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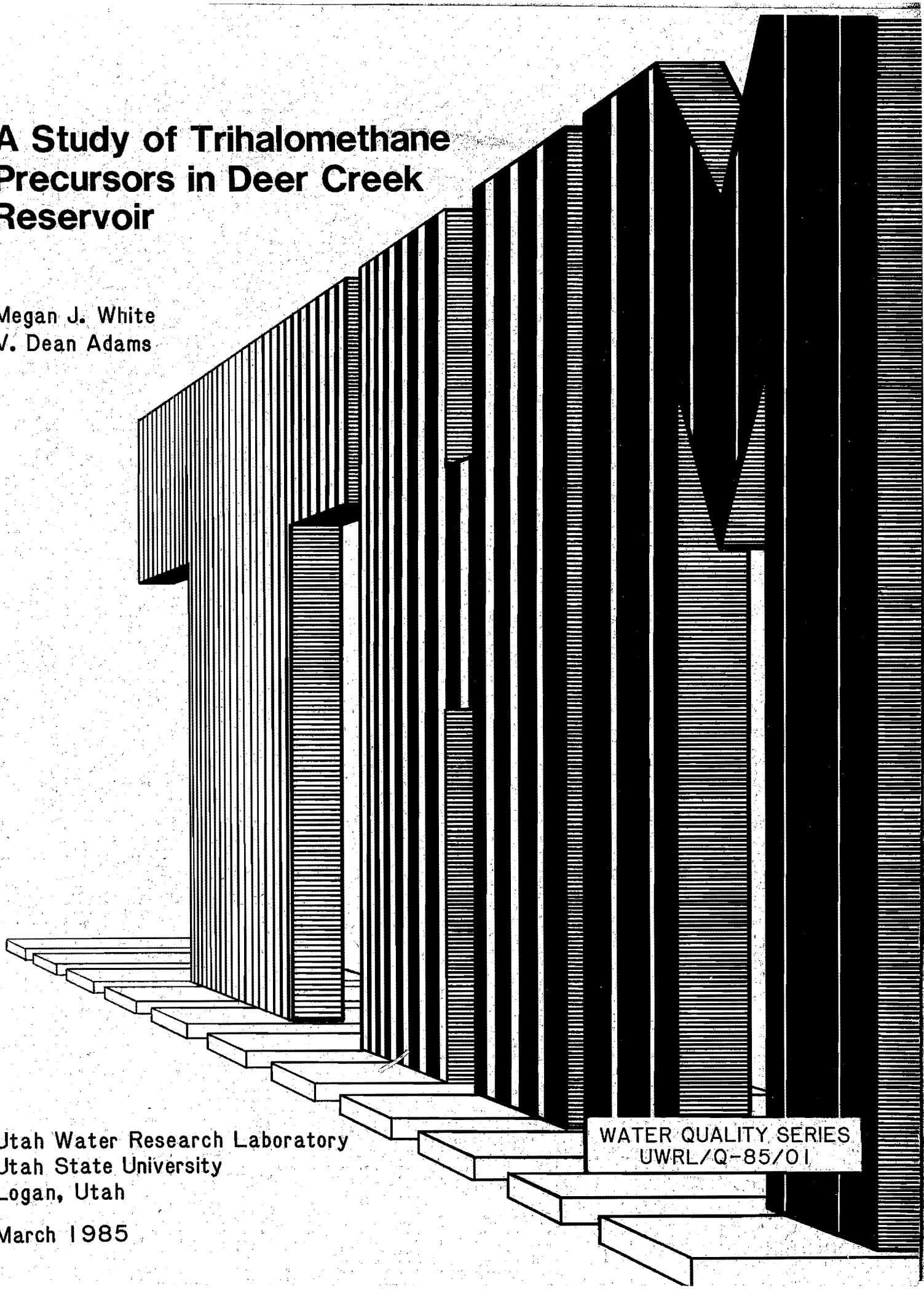

Utah Water Research Laboratory
Utah State University
Logan, Utah

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WATER QUALITY SERIES
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A STUDY OF TRIHALOMETHANE PRECURSORS IN DEER CREEK RESERVOIR

by

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ABSTRACT

Deer Creek Reservoir and tributaries were monitored from May to December 1983 in a study of the occurrence of trihalomethane (THM) precursors in the reservoir and nutrient dynamics of the reservoir system. Microcosms were used to study the effect of the following parameters on THM precursor production in the reservoir system: phosphorus loading, sediment, algal growth, and application of algicide. Additionally, THM precursor concentrations of interstitial water were analyzed in reservoir and microcosm sediment samples.

Microcosms treated with a high phosphorus loading (70 µg/l) had THM precursor concentrations significantly higher than those measured in microcosms treated with a low phosphorus loading (10 µg/l). The presence of sediment in microcosms did not significantly affect THM precursor concentrations. Algae growth did result in THM production significantly above that measured in microcosms without algae growth. No correlation between total organic carbon and terminal total trihalomethane concentrations was found to exist in microcosms. Potassium permanganate and copper sulfate were used as algicides. Applications of 0.3 mg/l potassium permanganate and 50 µg/l copper sulfate as Cu^{+2} did not appear to affect THM precursor, total phosphorus, total suspended solids, or volatile suspended solids concentrations in the microcosms. Anoxic phosphorus release occurred in dark microcosms after the dissolved oxygen concentration dropped below approximately 3.0 mg/l.

Considering all data collected, no significant difference in THM precursor concentration could be detected between tributary and reservoir samples. THM precursor concentrations in tributaries were found to vary significantly by season. Samples collected from three depths within the reservoir were not found to have significantly different mean terminal total trihalomethane concentrations over the sampling period. No correlation between total organic carbon and terminal total trihalomethane concentrations was found to exist. Total phosphorus concentrations in tributaries were quite high, particularly in Main and Daniels Creeks.

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INTRODUCTION

Nature of Problem

Deer Creek Reservoir currently supplies approximately 65 percent of the raw water annually to the Little Cottonwood Metropolitan water treatment plant for distribution to Salt Lake County. Little Cottonwood Creek contributes the remaining portion of water. Influent water quality problems at the Little Cottonwood Creek water treatment plant have been associated with Deer Creek Reservoir water since Little Cottonwood Creek is relatively pristine (Richards 1984). In addition to supplying a large proportion of water to the Little Cottonwood Metropolitan water treatment plant, Deer Creek Reservoir is used heavily for recreational purposes during the summer months. Regulation of trihalomethane (THM) concentrations, by the United States Environmental Protection Agency (USEPA), in public drinking water has resulted in the need to examine the mode by which THM precursors enter the reservoir or are generated within the reservoir. Currently, the maximum permissible level of total trihalomethanes (TTHMs) in a finished drinking water is 100 µg/l.

According to Richards (1984), instantaneous THM concentrations in finished water of the Little Cottonwood Metropolitan water treatment plant have recently varied from approximately 20 to 60 µg/l. Cook (1983) found a similar variation in instantaneous THM concentrations during a 16 month testing period at the Little Cottonwood Metropolitan water treatment plant. However, terminal trihalomethanes (Term THMs) were found to vary from 49 to 108 µg/l. Peters (1981) reported terminal total trihalomethane (Term TTHM) concentrations of around 90 µg/l between June and August 1980 in the Little Cottonwood Metropolitan water treatment plant effluent. Raw water from Deer Creek Reservoir travels through a 32 mile aqueduct to the treatment plant. Chlorination at a dose of approximately 0.5 mg/l Cl_2 occurs at the aqueduct headwaters (Richards 1984). The treatment scheme at the Little Cottonwood Metropolitan water treatment plant is documented in Cook (1983).

In the Deer Creek Reservoir system, precursors are delivered to the reservoir by tributaries and are generated within the reservoir itself. Sources of precursors in the reservoir were studied to more clearly define the THM problem in Deer Creek Reservoir and to aid in the formulation of recommendations to lower precursor concentrations in the reservoir and, therefore, in the Little Cottonwood Metropolitan water treatment plant's influent.

Objective

The overall objective of this project was to study the sources of THM precursors in Deer Creek Reservoir. Affects of phosphorus loading, algae growth, algicide application, and sediment on THM precursor production were studied. To achieve the research objective, it was necessary to:

1. Monitor (through monthly sampling) Term TTHM concentrations in Deer Creek Reservoir, tributaries of Deer Creek Reservoir, and the reservoir outflow to determine relative contributions of tributary and in-reservoir generation to total THM precursor concentration in Deer Creek Reservoir.

2. Monitor (through monthly sampling) selected chemical and physical

constituent concentrations in Deer Creek Reservoir, tributaries of Deer Creek Reservoir, and the reservoir outflow to study nutrient dynamics of the reservoir system and potential impact of these constituents on THM precursor concentrations.

3. Study the affect of phosphorus loading levels to microcosms of the reservoir system on Term TTHM concentrations over time.

4. Study the affect of algicide application (copper sulfate and potassium permanganate) to microcosms of the reservoir system on Term TTHM concentrations.

5. Study the impact of sediment in microcosms of the reservoir system on Term TTHM concentrations.

6. Study the impact of algae growth in microcosms of the reservoir on Term TTHM concentrations.

7. Evaluate the Term TTHM concentrations of interstitial sediment waters in the reservoir and in microcosms of the reservoir system.

LITERATURE REVIEW

Introduction

Presence of trihalomethanes (THMs) in drinking water was first documented by Rook (1974) and Bellar et al. (1974). THMs include primarily four compounds: Chloroform ($CHCl_3$); bromodichloromethane ($CHBrCl_2$); dibromochloromethane ($CHBr_2Cl$); and bromoform ($CHBr_3$). According to Walker (1983), THMs generally constitute only a fraction (typically about 20 percent) of the total organohalogens formed when chlorine reacts with natural organic compounds. The remaining, generally nonvolatile, compounds are still poorly identified and may be more hazardous than THMs. The USEPA chose to regulate THMs since they are easily measurable by-products of chlorination and indicate the presence of other chlorinated organic compounds. Reducing THM concentrations is relatively low cost and monitoring is feasible (Cotruvo 1981).

Regulation

In 1979, the USEPA promulgated regulations limiting the permissible levels of THMs in drinking water to a maximum contaminant level of 100 µg/l. Regulations apply to any community water system which adds disinfectant in the treatment process. Systems serving over 75,000 people were to comply with the regulations by November 1981. Systems serving populations between 10,000 and 75,000 were given until November 1983 to comply with the regulations, and compliance dates were to be set by the individual states for systems serving under 10,000 people (Cotruvo 1981).

Trihalomethane formation

Trihalomethanes form from the reaction or series of reactions of chlorine with a precursor material. Simple methyl ketones react through the classical haloform reaction mechanism (Rook 1980). The pattern of the reaction is believed to be successive replacement of hydrogen by chlorine on carbon alpha to a carbonyl group followed by eventual hydrolysis to produce CHX_3 and, generally, a carboxylate. The mechanism is postulated to be an initial proton dissociation from the alpha-carbon, giving an enolate carbonion which is subject to electrophilic attack by HOCl or OCl^- (Rook) 1980). Figure 1 illustrates proposed degradation pathways of fulvic acids and resorcinol.

The rate of proton dissociation is typically the rate determining step for the conditions under which the reactions have been studied extensively. However, most studies have occurred at pH values greater than 11 (Morris 1978). Larson and Rockwell (1979) described the reaction of aqueous chlorine with organic molecules as falling into three categories: addition, substitution, and oxidation. Larson and Rockwell (1979) also reported that several common natural carboxylic acids are readily attacked by hypochlorite in dilute solutions with loss of CO_2 and incorporation of chlorine into the residual molecule.

Precursors to Trihalomethane Formation

Humic and fulvic acids

In natural waters, two precursor types are dominant: humus material and algae. Of secondary importance are tannic acids and nitrogen containing compounds (Oliver and Lawrence (1979).

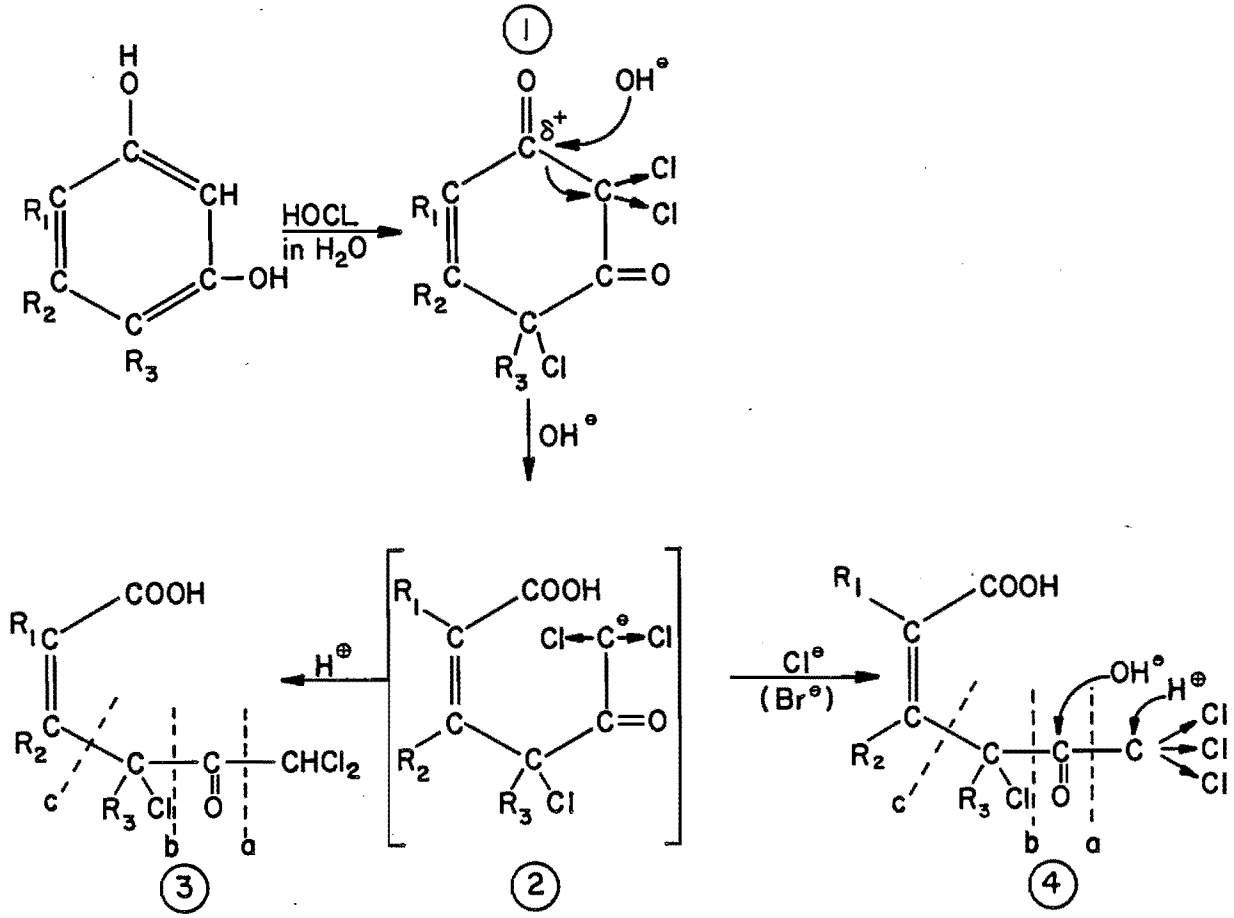

Figure 1. Proposed degradation pathways of fulvic acids and resorcinol (Rook 1977).

The humus molecule has been described by Trussell and Umphres (1978) as a huge amorphous mass of polyhetero-condensate with certain functional groups protruding from its surface that react with chlorine to form THMs. Humus material is composed of humic and fulvic acids which are differentiated largely on the basis of molecular weight. Humic and fulvic acids are derived from the decomposition of plant and animal matter (Hoehn et al. 1983). Young and Singer (1979) reported the mineralization of algae also produces humic acids. Fulvic acids are composed of compounds below a molecular weight of 1000. Humic acids consist of higher molecular weight compounds (Trussell and Umphres 1978). Fulvic acids have been described by Hoehn et al. (1983) as the acid soluble fraction of aquatic humus.

