.4	488.3	108.5	387.5
9/11/90	298	5	141.2	635.5	4.4	484.7	107.7	394.5
	299	5	143.8	647.3	4.4	492.9	109.5	398.8
	300	5	146.4	658.9	4.4	500.9	111.3	403.2
9/14/90	301	5	145.3	653.9	4.4	496.4	110.3	407.6
	302	5	147.8	665.1	4.4	504	112	412.6

	303	5	150.2	676.1	4.4	511.4	113.6	417.6
9/17/90	304	5	152.6	686.9	4.4	518.6	115.2	422.7
	305	5	155.4	699.1	4.4	527.2	117.2	426.7
	306	5	158.4	712.6	4.4	537.1	119.4	430.7
	307	5	161.7	727.5	4.4	548.4	121.9	434.6
9/21/90	308	5	163.7	736.6	4.4	555.7	123.5	438.6
	309	5	165.7	745.5	4.4	562.7	125.1	442
	310	5	167.6	754.1	4.4	569.5	126.6	445.4
	311	5	169.4	762.5	4.4	576.1	128	448.7
9/25/90	312	5	171.4	771.3	4.4	583	129.6	452.1
	313	5	175	787.4	4.4	595.5	132.4	466.9
	314	5	178.3	802.5	4.4	607.3	135	481.7
	315	5	181.5	816.6	4.4	618.5	137.5	496.5
9/29/90	316	5	183.7	826.7	4.4	626.8	139.3	511.3
	317	5	185.2	833.2	4.4	632.6	140.6	515.9
	318	5	186.8	840.6	4.4	639.3	142.1	520.5
10/02/90	319	5	191.3	861	4.4	656	145.8	525

Table C-17. Leachate Metals Concentration

TRIP	DATE	DAY	Cd mg/l	Cr mg/l	Cu mg/l	Fe mg/l
1	11/22/89	5	0.0004	0.0034	0.009	10.33
2	12/13/89	26	0.0003	0.0021	0.007	10.5
3	1/04/90	48	0.0005	0.0017	0.028	4.96
4	1/27/90	71	0.0003	0.0014	0.034	5.22
5	2/16/90	91	0.0004	0.0018	0.028	19.32
6	3/06/90	109	0.0002	0.0014	0.023	29.74
7	3/27/90	130	0.0001	0.0012	0.021	21.27
8	4/14/90	148	0.0001	0.0014	0.022	28.74
9	4/30/90	164	0.0003	0.0015	0.006	22.53
10	5/21/90	185	0.0009	0.0024	0.015	48.31
11	6/06/90	201	0.0015	0.0021	0.016	24.61
12	6/25/90	220	0.0028	0.0016	0.01	23.73
13	7/16/90	241	0.0007	0.0015	0.014	25.69
14	8/06/90	262	0.0009	0.0015	0.009	28.96
15	8/27/90	283	0.0925	0.0014	0.022	18.74
16	9/17/90	304	0.0214	0.001	0.015	7.35

Table C-17. Leachate Metals Concentrations (continued)

TRIP	DATE	DAY	Mn mg/l	Ni mg/l	Pb mg/l	Zn mg/l
1	11/22/89	5	0.77	0.013	0.004	0.045
2	12/13/89	26	0.74	0.01	0.001	0.051
3	1/04/90	48	0.68	0.182	0.006	0.063
4	1/27/90	71	0.77	0.184	0.001	0.048
5	2/16/90	91	1.06	0.177	0.002	0.056
6	3/06/90	109	1.03	0.18	0.002	0.052
7	3/27/90	130	1.06	0.174	0.002	0.047
8	4/14/90	148	1.12	0.178	0.002	0.207
9	4/30/90	164	1.06	0.031	0.003	0.093
10	5/21/90	185	1.02	0.033	0.006	0.23
11	6/06/90	201	1.14	0.014	0.005	0.123
12	6/25/90	220	1.00	0.017	0.002	0.122
13	7/16/90	241	0.96	0.016	0.005	0.095
14	8/06/90	262	0.89	0.019	0.004	0.087
15	8/27/90	283	0.87	0.115	0.004	0.127
16	9/17/90	304	0.77	0.021	0.002	0.07

Table C-18. Summary of Copper for each Experiment

Exper.	Reactor	MCRT day	Cu Dose	Days Used	MLVSS mg/L	MLSS mg/L
1	#1	30	2.0	252	1707	2250
2	#1	30	5.0	270 to 319	2270	3365
3	#2	8	2.5	39, 42, 46	525	588
4	#2	15	1.0	157, 160	1037	1387
5	#2	15	1.0	193 to 224	925	1414
6	#2	15	2.0	228 to 252	778	1058
7	#2	15	5.0	270 to 319	1162	1696
8	Don's	8	5.0	534, 538, & 546	941	1219
9	Don's	8	15.0	474	475	623

Exper.	Soluble Cu mg/L	Total Cu mg/L	Total Cu in System mg/system	Influent Total Cu mg/L	Ratio SolCu to MLVSS *10,000	Ratio SolCu to MLSS *10,000
1	0.196	8.71	39.19	1.45	1.15	0.87
2	0.51	82.36	370.6	4.40	2.26	1.53
3	0.815	5.96	26.8	2.09	15.52	13.86
4	0.164	5.48	24.7	0.75	1.58	1.18
5	0.167	8.17	36.8	0.75	1.81	1.18
6	0.284	8.69	39.1	1.28	3.65	2.68
7	0.75	50.45	227.0	4.30	6.47	4.43
8	0.930	25.8	116.1	4.12	9.88	7.63
9	1.37	?	?	11.2	28.84	21.99

Exper.	Ratio TotCu to MLVSS *10,000	Ratio TotCu to MLSS *10,000	Cu Loading mg/day	Specific Cu Loading on MLVSS mg/day/ mg/system	Specific Cu Loading on MLSS mg/day/ mg/system
1	51.0	38.7	8.7	11.3	8.59
2	363	245	26.4	25.8	17.4
3	114	101	12.5	53.1	47.4
4	52.9	39.5	4.5	9.64	7.21
5	88.3	57.8	4.5	10.8	7.07
6	112	82.1	7.68	21.9	16.1
7	434	297	25.8	49.3	33.8
8	274	212	24.7	58.4	45.1
9	?	?	67.2	314	240

Vita

Vance Allen Neal was born on July 13, 1963, in Seattle, Washington. While a baby Vance moved to Carthage, Missouri where he stayed through the 2nd grade. He lived in Cherokee, Kansas from 3rd through 7th grades. In 1976 the Neal family moved to Alexandria, Virginia where he lived until 1980. The summer 1980 to summer 1982, Vance attended the School of the Ozarks (SofO) in Point Lookout, Missouri. From August 1982 to May 1985 he attended the University of Missouri at Rolla (UMR), in Rolla, Missouri were he graduated with a Bachelor of Science in Civil Engineering. From July 1985 until November 1987, he was a U.S. Peace Corps Water Engineer Volunteer in Kenya, East Africa. He worked for six months as a water engineer for Ben Dyer Associates, Inc. engineering firm in Landover, Maryland. He started to pursue a Master of Science in Environmental Engineering at Virginia Polytechnic Institute and State University (VPI&SU), in Blacksburg, Virginia on fall 1988. From January 1991 to July 1992, worked full time with the Virginia State Water Control Board, in Bridgewater, Virginia as a permit writer. In July 1992, he successfully defended this thesis. Starting August 1992, he will be going to work for the Virginia Department of Health in Danville, Virginia.

Vance Allen Neal