The fulvic acid component of amorphorus organic matter in the natural environment is approximately 85 percent (Hoehn et al. 1983). Oliver and Visser (1980) and Rook (1977) identified the fulvic acid fraction to be of greatest importance in the production of THMs as compared to the humic acid fraction. This was evaluated using stream and lake samples of humic and fulvic acids. The increased significance of fulvic acids as opposed to humic acids in the formation of halogens was attributed to the high charge

densities and high surface activities present in the fulvic acids (Oliver and Visser 1980). Conversely, Babcock and Singer (1979) found the humic acid fraction of Michigan peat to yield larger amounts of chloroform when chlorinated as compared to the fulvic acid fraction. Jewitt and O'Brien (1979) reported that the THM yield of chlorinated fulvic acid is dependent on the particular fractions of the fulvic acids present. Fleischacker and Randtke (1983) found the THM yield of fulvic acid relative to humic acid to be strongly influenced by chlorine dosage. Consequently, evaluation of the yield of a precursor at a single chlorine dosage may give misleading information.

Veenstra and Schnoor (1980) observed chloroform production from humic material over the entire molecular weight spectrum studied but noted the greatest concentrations were detected from the molecular weight fraction of 1000 to 2800 apparent molecular weight. Veenstra and Schnoor (1980) also reported an average of 87 percent of the TTHMs formed from the 3000 and lower apparent molecular weight group in river water. Findings of Schnoor et al. (1979) varied for a composite sample collected over 2 winter months and for 16 river samples collected over a 5-month period. Chloroform yields were greatest between the molecular weight range of 1700 and 3000. However, in the 16 river samples, chloroform yields were greatest for molecular weight ranges from 2200 to 5000 and less than 1000. Schnoor et al. (1979) postulated that the considerable scatter present in these data was due to functional differences in organic moieties with time and indicated that chloroform concentrations cannot be predicted based solely on the knowledge of molecular weight and the total organic carbon (TOC) distribution of naturally occurring organics. Veenstra and Schnoor (1980) found soil cultivation to cause a shift in the humic acids in surrounding waterways from higher to lower molecular weights through the process of oxidative degradation resulting in an overall loss in soil organic content.

The traditional haloform reaction is zero order with respect to chlorine; however, it is premature to assume the same is true for the more complex reactions in natural waters (Trussell and Umphres 1978). Several moieties within the humic structure are capable of undergoing the haloform reaction (Peters et al. 1980). Peters et al. (1980) state that the possibility of deriving a general rate equation describing THM formation is unlikely due to complexity of the reactions and the variation in the structure of humic substances present in different waters. However, a rate equation may be formulated for a specific source water to predict affects of changing chlorination conditions on haloform formation (Peters et al. 1980).

Algae and algal extracellular products

THM production has been observed from the chlorination of algae and their extracellular products (ECPs). Algae and ECPs, by-products of algal growth, produce THM concentrations upon chlorination that are comparable to yields observed from humic and fulvic acids (Briley et al. 1980). ECPs have been characterized as compounds which are generally low-molecular weight organic acids and some higher molecular weight compounds. Algal ECPs are considered a significant portion of the total organic carbon pool in waters where algae are present (Hoehn et al. 1983). The amount of ECPs excreted depends on the type of algae, pH, and amount of light. Composition of ECPs depends on many diverse factors but the more common constituents include glycollate, polysaccharides, amino acids, peptides, amide nitrogen, organic phosphorus compounds, vitamins, lipids, phenolic and volatile substances, and various enzymes (Hoehn et al. 1983; Adams et al. 1975). Bacteria are capable of degrading algal ECPs and

produce their own ECPS. Bacteria and their associated ECPs are of unknown significance as THM precursors (Hoehn et al. 1983).

Hoehn et al. (1980) evaluated the production of chloroform from the chlorination of algae cultures at various growth stages. Chloroform concentrations per unit total organic carbon appeared to vary randomly with culture age, perhaps signifying that the organic compounds derived from algae at different stages in the algal life cycle differed considerably in their ability to yield THMs upon reaction with chlorine. Despite problems in experimental procedures, Hoehn et al. (1980) reported that chloroform yields were extremely high when the algae were in the late exponential growth phase. Results obtained by Briley et al. (1980) support the hypothesis that THM levels increase as algae reach the late exponential growth phase. Briley et al. (1980) further reported that THM levels declined as the stationary phase was entered. Morris and Baum (1978) produced data indicating that chlorophyll yields chloroform upon chlorination. Therefore, results reported by Briley et al. (1980) and Hoehn et al. (1980), which indicate greater chloroform production when chlorinating algae in the exponential growth phase may be due, in part, to greater concentrations of chlorophyll present in the algae during this growth phase. However, these results cannot be applied to natural aquatic systems since algal populations of uniform age do not exist naturally. Oliver and Shindler (1980) also reported that algal species affected chloroform yields.

Oliver and Shindler (1980) separated cells from ECPs produced by algal growth. In this experiment, the majority of chloroform yield was a result of algal cell and cell fragment chlorination. A conclusion drawn by Oliver and Shindler (1980) was that no single compound or specific cell component appeared responsible for THM production from chlorinated algae. Briley et al. (1980) also noted that chlorination of algae cells resulted in higher THM levels than those observed for isolated ECPs when compared at a chlorine contact time of 24 hours. Shorter chlorine contact times also exhibited lower levels of THMs for chlorinated ECPs as compared with algal cells but differences were smaller. Briley et al. (1980) claimed these results to be consistent with the observation that the reaction of algal biomass with chlorine is a relatively slow process. Chlorine contact with algal cells first lyses the cells releasing large amounts of THM precursors. The above mentioned results, obtained by Briley et al. (1980) and Oliver and Shindler (1980), conflict with those reported by Hoehn et al. (1980), who observed chlorinated algal ECPs to generally yield greater quantities of chloroform relative to the available total organic carbon than did chlorinated algal biomass.

The discrepancy could be due to several confounding factors. Culture age has been shown to significantly alter the quantity of THMs resulting from the chlorination of ECPs. Hoehn et al. (1983) conducted diurnal studies in which reservoir samples of ECPs were taken at regular intervals throughout a 24 hour period, chlorinated, and analyzed for THMs. The levels of THMs from the same source water varied greatly with time of day. Therefore, the time of day samples are collected may impact results obtained.

Factors Which Influence Trihalomethane Formation

Formation of THMs in the presence of a particular precursor concentration is affected by several factors including pH, temperature, chlorine contact time, chlorine dosage, and bromine concentration. Temperature and pH affect the rate at which the reaction between chlorine and a precursor material occurs. Chlorine contact time, chlorine dose, and bromine concentration govern the quantity of THM which can form.

pH and temperature

THM formation has been documented as extremely pH and temperature dependent. Stevens et al. (1976) attributed pH dependency to the rate-determining step of the haloform reaction being enolization of a ketone. Increased THM production is associated with increased pH. Stevens et al. (1976) reported increased THM production at higher pH values may be caused by the presence of certain reactive sites on the humic acid molecule that react at insignificant rates at lower pH but are reactive at higher pH. Mitcham et al. (1983) stated the the increase in THM formation at higher pH is expected since the haloform reaction is base-catalyzed. Kavanaugh et al. (1980) observed an approximately three fold increase in the rate constant (of THM formation) for each unit increase in pH. Oliver and Shindler (1980) studied the reaction of Anabena oscillariodes with chlorine at pH values of 7 and 11. The reaction was three to four times more rapid at pH 11 as compared to pH 7. Kavanaugh et al. (1980) found the haloform reaction to exhibit a typical Arrhenius-type dependence on temperature with a doubling of the rate constant for every 10°C increase in temperature between 0 and 30°C.

Chlorine contact time and free chlorine residual

Chlorine contact time and free chlorine residual (a function of chlorine dose) both impact final THM concentrations. Young and Singer (1979) observed a significant increase in the formation of chloroform with time when raw water samples were chlorinated. Additionally, Young and Singer (1979) reported that the presence of a free chlorine residual greater than 0.4 mg/l enhanced THM formation. The rate of THM formation was found to depend strongly on the applied chlorine concentration; with the rate increasing as the chlorine dose increased (Kavanaugh et al. 1980; Stevens et al. 1976; Otson et al. 1981).

Bromine

Presence of bromine (or the bromide ion) greatly affects both the total amount of THMs formed and speciation of THMs. When chlorine or hypochlorite is added to water containing bromide, there is a rapid formation of HOBr according to the reaction (Morris 1978):

$$Br^- + HOCl \rightleftarrows HOBr + Cl^- \qquad (1)$$

The resulting HOBr is an electrophilic agent (as is HOCl), but one that tends, generally, to react much more rapidly than HOCl (Morris 1978). Luong et al. (1982) reported that as bromide concentration increased, chloroform concentrations decreased. Additionally, Luong et al. (1982) found bromoform to be the major THM species at very high bromide levels. Oliver (1980) observed TTHMs to increase markedly with increasing bromide to three times the initial concentration in the absence of bromide. Similar results were obtained by Minear and Bird (1980) where TTHM concentrations were observed to increase stepwise as bromide concentration increased stepwise from 0 to 4.0 mg/l bromide.

Season

Seasonal variations in THM formation have been noted on numerous occasions (Hoehn et al. 1983; Otson et al. 1981; Veenstra and Schnoor 1980; Arguello et al. 1979; Brett and Calverly 1979; Peters 1981). Yearly patterns were reported in river water by Veenstra and Schnoor (1980) to exhibit lowest yields during late fall and early winter months. Peak yields occurred during early summer. Similarly, Otson et al. (1981) encountered lower THM concentrations when river water samples were chlorinated during the winter as opposed to summer. Arguello et al. (1979) found a general trend toward lower levels of THM concentrations during winter months. Water sources used in the study were not given.

Correlation of trihalomethane concentration with other parameters

Difficulty has been encountered by most researchers when attempting to establish correlations of total organic carbon, bromide, chlorophyll-a, and nonvolatile total organic carbon concentrations with THM production. Rook (1976) could not find a linear relationship between total organic carbon values and haloform production at varying precursor concentrations. Veenstra and Schnoor (1980) reported overall yields of TTHMs varied from 2.3 µg TTHM/l per mg TOC/l to 20.2 µg TTHM/l per mg TOC/l depending on time of year. Babcock and Singer (1979) did find a linear relationship to exist between chloroform produced and total organic carbon concentration for chlorinated humic acid solutions. The degree of linearity was not provided. Veenstra and Schnoor (1980) stated that in natural water systems, concentrations of organics may fluctuate by only a few milligrams per liter from winter to summer. Larger differences in THM production over the same time period may be due to organic molecule structure variations. A strong correlation ($r^2 = 0.96$) was observed by Arguello et al. (1979) to exist between the bromide concentration in raw water and the brominated trihalomethane concentrations in treated waters.

Hoehn et al. (1980) correlated THM levels with chlorophyll-a measurements from one reservoir water source. A significant relationship was apparent in data from one year but not other years. Walker (1983) stated that the weak correlation between chlorophyll-a and total organic carbon or THM measurements is not surprising since algae typically comprise only a small fraction (less than 10 percent) of the total organic carbon pool.

Varied success has been achieved in correlating nonvolatile total organic carbon concentrations with THM production. Symons et al. (1975) reported on 80 water supply systems in the National Organics Reconnaissance Survey and found a correlation coefficient of 0.75 when TTHM concentrations (in µmoles/l) were plotted against nonvolatile total organic carbon concentrations. In contrast, Young and Singer (1979) studied two water supply systems and found little fluctuation in raw water nonvolatile total organic carbon concentrations despite larger variations in the amount of measured chloroform. Difficulty in predicting finished water concentrations of chloroform on a given day based solely on nonvolatile total organic carbon concentrations is suggested by these findings. However, Young and Singer (1979) did indicate that the average organic carbon concentration in a water offers a good indication of the water's chloroform formation potential.

Trihalomethane Reduction

Reduction of product water THM concentrations has been approached from many directions. Reduction methods generally fall into four categories:

1. Precursor reduction at the water source (or before contact with chlorine).

2. Alternative oxidant pretreatment of source water prior to chlorine addition or elimination of pretreatment.

3. Use of alternative disinfectants.

4. THM removal after formation.

Success in reducing THM concentrations has been attained, to varying degrees, through use of the above mentioned methods.

Precursor reduction

Precursor reduction has occurred in two ways: reduction of precursor

production in the source water and removal of precursor material at (or near) the water treatment plant. Precursor reduction at the water source has focused primarily on limiting algae growth since humic material, the other fundamental precursor material, is considered ubiquitous. Removal of precursor material has been accomplished using coagulation/flocculation, adsorption onto carbon, and filtration. Lowering precursor concentrations before chlorine application has been very effective in reducing THM levels while continuing (free) chlorine disinfection.

Reduction of algal growth in drinking water source areas has occurred in the past principally for taste and odor control. Recently, algal growth control has gained greater importance in lowering THM concentrations in drinking water through reductions in biomass and ECPs, both precursor materials. Algae population dynamics are influenced primarily by an available nutrient pool and pulsed by seasonal variables of light and temperature (Putnam and Hein 1980). Muchmore (1978) stated the most direct control of algae in water-supply reservoirs is input control of critical nutrients to the reservoir. Lange and Kawczynski (1978) suggested carbonaceous material, rather than inorganic nutrients, may control eutrophication in some lakes. Walker (1983) reported that reducing watershed nutrient export to a water supply system is the most effective long term solution to eutrophication problems.

Alum treatment of reservoir waters has been shown to remove phosphorus from the hypolimnion and reduce the release of phosphorus from anoxic sediments therefore reducing algal growth by limiting phosphorus availability (Putnam and Hein 1980). As a result of alum application, particulate phosphorus in the water is removed by entrapment in the floc and dissolved phosphorus by adsorption to charged sites on the floc surface. The floc settles to the reservoir bottom and forms an effective barrier reducing internal phosphorus loading from the sediments. High cost is a disadvantage of this treatment (Putnam and Hein 1980). Medine (1979) studied the application of alum to a eutrophic reservoir microcosm. Application of alum at concentrations of 15 and 30 mg/l aluminum resulted in the successful precipitation/adsorption of phosphorus from the water column and the continual maintenance of low phosphorus levels for over 77 days following treatment.

When nutrient reduction is not feasible or has not had time to impact algal growth, various chemical and physical methods have been used to reduce existing algal populations. Use of algicides is the most common method for reducing existing algal growth. The most prevalent algicide is copper sulfate. Putnam and Hein (1980) reported that bluegreen algae are killed readily by copper sulfate but green algae can become resistant. All but a few algae species can be controlled by copper sulfate levels less than 1 mg/l; however, control of resistant algae species may require up to 2 mg/l. Copper sulfate application to reservoirs is often made on the basis of past experience; however, Muchmore (1978) has stated the amount of copper sulfate required to treat a water supply is dependent on type of algae, amount of organic matter present, water hardness, carbon dioxide content, water temperature, species of fish present, and amount of water treated. As an alternative to copper sulfate, the oxidizing agent potassium permanganate has been used successfully to control algae particularly in waters of high organic content (Muchmore 1978). An advantage of potassium permanganate as compared with copper sulfate is the lack of residual toxicity in treated waters (Muchmore 1978).

Destratification by aeration has been used to retard algae growth (Muchmore 1978). Historically, aeration

has been used to prevent nutrient regeneration during anoxic periods, increase the mixing depth of algae and thereby reduce growth due to poor light penetration, and subject algae to sudden shifts in hydrostatic pressure (Putnam and Hein 1980). Muchmore (1978) warns that aeration should be expected to have significant effects on the physical and chemical nature of the aquatic environment as well.

Substantial removal of THM precursors by coagulation and flocculation has been documented. Popularity of this technique is attributed to the presence of coagulation/flocculation facilities already in place at many treatment plants. Possible coagulants include trivalent metal ions (Al (III) and Fe (III)) and a variety of organic polyelectrolytes (Kavanaugh 1978).

Kavanaugh (1978) hypothesized that several mechanisms were responsible for the removal of humic substances by coagulation. Humics are anionic macromolecules with a variety of ionogenic groups, usually carboxyl and phenolic groups. Coagulation in waters results from charge neutralization by the charged hydrolysis species of the trivalent metal ions. Insoluble precipitates which can be trapped in flocculent particulates may also form. Humic acids have a higher molecular weight and are therefore more easily coagulated than fulvic acids. Kavanaugh (1978) reported humic acids can be satisfactorily removed to nearly 90 percent while fulvic acids can be removed to 60 percent. Davis and Gloor (1981) found alumina suspended in lake water adsorbed organic material most strongly in the molecular weight range of 1000 to 3000. This intermediate molecular weight fraction of natural organic matter forms the strongest complexes with transition metal ions. Algal biomass, according to Briley et al. (1980), would likely be removed by coagulation and filtration steps of normal water treatment; however, the degree of ECP removal in the coagulation process is somewhat uncertain.

Precursor reduction by coagulation/flocculation is affected by coagulant dosage, pH, mixing conditions, and settling conditions. Dose depends on organic compounds present, pH, and the ionic environment (Kavanaugh 1978). Coagulant dosages necessary for optimal precursor removal are generally higher than normally used in water treatment plants for particulate matter removal (Vogt and Regli 1981; Davis and Gloor 1981). According to Kavanaugh (1978), higher dosages of inorganic polymers may be needed to coagulate equal mass concentrations of fulvic as compared with humic acids. This is due to the low equivalent weight of fulvic acids as compared with humic acids and a correspondingly high charged density per unit mass. Humic acids have a correspondingly low charge density. The pH controls both speciation of the inorganic coagulant and charge of the organic molecule (Kavanaugh 1978). Therefore, pH affects the amount of coagulant needed. According to Davis and Gloor (1981), dissolved organic carbon removal appeared to reach a maximum in the pH range of 5 to 6 and decreased thereafter as pH increased. In addition, adsorption of higher molecular weight compounds appeared more pH dependent than lower molecular weight compounds. Kavanaugh (1978) reported initial mixing of coagulant and water improved the rate of the ionic reactions and could increase removal of organic compounds with lower coagulant doses.

An increased selectivity of alum coagulant for THM precursors over other organic constituents has been noted by several researchers (Young and Singer 1979; Davis and Gloor 1981; Oliver and Lawrence 1979). Young and Singer (1979) observed a 60 percent reduction in chloroform by alum coagulation/flocculation compared with a 40 percent reduction in total organic carbon at an alum dose of 25 mg/l. Davis and Gloor (1981) postulated that the selectivity

of trivalent metal coagulants for THM precursors results because precursors of organo-chlorine compounds contain necessary functional groups for reaction with the alumina surface.

Affects of moving the point of initial chlorination from ahead of coagulation/flocculation to after this unit process on THM concentrations in finished water are documented. Three water treatment plants in the Ohio River valley moved the point of chlorination from before the coagulation/flocculation basins to after the basins in an effort to remove THM precursors prior to chlorination (Ohio River Valley Water Sanitation Commission 1980). Coagulant dosages were not modified for THM precursor removal. Term THMs were significantly reduced when chlorination occurred after coagulation/flocculation as compared with before. Percent reductions in Term THMs were not computed since raw water Term THMs varied during the experiment (Ohio River Valley Water Sanitation Commission 1980).

Blanck (1979) reported on another water treatment plant where the point of chlorination was moved from the intake to the effluent from the settling basin resulting in a 76 percent decline in THM levels. Stevens et al. (1976) identified the point of chlorination in the treatment process to represent the most important variable to be considered for change in attempts to reduce Term THM concentrations in finished drinking water. Several researchers noted that chlorinating after the coagulation/flocculation stage required a smaller chlorine dose to achieve the same free chlorine residual (Young and Singer 1979; Ohio River Valley Water Sanitation Commission 1980; Blanck 1979).

Reduction in precursor concentrations has been accomplished by adsorption onto activated carbon and resins. Stevens et al. (1976) reported the chlorination of granular activated carbon (GAC) filtered water resulted in significantly less chloroform production than chlorination of raw water. However, Stevens et al. (1976) also reported the effectiveness of GAC filtration was relatively shortlived--a matter of only a few weeks under conditions of pilot plant operation. McCreary and Snoeyink (1980) found the adsorptive capacity of carbon to vary with the source of humic material. Two low acid humic materials, leaf fulvic acid and commercial humic acid, were adsorbed more strongly than the more acidic soil humic and fulvic acids. Additionally, an inverse correlation was found to exist between the adsorptivity of each humic substance and the total amount of carboxyl groups present in the substance. Advantages of coagulation for precursor removal as compared with GAC were reported by Kavanaugh (1978) to include:

1. Little or no capital investment.

2. Minimal increase in unit operation costs.

3. Well known technology.

However, coagulation is less effective than GAC for the removal of organics of synthetic origin (Kavanaugh 1978).

Macroporous strong and weak base resins were reported by Rook and Evans (1979) to be effective in removing humic substances from natural waters. Organics were adsorbed on the hydroxide form of weak base resins, and organics were eluted from the resins with hydrochloric acid. This resin type was found to be about 5 percent effective in removing humic acids from Rhine River water during a 2-year period. However, Rook and Evans (1979) noted the elution of organics from ion exchange resins could pose a considerable disposal problem.

Reverse osmosis was suggested by Odegaard and Koottatep (1982) to be suitable for removal of humic material from waters. Because of the

high molecular weight of humic material, it was expected that relatively open membranes could be used in the reverse osmosis process resulting in a high product water flux. They demonstrated that reverse osmosis is a feasible alternative for removal of humic substances from surface waters in small water works. Pilot plant tests would be required to choose the most suitable membrane.

Pretreatment elimination or alternative oxidant pretreatment

Pretreatment of raw water with chlorine is widely practiced for the removal of nuisance organisms from treatment systems. However, if the treatment plant is removing significant amounts of precursors, it would be advantageous to delay chlorination (eliminate pretreatment) or use an alternative disinfectant for pretreatment. Alternative disinfectants which have been used for pretreatment include chlorine dioxide, ozone, hydrogen peroxide, and potassium permanganate.

In addition to examples previously mentioned, where the point of chlorination was delayed until coagulation/flocculation was accomplished, Briley et al. (1980) reported the termination of prechlorination and use of only post treatment chlorination resulted in a 70 percent decrease in TTHMs. Young and Singer (1979) reported on a water treatment plant in North Carolina which terminated prechlorination of raw water and began chlorination directly after clarification. A 40 percent reduction in average chloroform production was realized. Vogt and Regli (1981) suggested prechlorination for the control of bacteria, algae and slime growth within a treatment plant could be replaced with periodic shock chlorine dosages or, in the case of algae, with copper sulfate treatment.

Blanck (1979) reported on the use of chlorine dioxide as a substitute for prechlorination. The oxidative efficiency of chlorine dioxide is not impaired over a wide pH range and it does not react with such chlorine demanding materials as nitrogeneous compounds. Chlorine dioxide is a useful pretreatment disinfectant as it destroys taste producing phenolic compounds and also serves as an algicide. Additionally, the use of chlorine dioxide as opposed to chlorine for pretreatment has been shown to reduce TTHMs by 59 to 90 percent (Blanck 1979).

Ozone has been investigated as an alternative to chlorine for pretreatment. Ozone is known to react as an electrophile as does hypochlorous acid in all the proposed mechanisms for chloroform production in natural water systems (Riley et al. 1978). In an experiment reported by Riley et al. (1978), the affects of preozonation on chloroform production were extremely pH dependent. When the pH of the system was less than 10, preozonation resulted in diminished chloroform production, whereas at a system pH of greater than 10, chloroform production was enhanced by low ozone dosages. It was suggested by Riley et al. (1978) that ozone ties up electron-rich sites which would otherwise react with hypochlorous acid and produce chloroform. Furthermore, carbonyl compounds are likely to be the products of the ozonation reaction. Certain carbonyl compounds, especially methyl ketones, are known to react with hypochlorous acid to produce chloroform, but significant rates of chloroform production are normally only attained at high pH because of a base-catalyzed rate limiting keto-enol tautomerization. Riley et al. (1978) hypothesized this to be a possible explanation for enhanced chloroform yields which were found only if chlorination occurred at high pH following ozonation at any pH. Glaze et al. (1982) reported that ozonation is capable of oxidizing molecular sites which, upon chlorination, would produce THMs but oxidation of the carbonaceous matrix of natural waters by ozone also produces THM precursors. Glaze et al.

(1982) concluded that the secondary precursors (caused by ozonation) were significantly less reactive than the initial precursors. Rook (1976) studied the affects of moderate ozone doses at a contact time of 8 minutes. Reduction in TTHMs diminished as the time interval between ozonation and chlorination increased. Rook (1976) inferred from this experiment that the organic precursors had either gradually lost ozonides or new reactive methyl ketones were formed.

Ozone may react with an organic or inorganic substrate or with microorganisms. These relatively slow reactions must compete with the potentially rapid decomposition of the O_3 molecule to form hydroxyl radicals ($OH\cdot$). The hydroxyl radical is a powerful nondescriminating oxidizing agent and a desirable intermediate for oxidation of solutes. The rate of O_3 decomposition is a complex function of temperature, pH, and the concentration of organic and inorganic constituents. The carbonate and bicarbonate ions can react with the hydroxyl radical to form secondary species, namely $CO_3\cdot$ or $HCO_3\cdot$ radicals. These react with organic solutes considerably more slowly than the hydroxyl radical (Trussell and Umphres 1978).

The advantages of hydrogen peroxide pretreatment as an alternative to chlorination have been studied. Hydrogen peroxide is a strong oxidant providing a source of free radicals (Russell 1979; Malaiyandi et al. 1980). Voss et al. (1980) studied the treatment of filtered river water and synthetic humic acid samples with hydrogen peroxide. After a hydrogen peroxide contact time of 22 hours, chlorination of samples yielded no detectable chloroform. At a hydrogen peroxide contact time of 30 minutes, chloroform concentrations, upon sample chlorination, were reduced to 80 percent of those found with no hydrogen peroxide pretreatment. The pH range where hydrogen peroxide is effective was reported by Voss et al. (1980) to extend from at least 4 to 10. Hydrogen peroxide treatment is relatively low cost (Malaiyandi et al. 1980).

Potassium permanganate pretreatment has been found by Voss et al. (1980) to reduce chloroform production by 83 percent at a contact time of 1 hour as compared with chlorine pretreatment. Blanck (1979) reported a 76 percent reduction in THMs at a river water treatment plant when prechlorination in the clarifiers was eliminated and potassium permanganate feed was begun. Weber (1972) has stated that the necessity for removing MnO_2 subsequent to oxidation and the need for providing sufficient reaction time make the addition of permanganate prior to coagulation desirable. Therefore, potassium permanganate is well suited for use in pretreatment.

Alternative primary disinfectants

In addition to alternatives to chlorine pretreatment, alternatives to chlorine as a primary disinfectant have also been investigated. chlorine dioxide, ozone, and chloramines have all been studied comparatively with chlorine as to their disinfecting ability and as a means of controlling THMs.

According to Katz (1980), chlorine dioxide offers advantages and disadvantages for water disinfection as compared with chlorine. Chlorine dioxide will not react with organic compounds to yield THMs, chlorine dioxide's oxidative efficiency is not impaired over a wide pH range, and longer lasting oxidant residual is provided by chlorine dioxide as compared to free chlorine. A disadvantage is the excess chlorine resulting from manufacture of chlorine dioxide that typically carries over into the product water. Excess chlorine liberation is common in U.S. chlorine dioxide production. Free chlorine may then react with precursor material in the water and produce THMs (Katz 1980). Vogt and Regli (1981) reported that when

chlorine dioxide concentration was approximately twice that of free chlorine, THM formation was reduced by 90 percent compared with use of chlorine only. With 1.2 times more free chlorine than chlorine dioxide, THM formation was still reduced by more than 60 percent. Presently, there are uncertainties regarding the health effects of chlorine dioxide in drinking water particularly with respect to presence of the chlorite ion (ClO_2^-) (Katz 1980; Weber 1972). When chlorine dioxide oxidizes organics, the following reaction can take place (Katz 1980):

$$\text{organic} + ClO_2 \rightleftarrows \text{oxidized organic} + ClO_2^- \quad (2)$$

The USEPA is currently examining potential health risks associated with the chlorite ion (Katz 1980).

Ozone is used for drinking water purification in over 100 municipalities in Europe (Weber 1972). Ozone is a more efficient disinfectant than chlorine (Vogt and Regli 1981). Because ozone has a higher oxidation potential than all other oxidants, fewer partially oxidized organics which pose health risks should result from its application. Rook (1976) combined moderate ozonation of river water followed by moderate chlorination and observed a 50 percent reduction in haloform production as compared with a chlorine only treatment. Weber (1972) stated the present disadvantages associated with ozone are related mainly to the costs and efficiencies of ozone generating equipment.

Use of chloramine as a primary disinfectant has been examined. Brodtmann and Russo (1979) stated that the use of chloramine as a disinfectant is appropriate at this time because of its negligible THM formation potential. Biocidal effectiveness, according to Brodtmann and Russo (1979), of chloramine as compared to free chlorine treatment is not so much lower as to preclude chloramine treatment from consideration. Brodtmann and Russo (1979) studied the disinfecting capability of chloramine and concluded that good disinfection was consistently achieved and regrowth in the distribution system was insignificant. Additionally, a long lived disinfectant residual throughout the distribution system was provided. It was concluded that when properly applied at effective dosages, chloramine produced 100 percent kills of pathogenic bacterial species and also effectively reduced total bacterial populations to an acceptable range. Norman et al. (1980) reported chloramines provide strong bactericidal effects when organic matter is present. Additionally, Norman et al. (1980) noted that the hypochlorite ion is not much more effective as a disinfectant than monochloramine.

Combined chlorine in distribution systems

Ammonia application after a period of free chlorine contact with water has been studied as a method to reduce the contact time between organic precursors and free chlorine. Addition of ammonium sulfate after chlorination was reported by Norman et al. (1980). Reduction in TTHMs after ammonia addition started was 50 percent at the clearwell. The average reduction in the distribution system (after ammonization) was 75 percent.

Trihalomethane removal after formation

Powdered activated carbon (PAC) and GAC have been found to adsorb trihalomethanes present in finished water. Rook (1976) found a significant reduction in THM levels when PAC was applied in high doses (20 to 40 mg/l). Symons et al. (1975) found water treatment plants using PAC to have lower THM levels than plants not using the carbon. Rook (1976) analyzed GAC for adsorption of trihalomethanes and found the haloforms broke through after a relatively short period of 2 to 3 weeks even though

the carbon was still effective in removing larger chlorinated molecules.

Many halogenated compounds, including trihalomethanes, are known to partition from water to air owing to their hydrophobic behavior in aqueous solution (Roberts and Dandliker 1983). Umphres et al. (1983) studied the removal of THMs from drinking water by packed water aeration and found the method to be relatively low cost as compared with other processes for removing volatile trace organics (i.e., adsorption onto resins or activated carbon). Research reported by Umphres et al. (1983) evaluated constants for a process design model described by Kavanaugh and Trussell (1980). This permitted the design for removal of a variety of volatile organics at water loading rates or packing depths other than those specifically evaluated by pilot testing. Air pollution potential of this treatment method was not addressed.

MATERIALS AND METHODS

Study Site

Deer Creek Reservoir

Figure 2 illustrates Deer Creek Reservoir and its tributaries. Deer Creek Reservoir is located at 40°24' N latitude and 111°25' W longitude. Elevation of the reservoir is 5270 ft (1607 m). Precipitation amounts and temperature by month are presented in Table 1 and represent average values from the last 40 years. The reservoir is approximately 7 mi (11.3 km) long and up to 0.75 mi (1.2 km) wide. Dam construction was completed by the Bureau of Reclamation in 1941. In 1952, a tunnel was completed to import water from the Duchesne River drainage into the Provo River. In addition, a canal was built to import water from the Weber River drainage into the Provo River. These additional waters made it possible to consistently fill and manage Deer Creek Reservoir (Merritt et al. 1977).

Table 1. Mean precipitation and air temperature data for Deer Creek Reservoir from 1942 to 1982 (U.S. Department of Commerce 1982).

Month	Precipitation (in)	Temperature (°F)
Jan	2.80	19.6
Feb	2.31	23.3
Mar	1.93	31.2
Apr	1.75	42.4
May	1.39	51.5
Jun	1.42	58.6
Jul	0.61	67.1
Aug	1.08	65.6
Sep	1.00	56.5
Oct	1.75	46.1
Nov	2.33	33.8
Dec	2.97	25.4
Annual	21.33	43.4

Deer Creek Reservoir has a surface area of 2787 ac (11.28 km^2), volume of 157,182 ac-ft (193.9 x 10^6 m^3), mean depth of 60.5 ft (18.4 m), maximum depth of 137 ft (42 m), and a drainage area of 560 mi^2 (1451 km^2). The reservoir outlet is 25 ft (7.6 m) from the base of the dam (Merritt et al. 1977). Mean residence time in the reservoir is 6 months, however residence time is much shorter than this during high runoff periods. According to Merritt et al. (1977), two trophic states exist in Deer Creek Reservoir differentiated in space. Area from the dam to about mid-lake is dominated by diatom flora throughout the summer season and can be considered mesotrophic to slightly eutrophic. Reservoir area north of mid-lake supports a heavy blue-green algal flora by late summer. This portion of the reservoir is eutrophic (Merritt et al. 1977).

Tributaries

Primary tributaries of Deer Creek Reservoir, based on flow, include the Provo River, Main Creek, and Daniels Creek. Of secondary importance is Deckers Creek. Contributions (by percentage) of tributaries to total flow into Deer Creek Reservoir were documented by Merritt et al. (1977) and are presented in Table 2. During the period of October 1977 to September 1983, Snake Creek contributed 16.8

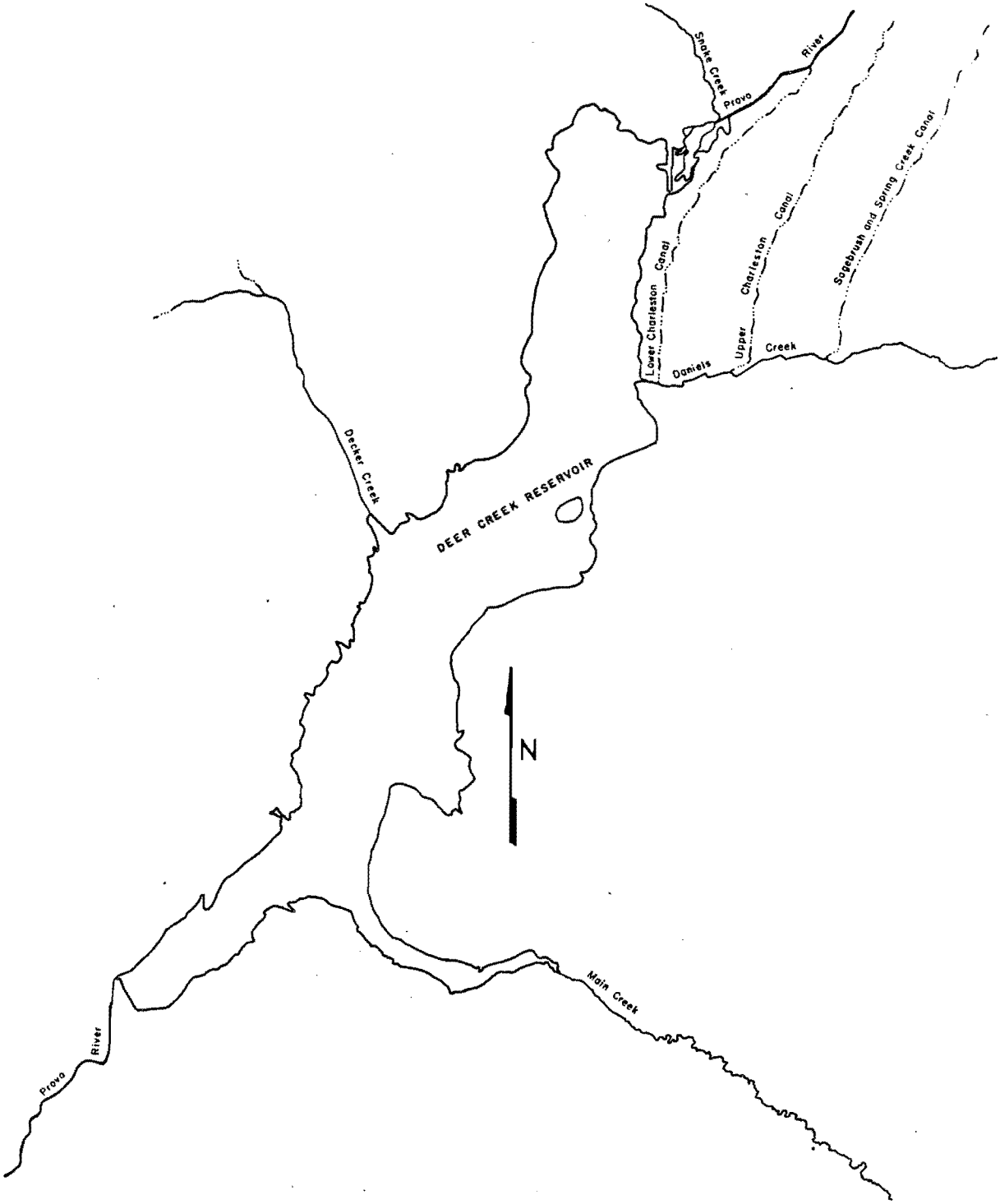

Figure 2. Deer Creek Reservoir and its tributaries.

Table 2. Contribution of tributaries to total flow in Deer Creek Reservoir drainage (Merritt et al. 1977).

Tributary	Percentage
Provo River and Snake Creek	94.4
Main Creek	3.3
Daniels Creek	1.2
Deckers Creek	0.8

percent (with a standard deviation of 1.6) of the combined Provo River and Snake Creek flow. Daniels Creek drains three irrigation canals: Sagebrush and Spring Creek Canal, Upper Charleston Canal, and Lower Charleston Canal. During 1980, Mountainland Association of Governments sampled the Deer Creek Reservoir watershed extensively. Based on flows taken during this study, the Sagebrush and Spring Creek Canal, Upper Charleston Canal, and Lower Charleston Canal comprise 28, 38, and 16 percent of the total flow in Daniels Creek respectively as it enters Deer Creek Reservoir (Mountainland Association of Governments 1983).

Land use

Land uses in areas surrounding the Provo River consist mainly of irrigated agriculture and livestock grazing. Between river miles 2.5 and 6.0 above Deer Creek Reservoir, increased agricultural activity occurs. Much of the land adjacent to the river is pasture land with some irrigated cropland. Between river miles 0.75 and 2.5 above Deer Creek Reservoir, land is used extensively for irrigated cropland. At least two irrigation return flows enter the river in this segment. Spring Creek enters the Provo River 1.75 miles above the reservoir, however this flow is completely diverted during the irrigation season.

Daniels Creek is intermittent above the confluence with Sagebrush and Spring Creek. Land use above this confluence is irrigated cropland and pasture. Irrigated agriculture and a dairy operation are the primary land uses along the Lower Charleston Canal. Dairy cattle have direct access to the stream much of the time. Land in the vicinity of Spring Creek and the Upper Charleston Canal is used primarily for irrigated agriculture and livestock grazing. Along Sagebrush and Spring Creek Canal land is devoted to pasture and hay fields (Mountainland Association of Governments 1983). Lake Creek feeds the Sagebrush and Spring Creek Canal. Sheep and cattle grazing along with rock quarrying and recreation are the land uses adjacent to Lake Creek. Main Creek derives its flow from Spring Creek (Wallsburg) along with other miscellaneous tributaries. Livestock grazing is prevalent in this area (Mountainland Association of Governments 1983).

Snake Creek flows past the Wasatch Mountain State Park golf course and picnic area approximately 3.4 river miles above the confluence with the Provo River. Mahagony Spring and Pine Creek enter Snake Creek approximately 3.5 river miles above the confluence. Hot springs are abundant between the Wasatch Mountain State Park golf course and Midway. Grazing and irrigated agriculture in addition to homes are primary land uses in the areas of 2.2 to 3.0 river miles above the confluence. The concentration of feedlots increases adjacent to the creek as it flows toward the Provo River. Flow directly through barnyards and feedlots was noted at points along the river course (Mountainland Association of Governments 1980).

Nutrient concentrations and flow in selected tributaries

Mean seasonal values and standard deviations for total phosphorus; orthophosphorus; nitrate and nitrite concentrations; and flow are presented

in Table 3 for Snake Creek just above the confluence with the Provo River, the Provo River above the confluence with Snake Creek, Main Creek just before entry to Deer Creek Reservoir, and Daniels Creek just before entry to Deer Creek Reservoir. Data in Table 3 were collected by the U.S. Bureau of Reclamation, the Utah State Department of Health, and Mountainland Association of Governments over a time period from 1979 to 1981. Insufficient data were available for Deckers Creek. Mean seasonal values and standard deviations of total phosphorus, orthophosphorus, nitrate and nitrite concentrations, and flow for the Lower Charleston Canal, Upper Charleston Canal, and Sagebrush and Spring Creek Canal, tributaries of Daniels Creek, are presented in Table 4. These data were collected by Mountainland Association of Governments over a time period from 1979 to 1980.

Geology

Geology of the immediate area surrounding Deer Creek Reservoir is composed primarily of limestone and alluvium with smaller amounts of sandstone, shale, and siltstone. The Provo River course flows primarily through alluvium. Snake Creek flows through areas of limestone in addition to alluvium. Snake Creek also flows through smaller areas of calcareous marine sediments, red siltstone and sandstone, and andesetic pyroclastic rocks. Main Creek flows through intercalated limestone followed by recent alluvium. Daniels Creek flows through intercalated limestone, sandstone with minor shale and siltstone into recent alluvium. Deckers Creek flows through shale, red siltstone, sandstone, shale, limestone, and calcareous sandstone respectively as its elevation declines (Utah Geological and Mineral Survey 1980).

Soils

Soils in the Deer Creek Reservoir area are composed largely of the Gappmayer-Heneger-Wallsburg association with smaller areas of the Kovich-Fluventic Haploborrolls-Crooked Creek association to the north and the Yeates Hollow-Watkins Ridge-Deer Creek association to the east. The Gappmayer-Heneger-Wallsburg association is derived from mixed sedimentary rocks on mountainsides and alluvial fans. The soils are well drained and the water table lies greater than 5 ft (1.5 m) below the surface. The Kovich-Fluventic Haploborrolls-Crooked Creek association is formed in mixed alluvium on floodplains, low stream terraces, and valley floors. Textures and depth of soils vary significantly within short distances. The water table fluctuates with stream flow normally between 2 and 5 ft (0.6 and 1.5 m); however, many areas are flooded for short periods in most years. The Yeates Hollow-Watkins Ridge-Deer Creek association is formed in alluvium and residum from mixed sedimentary rocks on foothills and alluvial fans (Woodward et al. 1976).

Microcosm Study

Microcosm description

Microcosms were used to study the affect of the following parameters on THM precursor concentrations in the reservoir system: phosphorus loading, sediment, algal growth, and application of algicide. Microcosms were not intended to duplicate Deer Creek Reservoir conditions but rather to simulate the reservoir system while permitting study of variation in selected parameters. The microcosm apparatus is illustrated in Figure 3. Gaseous, aqueous, and solid phases were included in the microcosms. Dimensions of these phases are shown in Figure 3. Microcosms were semi-continuous systems. The gaseous phase had an interface with a 2.5 percent sulfuric acid solution containing methyl red dye to prevent interaction between the microcosm gaseous phase and the outside atmosphere (Porcella et al. 1975).

All interior microcosm surfaces were either glass or teflon to eliminate

Table 3. Mean seasonal values for various parameters in Snake Creek, Provo River, Main Creek, and Daniels Creek. Values in parentheses are standard deviations (Wagner 1983; Utah State Department of Health 1979, 1980, 1981; Mountainland Association of Governments 1983).

Tributary	Months	Total Phosphorus (µg/l)	Ortho Phosphorus (µg/l)	Nitrate (mg/l)	Nitrite (µg/l)	Flow (cfs)	Number of Observations
Snake Creek	Mar-May	71 (33)	65 (34)	0.73 (0.18)	12 (4)	60 (23)	12
	Jun-Aug	48 (12)	45 (13)	0.77 (0.28)	19 (12)	66 (13)	11
	Sep-Nov	73 (22)	42 (14)	0.64 (0.19)	23 (13)	59 (6.1)	5
	Dec-Feb	85 (13)	57 (13)	0.67 (0.03)	5 (4)	57 (4.9)	3
Provo River	Mar-May	48 (40)	26 (15)	0.61 (0.62)	<10	719 (253)	10
	Jun-Aug	64 (43)	52 (37)	0.93 (0.70)	9 (9)	471 (386)	12
	Sep-Nov	69 (29)	55 (25)	0.90 (0.50)	12 (3)	83 (31)	6
	Dec-Feb	No data available					
Main Creek	Mar-May	70 (39)	33 (14)	0.23 (0.11)	3 (3)	66 (55)	13
	Jun-Aug	41 (12)	32 (14)	0.31 (0.18)	5 (2)	48 (48)	9
	Sep-Nov	47 (9)	32 (17)	0.47 (0.17)	9 (9)	13 (8)	6
	Dec-Feb	80 (19)	35 (13)	0.76 (0.11)	2 (1)	22 (3)	3
Daniels Creek	Mar-May	118 (36)	76 (49)	0.46 (0.18)	7 (4)	63 (68)	12
	Jun-Aug	121 (47)	102 (33)	1.1 (0.72)	11 (6)	27 (35)	7
	Sep-Nov	154 (92)	140 (83)	1.2 (0.44)	14 (12)	12 (7.7)	5
	Dec-Feb	140 (0)	94 (18)	1.4 (0.21)	5 (3)	10 (2.1)	2

Table 4. Mean seasonal values for various parameters in the Lower Charleston Canal, Upper Charleston Canal, and Spring and Sagebrush Creek. Values in parentheses are standard deviations (Mountainland Association of Governments 1983).

Tributary	Months	Total Phosphorus (µg/l)	Ortho Phosphorus (µg/l)	Nitrate (mg/l)	Nitrite (µg/l)	Flow (cfs)	Number of Observations
Lower Charleston Canal	Mar-May	89 (25)	60 (26)	2.0 (1.0)	19 (5.2)	5 (1)	6
	Jun-Aug	74 (7.8)	69 (7.0)	2.1 (0.75)	23 (14)	5 (4)	8
	Sep-Nov	90 (20)	60 (22)	1.3 (0.37)	11 (7.5)	6 (4)	4
	Dec-Feb	131 (13)	84 (0.7)	1.6 (0.07)	12 (9)	3 (3)	2
Upper Charleston Canal	Mar-May	188 (48)	175 (44)	0.81 (0.20)	31 (9)	15 (2)	4
	Jun-Aug	170 (44)	123 (21)	0.46 (0.31)	27 (10)	15 (2)	3
	Sep-Nov	124 (93)	109 (105)	1.3 (0.63)	14 (18)	6 (4)	2
	Dec-Feb	No data available					
Sagebrush and Spring Creek	Mar-May	142 (59)	100 (49)	0.60 (0.29)	6 (3.6)	9 (4)	7
	Jun-Aug	135 (23)	144 (31)	0.58 (0.28)	6 (6)	8 (3)	6
	Sep-Nov	167 (5.8)	143 (5.8)	0.57 (0.40)	18 (17)	11 (8)	3
	Dec-Feb	165 (35)	81 (20)	1.3 (0.14)	4 (0.7)	8 (3)	2

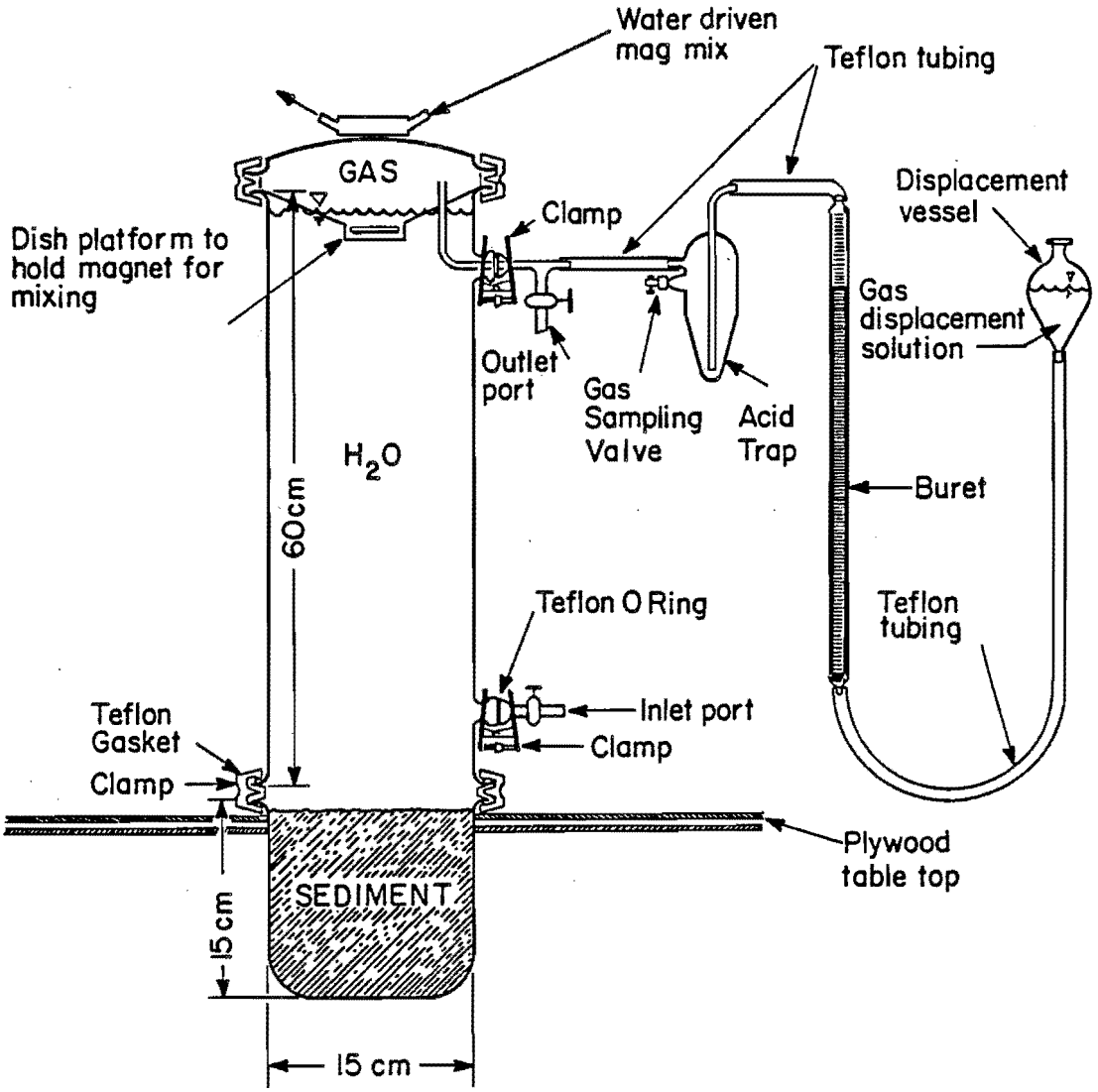

Figure 3. Schematic of microcosm (Dickson et al. 1982).

the possibility of organic contamination. Microcosms were prepared for use by washing, rinsing with double deionized water (DDW), and heating in a 550°C oven for 1 hour to remove any organic material present. A water driven magnetic stirrer continuously mixed the aqueous phase to facilitate gas exchange across the gaseous/aqueous phase boundary and eliminate stratification within the aqueous phase. Additional details concerning this microcosm system can be found in Dickson et al. (1982).

Experiment design

Parameters which were varied included lighting, phosphorus loading, and sediment presence. Four treatments with three replicates of each treatment were studied over time. The variable combinations investigated were:

1. Diurnal light, low phosphorus loading, with sediment (LIGHT L P SED).

2. Diurnal light, high phosphorus loading, with sediment (LIGHT H P SED).

3. Diurnal light, high phosphorus loading, without sediment (LIGHT H P NOSED).

4. Dark, high phosphorus loading, with sediment (DARK H P SED).

Diurnal lighting conditions consisted of a 16 hour light-8 hour dark cycle with lighting provided by Optima 50 fluorescent bulbs (Duro Test Corp.) connected to an automatic timer. Light intensity on the microcosms ranged from 510 to 590 μ Einsteins/m^2 s. Treatment began at the microcosm setup time and continued for 80 days until the experiment conclusion. An 80 day experimental period was chosen based on previous microcosm studies (Werner 1982; Dickson et al. 1982) and by examination of data throughout the experiment.

On day 58, a study to investigate the affect of algicide application on THM precursor production was begun. Two chemicals were used as algicides based on previous research; copper sulfate and potassium permanganate (Muchmore 1978; Putnam and Hein 1980). The three replicates of each treatment type were divided up by treating one microcosm with copper sulfate at a concentration of 50 μg/l Cu^{+2}; one with 0.3 mg/l potassium permanganate; and reserving one replicate as a control (no algicide treatment).

Setup procedure

Sediment for the microcosm experiment was obtained from Deer Creek Reservoir during late spring using an Eckmann dredge. Sediment was taken from the upper 15 cm of the reservoir floor at a position in the lake illustrated in Figure 4. Sediment was transported to the Utah Water Research Laboratory (UWRL) in a teflon lined drum and stored at 4°C overnight. The sediment was completely mixed before placement in the microcosms. A sample of this sediment was reserved for total nitrogen, total phosphorus, and total organic carbon analyses. Techniques used in these analyses are listed in Appendix A. Sediment volumes added to each microcosm were recorded and densities of two sediment samples were measured to determine the mass of sediment added to each microcosm. To increase sediment homogeneity between microcosms, small quantities of sediment were added to each microcosm sequentially until the appropriate volume of sediment was in place.

The aqueous phase of the microcosms was composed of a synthetic medium which simulated the chemistry of Deer Creek Reservoir water excluding phosphorus and nitrogen concentrations. Chemistry of Deer Creek Reservoir water was ascertained using the most recent data available from the Utah State Department of Health. Data used were collected in 1981 and included only surface samples.

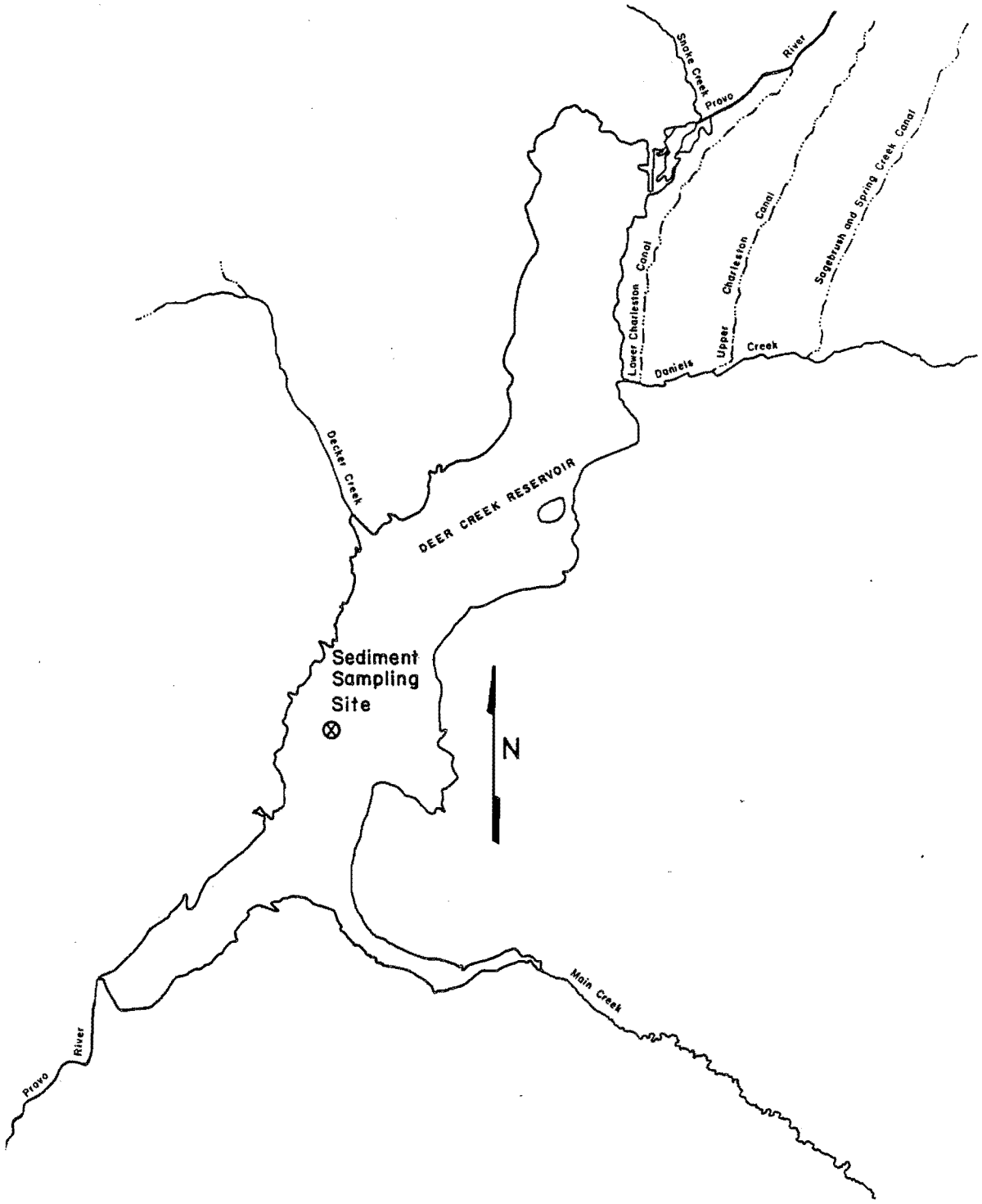

Figure 4. Location of sediment sampling site for the microcosm study.

Averages for major constituents and standard deviations were determined and are listed in Table 5. Synthetic nutrient medium was generated using a number of chemicals in quantities to yield the desired final concentrations of primary constituents (Table 6). Chemical composition of stock solutions and the final medium for the low phosphorus and the high phosphorus types are listed in Tables 7 and 8 respectively. Phosphorus concentrations of 10 and 70 µg/l were selected for the two medium types. Total phosphorus concentrations over 70 µg/l have been measured in tributaries of Deer Creek Reservoir on occasion (Mountainland Association of Governments 1983). A total phosphorus concentration of 10 µg/l represents approximately the lowest achievable loading to the reservoir. Therefore, concentrations of 10 and 70 µg/l reflect actual or possible environmental conditions and also allowed the study of differential phosphorus loading to the reservoir system. Nitrogen concentrations were selected to ensure phosphorus was the limiting nutrient.

Glass containers were always used for the storage of stock solutions and diluted medium solutions. The volume of medium added to individual microcosms was measured and recorded. In addition to the synthetic medium, 1 ℓ of fresh reservoir water was added to the aqueous phase of each microcosm providing an inoculum of organisms from Deer Creek Reservoir. After the addition of all aqueous material, microcosms were maintained in the dark for two days to allow suspended sediment to settle. After this time, microcosms were sealed from the atmosphere, the light cycle was established for the diurnal microcosms, and dark microcosms were placed in a container sealed from light. Initial physical conditions of each microcosm are listed in Table 9. Initial composition of the gaseous phase was that of atmospheric air.

Microcosm maintenance

Microcosms were maintained by exchanging approximately 1 ℓ of the appropriate medium with 1 ℓ of the microcosm's aqueous phase every other day. In the microcosms without sediment, approximately 1.3 was exchanged. These exchange rates provided a residence time of approximately 20 days. A 20-day residence time was used based on previous microcosm studies (Werner 1982; Dickson et al. 1982). Media were chilled approximately 6°C below the temperature of the microcosms aqueous phase to eliminate the possibility of fresh medium loss during the exchange procedure by means of short circuiting (Porcella et al 1975). During medium exchange, fresh medium was added through the lower inlet port of each microcosm while effluent was removed from the upper outlet port. Gas levels in the manometers were read before medium exchange and were adjusted to their approximate initial value after medium exchange. This ensured that approximately equal quantities of medium were added to and effluent removed from the microcosms. Effluent volume was measured and recorded. On test day 58, copper sulfate or potassium permanganate was applied to appropriate microcosms through the synthetic nutrient medium.

Additional measurements were made at the time of nutrient medium exchange to enable the determination of net production or consumption of gas since the last exchange. These measurements included barometric pressure, room temperature, and effluent temperature. A complete list of parameters measured and rationale for measurement was constructed by Werner (1982) and is presented in Table 10.

Sampling and analyses

Every 10 days, effluent from the nutrient medium exchange of each microcosm was collected for chemical and physical analyses. Parameters which were measured throughout the microcosm experiment, including techniques used, are listed in Table 11. Volatile suspended solids, total suspended solids, and total nitrogen analyses

Table 5. Chemical composition of Deer Creek Reservoir surface samples measured between April and November 1981 (Utah State Department of Health 1981).

Parameter	Mean (mg/l)	Standard Deviation	Number of Observations
Calcium	56	3.8	13
Magnesium	16	2.9	13
Sodium	13	0.97	13
Potassium	3	0.4	13
Chloride	11	1.4	11
Sulfate	58	5.1	13
Total Phosphorus	<0.05		27
Ortho Phosphorus	<0.04		27
Nitrate	0.43	0.24	27
Nitrite	<0.01		27
Ammonia	<0.1		27
Alk. (as $CaCO_3$)	144	10.8	22

Table 6. Final concentrations of various constituents in the two types of Deer Creek Reservoir synthetic nutrient media.

Parameter	Low Phosphorus Medium	High Phosphorus Medium
Calcium (mg/l)	55.8	55.8
Magnesium (mg/l)	16.0	16.0
Sodium (mg/l)	12.7	12.7
Potassium (mg/l)	2.5	2.5
Chloride (mg/l)	11.0	11.0
Sulfate (mg/l)	58.0	58.0
Phosphorus (µg/l)	10	70
Nitrate-Nitrogen (mg/l)	0.0967	0.6779
Alkalinity (mg/l as $CaCO_3$)	144.	144.
pH	7.9	7.9

Table 7. Synthetic low phosphorus Deer Creek Reservoir medium.

Compound	Quantity* in Stock Solution (g/l)	Dilution Factor for Final Aqueous Medium	Final Concentration in Microcosm Medium (mg/l)
$CaCl_2$	1.1283	1 → 100	11.28
$MgCl_2$-$6H_2O$	1.0871	1 → 100	10.87
$MgSO_4$-$7H_2O$	14.8819	1 → 100	148.82
$KHCO_3$	0.6401	1 → 100	6.40
$NaHCO_3$	4.6392	1 → 100	46.39
$NaNO_3$	0.5874	1 → 1000	0.5874
KH_2PO_4	0.0439	1 → 1000	0.0439
$Ca(OH)_2$**	0.0956	No dilution	95.6

*Weighed to 0.0001 g.
**Stock solution was not made for this compound. Bubbling with CO_2 was required to dissolve the compound.

Table 8. Synthetic high phosphorus Deer Creek Reservoir medium.

Compound	Quantity* in Stock Solution (g/l)	Dilution Factor for Final Aqueous Medium	Final Concentration in Microcosm Medium (mg/l)
$CaCl_2$	1.1283	1 → 100	11.28
$MgCl_2$-$6H_2O$	1.0871	1 → 100	10.87
$MgSO_4$-$7H_2O$	14.8819	1 → 100	148.82
$KHCO_3$	0.6401	1 → 100	6.40
$NaHCO_3$	4.6392	1 → 100	46.39
$NaNO_3$	4.1160	1 → 1000	4.1160
KH_2PO_4	0.3070	1 → 1000	0.3070
$Ca(OH)_2$**	0.0956	No dilution	95.6

*Weighed to 0.001 g.
**Stock solution was not made for this compound. Bubbling with CO_2 was required to dissolve the compound.

Table 9. Initial physical conditions of microcosms.

Microcosm Number	Treatment	Wet Sediment Wt.* (g)	Gaseous Phase Vol. (l)	Aqueous Phase Vol. (l)
1	LIGHT L P SED	2898	0.971	10.3
2	LIGHT L P SED	3088	0.953	10.4
3	LIGHT L P SED	3110	0.965	10.4
4	LIGHT H P SED	2972	0.991	10.5
5	LIGHT H P SED	3025	0.970	10.4
6	LIGHT H P SED	2866	0.976	10.5
7	LIGHT H P NOSED	0	0.871	13.7
8	LIGHT H P NOSED	0	0.984	13.7
9	LIGHT H P NOSED	0	0.933	13.7
10	DARK H P SED	2951	0.942	10.4
11	DARK H P SED	2940	0.982	10.2
12	DARK H P SED	3131	0.971	10.2

*Sediment was 83 percent water by weight.

Table 10. Parameters measured on medium exchange dates (Werner 1982).

Parameter Measured	Rationale
Room Temperature	Early detection of problems associated with temperature change.
Temperature of Fresh Medium	Assure temperature is low enough to preclude immediate mixing with microcosm aqueous phase. Necessary for calculations to determine dissolved gases entering the microcosms.
Temperature of Effluent Aqueous Phase	Necessary to determine gas solubilities and therefore removal from microcosms. Correct volume of overlying gaseous phase to standard temperature based on its volume at the temperature of the microcosms aqueous phase.
pH of Fresh Media	Assure pH is in proper range to avoid shock to biological organisms in microcosm.
Volume of Effluent Aqueous Phase	Used for mass balance calculations of microcosms constituents (e.g. nutrients and dissolved gases).
Initial Manometer Reading	Calculate net change of gases from previous date.
Final Manometer Reading	Initial point for determining net change of gases for next date. Determine if more or less medium entered the microcosm than aqueous phase removed.
Barometric Pressure	Correct gas volume to standard pressure.

Table 11. Chemical and physical parameters measured in microcosm effluent samples.

Parameter	Technique	Reference
Ortho Phosphorus	Ascorbic Acid	APHA 1980, p. 420
Total Phosphorus	Persulfate Digestion-Ascorbic Acid	APHA 1980, p. 420
Total Organic Carbon	Wet Oxidation-Infrared	APHA 1980, p. 471
Soluble Total Organic Carbon	Wet Oxidation-Infrared	APHA 1980, p. 471
Ammonia	Indophenol	APHA 1980, p. 360
Nitrate	Automated Cadmium Reduction, AZO DYE	APHA 1980, p. 376
Nitrite	Automated AZO DYE	APHA 1980, p. 380
Total Nitrogen	Persulfate	Solorzano and Sharp 1980, p. 751
Alkalinity	Potentiometric Titration	APHA 1980, p. 253
Calcium	EDTA Titrimetric	APHA 1980, p. 185
Total Hardness	EDTA Titrimetric	APHA 1980, p. 195
pH	Electrometric	APHA 1980, p. 402
Total Suspended Solids	Gravimetric	APHA 1980, p. 94
Volatile Suspended Solids	Gravimetric	APHA 1980, p. 97
Dissolved Oxygen	Winkler/Azide	APHA 1980, p. 390
Terminal Trihalomethanes	Liquid/Liquid Extraction	USEPA 1979, p. 68683

began on day 40 of the experiment. Periodically, a sample of each microcosm's effluent was preserved with Lugols solution for subsequent algae identification and quantification.

THM precursor concentration was evaluated by measuring terminal total trihalomethane (Term TTHM) concentration. Term TTHMs are also referred to as maximum total potential. The analysis of soluble Term TTHM concentration began on day 58 of the experiment. Soluble samples were prepared by filtering through prewashed 0.45 micron GF/C glass fiber filters after which the filtrate was placed in a 40 ml glass THM sampling vial and treated similarly to other Term TTHM samples. Term TTHM concentrations were evaluated by injecting a 40 ml sample with 20 µl commercial 5 percent hypochlorite solution (Clorox) followed by incubation at 25°C for 7 days after which time samples were placed in a refrigerator at 4°C until gas chromatograph analysis. When the analysis was performed, a portion of each sample was tested for a chlorine residual using a HACH DPD colorimetric comparator kit. A residual must be present for the Term TTHM analysis to be valid.

THM analysis was conducted using a liquid/liquid extraction technique with a 99 percent pure hexane solvent (Fisher Chemical Co.). Extraction and sampling techniques are documented in the Federal Register (USEPA 1979). Extracted samples were subsequently injected into a Hewlett-Packard model 5880A gas chromatograph with a Hewlett-Packard model 7672A automatic sampler used under the following conditions:

Column - 4 mm ID X 2 m long glass packed with 3 percent SP-1000 on Supelcoport (100/120 mesh) (Supelco, Inc.)
Flow Rate - 40 ml/min
Injector Temperature - 100°C
Oven Temperature Initial - 75°C
Oven Temperature Initial Time - 1.5 min
Oven Temperature Program Rate - 30°C/min
Oven Temperature Final - 100°C
Total Run Time - 7.0 min
Detector Temperature - 250°C
Carrier Gas - Nitrogen
Detector - Electron Capture, Ni63

Standardization of the gas chromatograph was always performed before THM analysis using Supelco, Inc., THM standards. Five standard concentrations were used and sample concentrations always fell within the standard range. Term TTHM concentrations were derived for all samples by adding the respective concentrations of chloroform, bromodichloromethane, dibromochloromethane, and bromoform. Quality control samples of unknown THM concentrations were analyzed quarterly. Additionally, state certification samples were analyzed. All quality control assurance tests were passed during the course of this research. When selected microcosms were treated with copper sulfate or potassium permanganate, the measurement of Term TTHM concentrations in microcosm effluents was performed approximately every other day for all microcosms for 1 week to assess the impact of these chemical additions on THM precursor concentrations.

Gas samples were collected approximately every 10 days in syringes through gas sampling valves of the microcosms (Figure 3). Gas analysis for concentrations of nitrogen, oxygen, carbon dioxide, and methane was performed in triplicate for each microcosm. A Hewlett-Packard model 5750 gas chromatograph was used under the following operating conditions:

Columns - 1.8 m X 0.42 cm OD stainless-steel containing 60-80 molecular sieve 5A (for O_2, N_2, CH_4)
- 1.8 m X 0.42 cm OD stainless-steel containing 120 Poropak S (for CO_2)
Flow Rates - 35 ml/min

Temperature - Column - 60-70°C
Detector - 180°C
Injector - 120°C
Carrier Gas - Helium

Analyses at experiment termination

Biomass quantities were assessed for each microcosm by filtering aliquots of microcosm fluid through prewashed, preweighed GF/C glass fiber filters to measure suspended biomass. Filters were then washed at 103°C for 48 hours, weighed, washed at 550°C for 30 minutes and reweighed. All surfaces within each microcosm were scraped using rubber spatulas and placed on prewashed, preweighed GF/C glass fiber filters to assess periphytic biomass. Samples were dried at 103°C for 48 hours and weighed. All weighing was carried out on a Sartorius balance accurate to 0.0001 g.

Sediment samples from each microcosm were obtained by inserting 2.5 cm diameter glass tubes vertically through the sediment profile. A small glass tube was inserted adjacent to the sampling tube to relieve the vacuum as the stoppered sampling tube was being withdrawn. Duplicate sediment samples were taken from each microcosm. The glass tubes containing sediment were stoppered at both ends and frozen until analyses were performed. Total phosphorus and total organic carbon analyses were performed on sections from the surface to 2 cm, 2 cm to 6 cm, and greater than 6 cm. A composite sediment sample from each microcosm was analyzed for total nitrogen. Techniques used in sediment analyses were identical to those previously described. In addition, a mixed sediment sample was retained from each microcosm in a glass container. This sediment was later centrifuged and the resulting separated liquid chlorinated and analyzed for Term TTHM concentration to evaluate THM precursor concentrations in microcosm sediment interstitial water.

Data analysis

Mass balance analyses for microcosms were performed using a modified version of the FORTRAN program MICRO (Porcella et al. 1975; Werner 1982). Program MICRO was written specifically for microcosm data analysis. A version of the modified program is documented in Werner (1982). Analysis of variance was used, unless otherwise indicated, to evaluate significance of differences between selected parameter concentrations. Statistical analyses were performed using the computer package SPSS. Mass balance and statistical analyses were conducted using a VAX computer at Utah State University.

Tributary and Reservoir Study

Sampling

To quantify THM precursor and nutrient inputs to and outputs from Deer Creek Reservoir, sampling sites were located close to the outlets of significant (in terms of flow) tributaries of Deer Creek Reservoir and the outflow from Deer Creek Reservoir. Tributary sampling site locations are presented in Figure 5. Deckers Creek was sampled on one occasion only since it was considered to have a negligible impact on water quality in Deer Creek Reservoir due to low flow. The location of five reservoir sampling sites are presented in Figure 5. Sampling of reservoir tributaries and outflow was performed approximately monthly. Sampling of Deer Creek Reservoir tributaries and outflow included measurements of flow, pH, temperature, and dissolved oxygen in the field. Apparatus used in acquiring field measurements are listed in Table 12. Reservoir and tributary sampling were conducted at similar times. Sampling of Deer Creek Reservoir included field measurements of pH, temperature, and dissolved oxygen. Apparatus used in acquiring these measurements are identical to those used during tributary sampling (Table 12).

Grab samples for chemical and physical parameter analyses were collected in 6 N hydrochloric acid

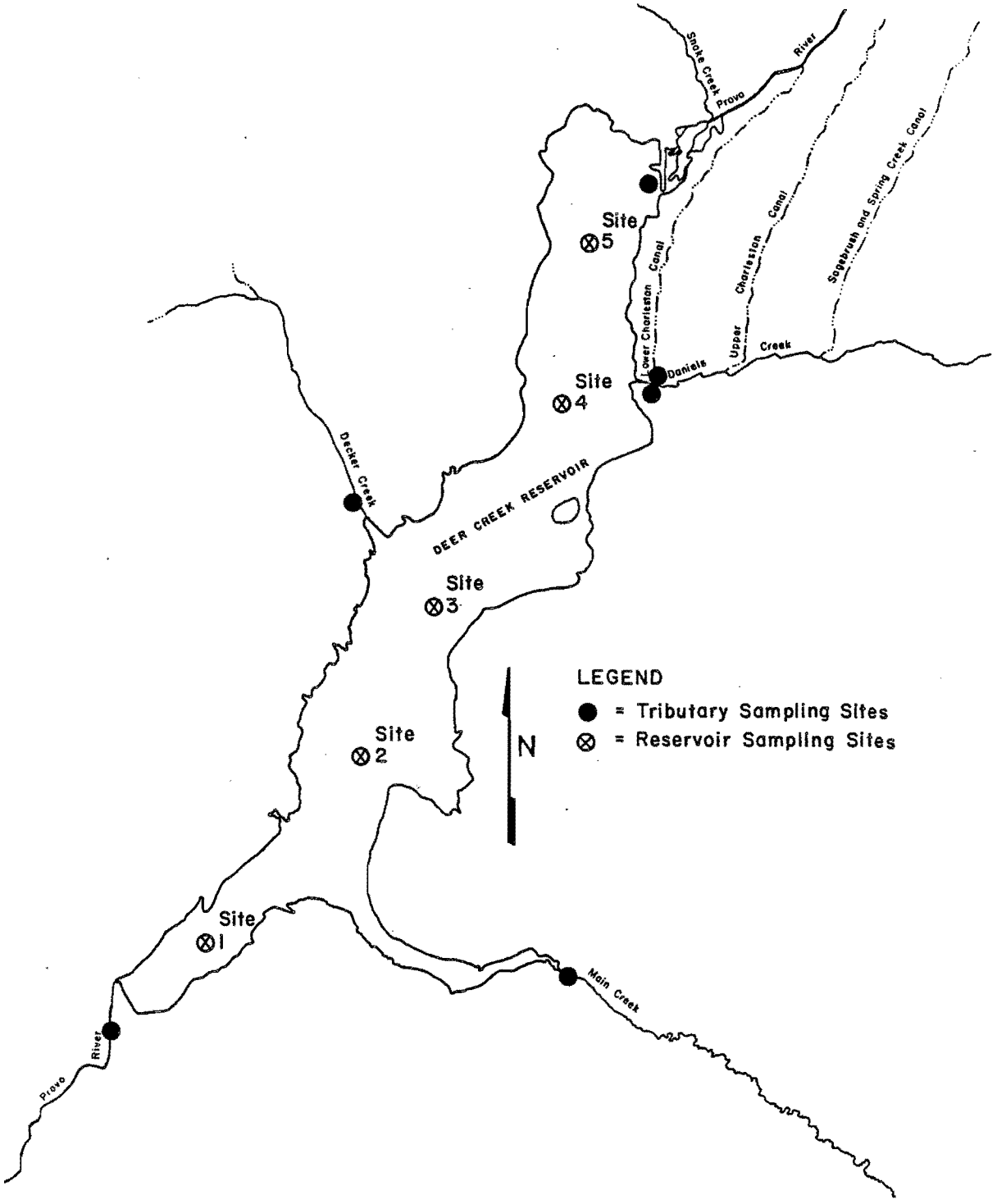

Figure 5. Location of tributary and reservoir sampling sites.

Table 12. Apparatus used in acquiring field measurements.

Measurement	Equipment/ Standardization
pH	Graphic Controls Corporation Portable pH meter; Potentiometric-Electrode Standardized at pH 7 and 9 (APHA 1980)
Dissolved	YSI Model 54 ARC; Standardized using Winkler Method (APHA 1980)
Flow	Marsh-McBirney Velocity Meter and Channel Geometry Data

washed and DDW rinsed containers. Tributary grab samples were taken in well mixed areas just under the water surface. Reservoir samples were collected in the established sites. When possible, two depth samples, one in the middle of the water column and one adjacent to the sediment (middle and deep), were taken at each reservoir sampling site using a Kemmerer water sampler in addition to a surface sample. At all sampling points, THM samples were taken in prepared glass vials. All samples were packed in ice and transported to the UWRL.

Chemical and physical parameter analyses

Chemical and physical parameters measured in tributary, reservoir, and reservoir outflow samples are listed in Table 13. Techniques used in the analysis of these parameters are also in Table 13. THM precursor concentrations were evaluated by measuring Term TTHM concentration as in the microcosm study. Sample preservation was performed when necessary according to APHA (1980) and Adams et al. (1981).

Sediment analysis

The role of interstitial water from Deer Creek Reservoir sediment in providing THM precursors to the reservoir water column was evaluated on sediment samples collected from Deer Creek Reservoir. Sediment from Deer Creek Reservoir was obtained on August 29, 1983, from two locations within the reservoir using an Eckmann dredge (Figure 6). These locations were determined to be representative of average sediment conditions throughout the reservoir based on discussions with Messer (1984). Interstitial water present in the sediment was extracted using a centrifuge and the resulting liquid chlorinated and analyzed for Term TTHM concentrations using the procedure previously described.

Data analysis

Analysis of variance was utilized to evaluate significance of differences between selected parameter concentrations in the tributary and reservoir study. Statistical analyses were performed using the statistical package and computer system previously described.

Table 13. Chemical and physical parameters measured in samples of tributaries, Deer Creek Reservoir, and the reservoir outflow.

Parameter	Technique	Reference
Ortho Phosphorus	Ascorbic Acid	APHA 1980, p. 420
Total Phosphorus	Persulfate Digestion-Ascorbic Acid	APHA 1980, p. 420
Total Organic Carbon	Wet Oxidation-Infrared	APHA 1980, p. 471
Soluble Total Organic Carbon	Wet Oxidation-Infrared	APHA 1980, p. 471
Ammonia	Indophenol	APHA 1980, p. 360
Nitrate	Automated Cadmium Reduction, Azo Dye	APHA 1980, p. 376
Nitrite	Automated Azo Dye	APHA 1980, p. 380
Alkalinity	Potentiometric Titration	APHA 1980, p. 253
Total Nitrogen	Persulfate	Solorzano and Sharp 1980, p. 751
Calcium	EDTA Titrimetric	APHA 1980, p. 185
Total Hardness	EDTA Titrimetric	APHA 1980, p. 195
pH	Electrometric	APHA 1980, p. 402
Sulfate	Turbidimetric	APHA 1980, p. 439
Chloride	Mercuric Nitrate Titrimetric	APHA 1980, p. 271
Total Suspended Solids	Gravimetric	APHA 1980, p. 94
Volatile Suspended Solids	550° C, Gravimetric	APHA 1980, p. 97
Total Dissolved Solids	Gravimetric	APHA 1980, p. 93
Dissolved Oxygen	Winkler/Azide	APHA 1980, p. 390
Terminal Trihalomethanes	Liquid/Liquid Extraction	USEPA 1979, p. 68683

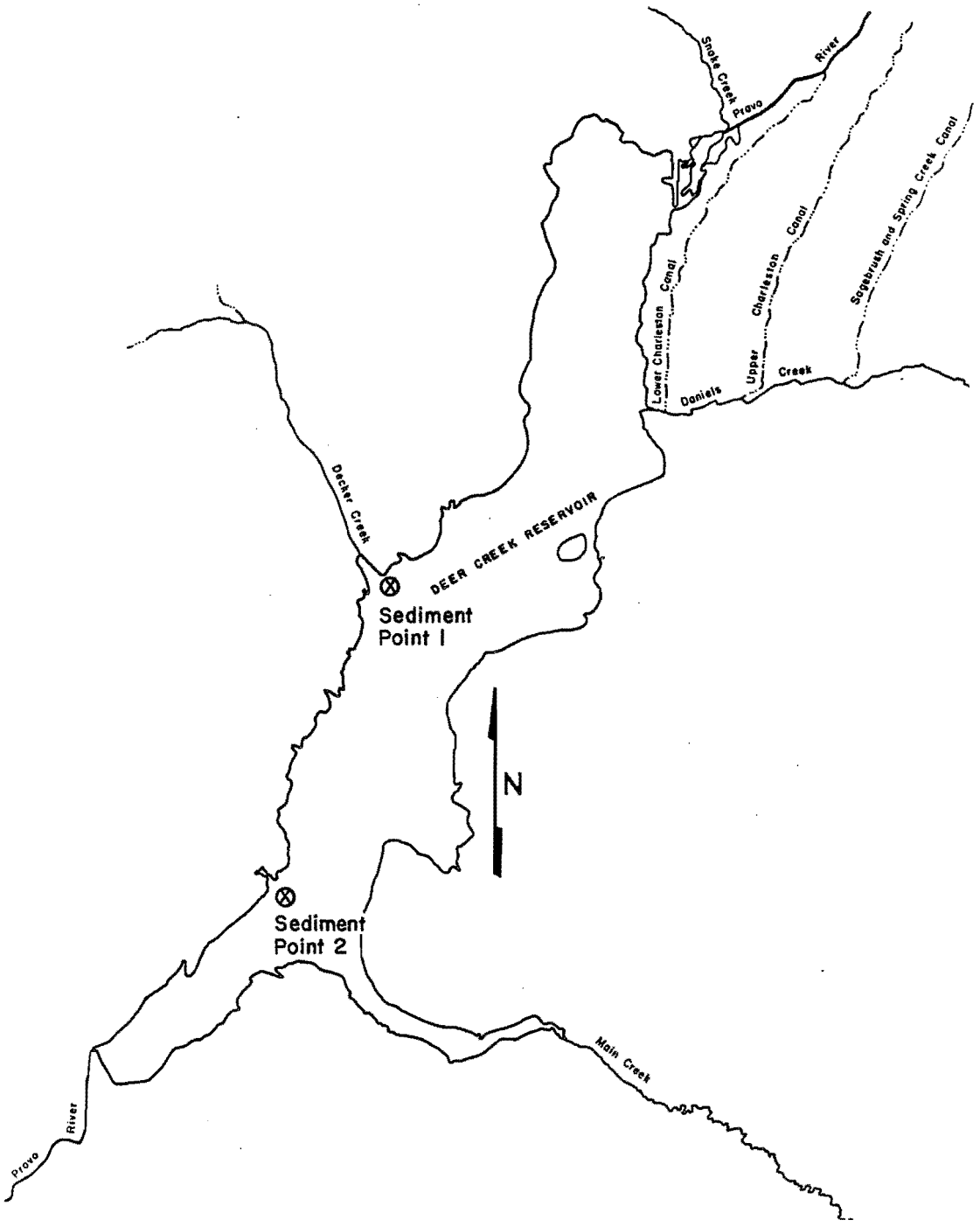

Figure 6. Location of sediment sampling points for analysis of trihalomethane precursors in sediment interstitial water.

RESULTS AND DISCUSSION

Microcosm Study

Visual observations

Visual observations of microcosm conditions over time are recorded in Appendix B. Algae growth was first noticed in the LIGHT L P SED, LIGHT H P SED, and LIGHT H P NOSED treatments on days 20, 18, and 25 respectively.

Aqueous chemistry

Results of various parameters measured in microcosm effluent at 10 day intervals are presented in this section. Mean concentrations for each treatment were derived using data from the three replicate microcosms. Mean total phosphorus concentrations in microcosm effluent of each treatment versus time are presented in Figure 7 (data are in Appendix C). On the first analysis day, mean total phosphorus concentration in the LIGHT L P SED treatment was 58 µg/l. A comparison of this concentration with the medium concentration of 10 µg/l indicates substantial release of phosphorus (approxiately 48 µg/l) from microcosm sediments occurred during the two day sediment settling period after microcosm assemblage and before the first analysis day. A similar level of phosphorus release from sediments was evident in the LIGHT H P SED treatment as the mean total phosphorus concentration on the first analysis day was 115 µg/l compared with a media concentration of 70 µg/l. Therefore, the amount of phosphorus released in LIGHT H P SED microcosms was approximately 45 µg/l which is almost identical to the quantity released from LIGHT L P SED microcosms. In LIGHT H P NOSED microcosms, the mean initial total phosphorus concentration was 68 µg/l which is essentially undifferentiable from the media concentration of 70 µg/l. Microcosms kept under dark conditions exhibited an initial phosphorus sediment release similar to microcosms kept under diurnal lighting conditions (approximately 32 µg/l).

Mean total phosphorus concentration was determined to be greater (at a confidence level of 99.9 percent) in the DARK H P SED treatment as compared with the LIGHT H P SED treatment. This was evaluated by the summation of data from all test days for each microcosm. When data from individual sampling days were analyzed, mean total phosphorus concentrations were found to be significantly greater (above the 95 percent confidence level) in the dark treatment as compared with the diurnal treatment beginning day 20 through the remainder of the experimental period. It was expected that mean total phosphorus concentration would be significantly greater in the aqueous phase of dark microcosms compared with similar diurnal microcosms since inorganic phosphorus release from sediment should occur when anoxic conditions develop (Messer 1984).

A comparison of total phosphorus concentrations in LIGHT H P SED versus LIGHT H P NOSED treatments over the entire experimental period did not indicate a significant difference in mean total phosphorus concentration between the two treatments. Overall, the mean concentration of total phosphorus in the LIGHT H P SED treatment was slightly greater than in the similar treatment without sediment. The general lack of significance between total phosphorus concentrations in similar micrcosms with and without sediment indicates sediment release of phosphorus

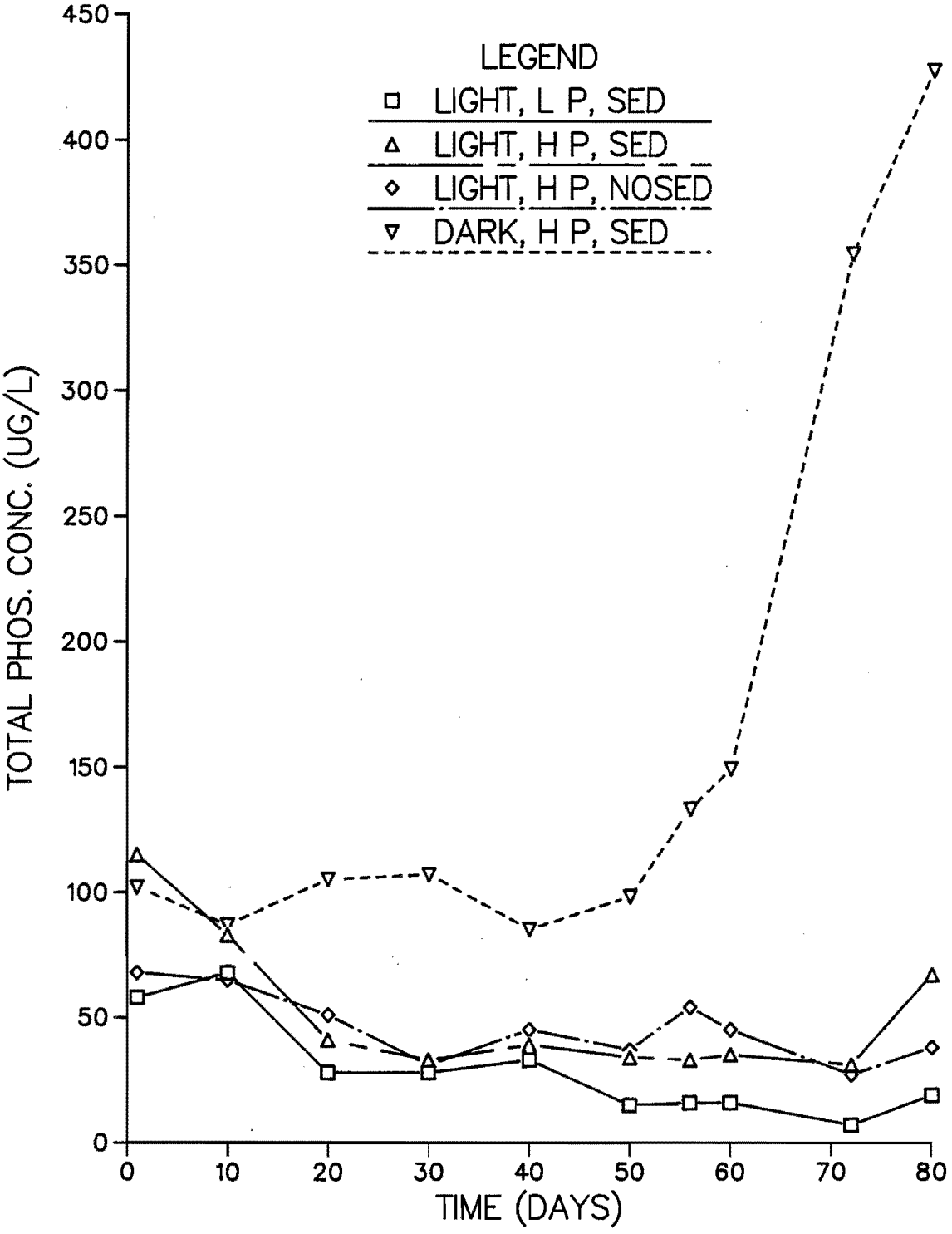

Figure 7. Mean total phosphorus concentrations of each microcosm treatment versus time.

in diurnal microcosms with a high phosphorus loading did not occur to a significant degree over the 80 day experimental period. However, significant sediment release did occur during the initial sediment settling stage of the experiment.

In comparing total phosphorus concentrations over the entire experimental period in effluent from LIGHT L P SED and LIGHT H P SED microcosms, mean total phosphorus concentrations were found to be significantly greater (at a 96 percent confidence level) in LIGHT H P SED microcosms. This trend was constant throughout the entire experiment with mean total phosphorus concentrations consistently greater in diurnal microcosms treated with a high phosphorus loading compared with a low phosphorus loading. This result is reasonable since a 60 µg/l phosphorus differential existed between low and high phosphorus media.

Mean orthophosphorus concentrations in microcosm effluent of each treatment versus time are presented in Figure 8 (data are in Appendix C). By examining Figures 7 and 8, it is evident that in the LIGHT L P SED and LIGHT H P SED treatments, initial release of available phosphorus from sediments was followed by sharp declines in both total and orthophosphorus concentrations. It appears orthophosphorus was being utilized to establish algae populations. Declines in total phosphorus concentration indicate equilibration of the system to steady state conditions through mechanisms of medium addition and effluent removal, algae growth on microcosm surfaces, and algae settling. Although sediments are known to behave as phosphorus traps in some cases under aerobic conditions, this phenomenon was not apparent in the experiment as similar microcosms with and without sediment had similar total and orthophosphorus concentrations. Steady state total phosphorus concentrations appeared to be approximately 15 µg/l and 40 µg/l in LIGHT L P SED and LIGHT H P SED treatments respectively. In LIGHT H P NOSED microcosms, mean total phosphorus concentrations declined initially and oscillated around approximately 40 µg/l. In the LIGHT L P SED treatment, a steady state total phosphorus concentration of 15 µg/l indicates accumulation of phosphorus in the algal populations. In LIGHT H P SED and LIGHT H P NOSED treatments, steady state total phosphorus concentrations of 40 µg/l indicate the utilization of phosphorus by the attached and settled algae populations.

In the DARK H P SED treatment, mean total phosphorus concentrations oscillated around 90 µg/l between days 1 and 60 after which time accumulation of phosphorus in the aqueous phase increased sharply. Figure 9 illustrates mean dissolved oxygen concentrations in the four microcosm treatments versus time. Concurrent examination of Figures 7 and 9 illustrates that mean total phosphorus concentrations in the DARK H P SED treatment began increasing when dissolved oxygen concentration dropped below approximately 3 mg/l. The increase in total phosphorus concentration associated with a low dissolved oxygen concentration was due, most likely, to the development of anoxic microsites adjacent to the sediment resulting in phosphorus release from iron complexes which has been documented to occur in Deer Creek Reservoir sediments by Messer (1984). A similar result, though not to the degree seen here, was reported by Werner (1982) after dissolved oxygen concentrations dropped below approximately 2.0 mg/l in dark microcosms.

Graphs of total phosphorus concentration versus time in each microcosm, grouped by treatment, are presented in Appendix D. Algicide treatment administered to each microcosm on day 58 of the experiment is noted in parentheses on the legend of these graphs. No general trend in total phosphorus concentration change is evident between application of particular algicides and

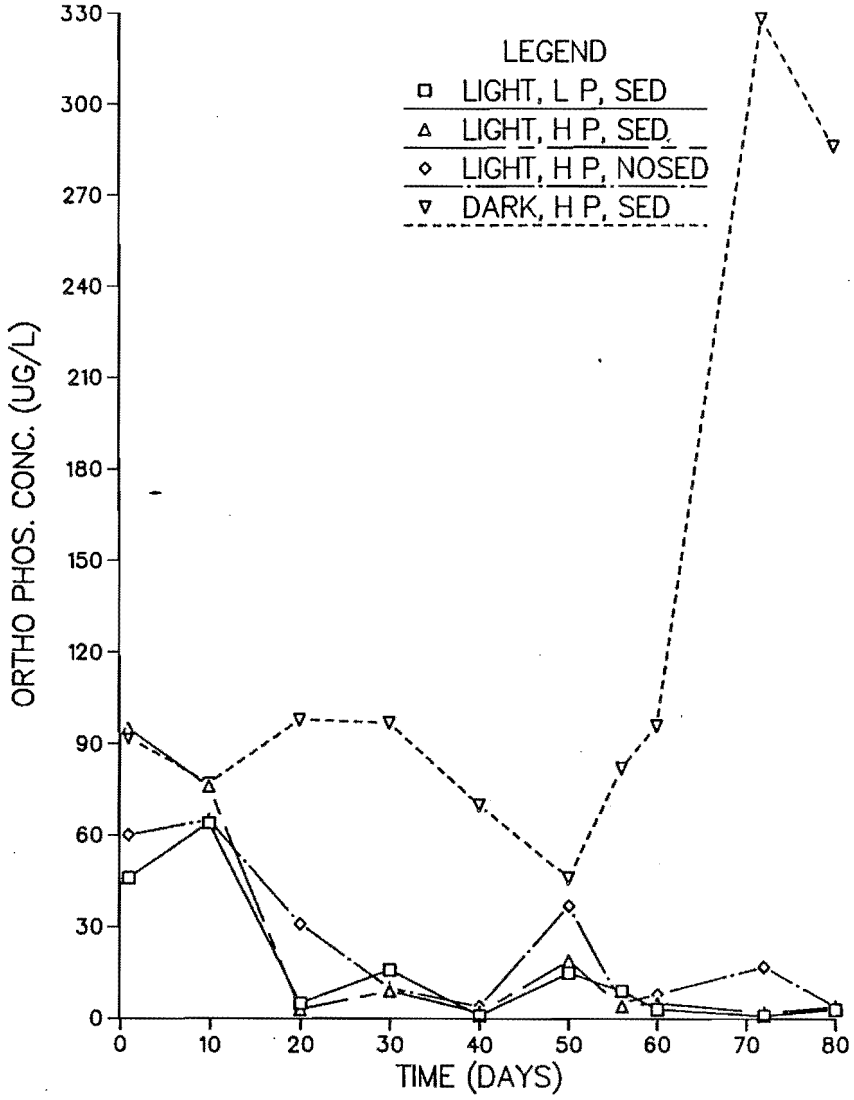

Figure 8. Mean ortho phosphorus concentrations of each microcosm treatment versus time.

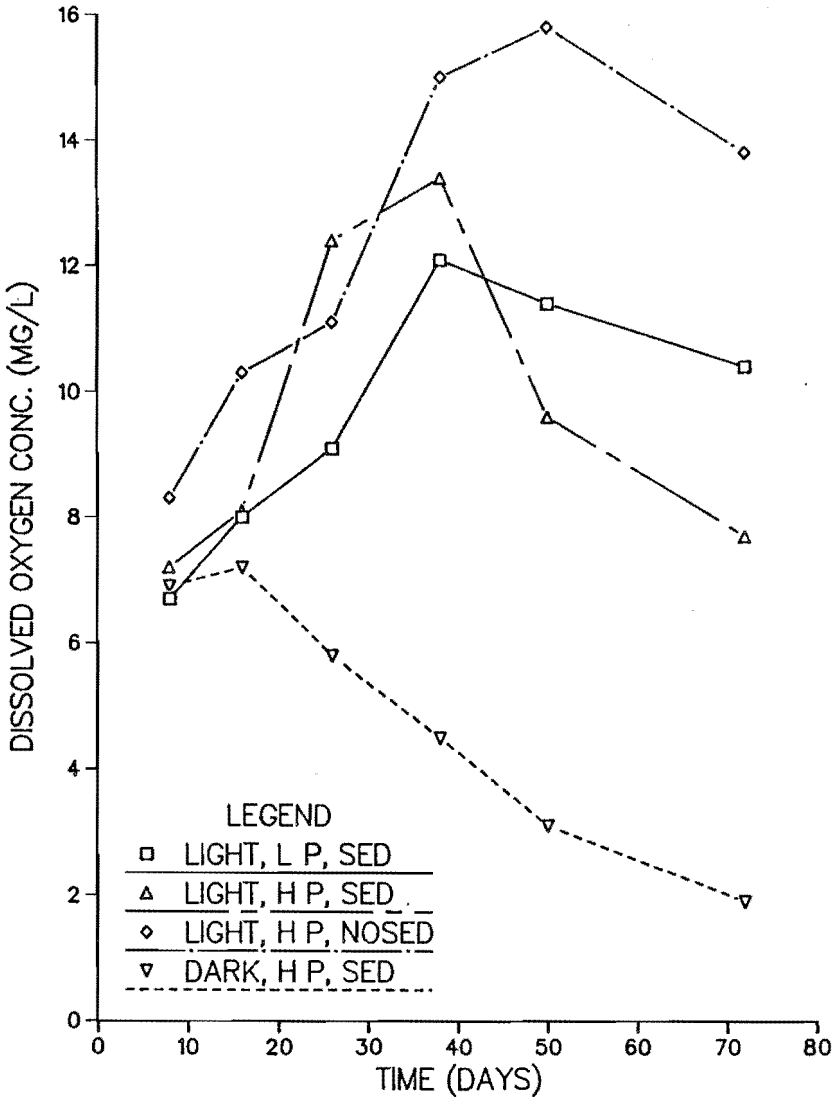

Figure 9. Mean dissolved oxygen concentrations of each microcosm treatment versus time.

treatment types. After experiment day 60, substantially more variation was evident in total phosphorus concentrations between the LIGHT H P SED microcosms; however, by examining all figures in Appendix D, this cannot be necessarily attributed to differential algicide application.

Mean total organic carbon concentrations in microcosm effluent of each treatment versus time are presented in Figure 10 (data are in Appendix C). Results were quite variable between microcosms of the same treatment but particularly in the LIGHT H P NOSED treatment. Over the entire experimental period in LIGHT L P SED and LIGHT H P SED treatments, mean total organic carbon concentration in the LIGHT H P SED treatment were not found significantly different. Mean total organic carbon concentration was found to be significantly higher, at the 98 percent confidence level, in the LIGHT H P SED treatment compared with the DARK H P SED treatment considering data from the entire experimental period. No significant difference could be found to exist between mean total organic carbon concentrations in LIGHT H P SED versus LIGHT H P NOSED treatments. However, the overall mean concentration in microcosms without sediment was somewhat higher than in microcosms with sediment. Soluble total organic carbon concentrations are in Appendix C. The contribution of soluble total organic carbon to total organic carbon in all microcosms are quite variable over time.

Mean nitrate concentrations in microcosm effluent of each treatment versus time are presented in Figure 11 (data are in Appendix C). For LIGHT L P SED microcosms, nitrogen loading was 0.0967 mg NO_3-N/l. Therefore, examination of Figure 11 indicates a relatively constant use of nitrate occurred throughout the experiment through the mechanism of algae and bacteria growth. In high phosphorus loaded microcosms, the nitrogen loading was 0.6779 mg NO_3-N/l. In LIGHT H P SED and LIGHT H P NOSED treatments, the degree of nitrate utilization was very high between days 1 and 30 after which the rate of utilization declined. Days 1 through 30 corresponded with the period of algae and bacteria population establishment. Although mean nitrate concentrations in the DARK H P SED treatment behaved similarly over time to other high phosphorus treatments, different mechanisms were most certainly operative under dark as compared with diurnal conditions. In the DARK H P SED treatment, declines in nitrate levels through approximately day 50 were proably due to bacteria growth. As previously discussed, after day 50 oxygen tensions became low and anoxic microhabits were believed to have become established resulting in denitrification. No discernible effect in nitrate concentration resulted from the various applications of algicides.

Mean ammonia concentrations in microcosm effluent for each treatment versus time are shown in Figure 12 (data are shown in Appendix C). In LIGHT L P SED and LIGHT H P SED treatments, mean ammonia concentrations were initially very high and rose between days 1 and 10 reaching a maximum of 1690 µg/l and 1440 µg/l respectively. Rapid declines in ammonia concentration occurred between days 10 and 50 in LIGHT L P SED microcosms and days 10 and 30 in LIGHT H P SED microcosms until steady state conditions were attained. In the DARK H P SED treatment, ammonia levels were initially of the same magnitude as other microcosm treatments with sediment, but increased to a maximum of about 1840 µg/l on day 40 after which declines occurred. During the entire experiment, ammonia levels in dark microcosms were over 1200 µg/l. Ammonia production caused by microbial decomposition of organic nitrogen (ammonification) was probably the mechanism by which ammonia levels rose in the DARK H P SED treatment. In the LIGHT H P NOSED treatment, ammonia levels were initially undetectable, then oscillated throughout the experiment from below detection

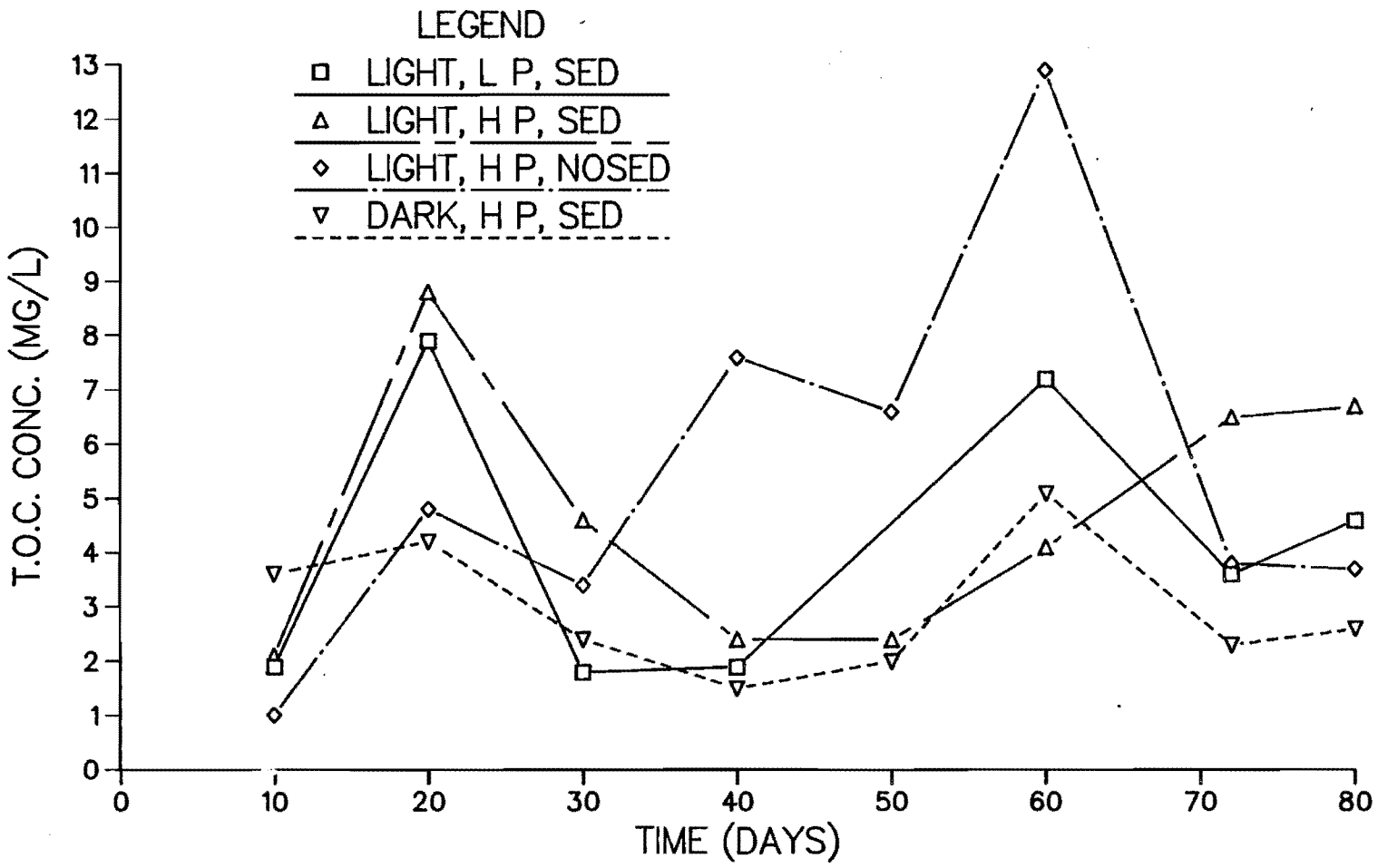

Figure 10. Mean total organic carbon concentrations of each microcosm treatment versus time.

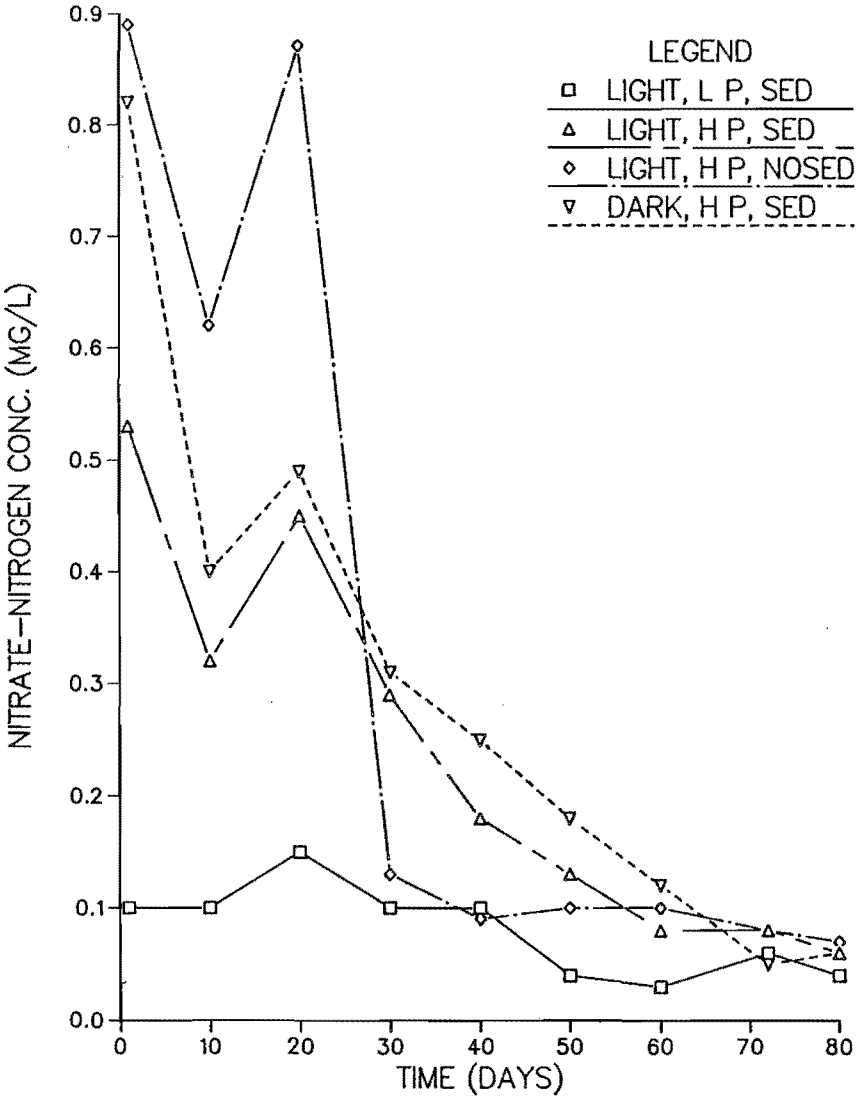

Figure 11. Mean nitrate concentrations of each microcosm treatment versus time.

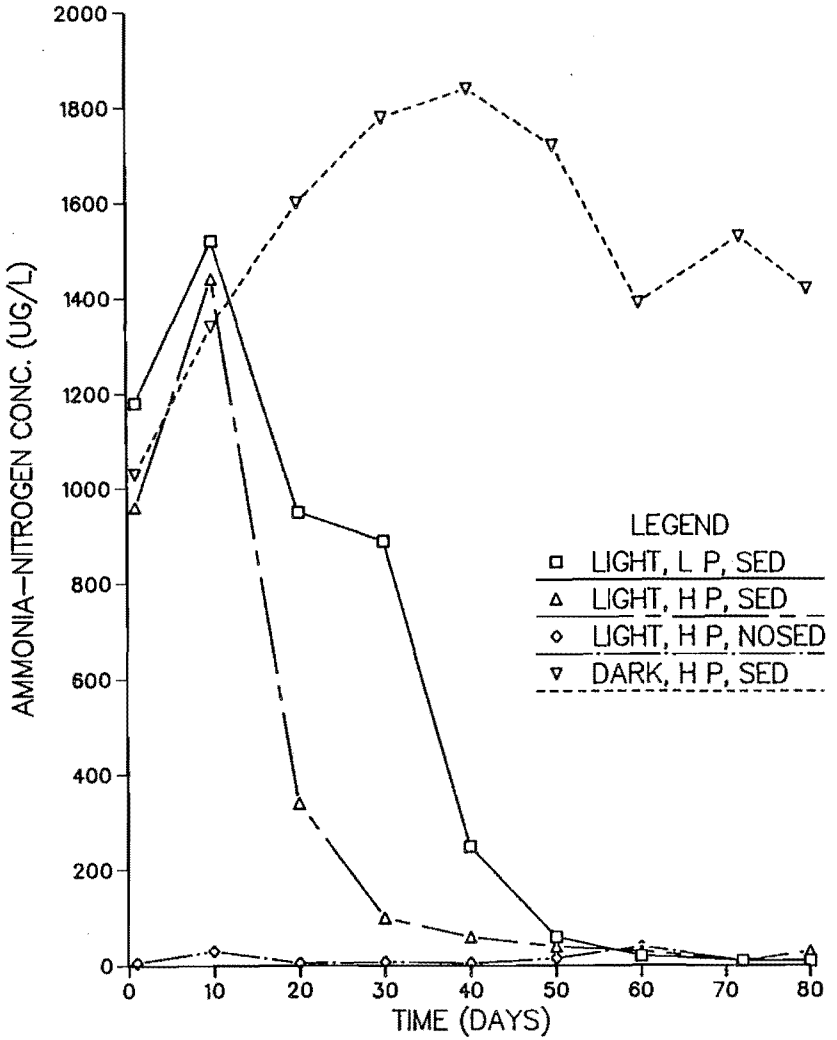

Figure 12. Mean ammonia concentrations of each microcosm treatment versus time.

limits to a high of 50 µg/l. From these results it is clear that sediment presence led to high initial ammonia concentrations in diurnal microcosms.

Nitrite concentrations in effluent of each microcosm over time are presented in Appendix C. LIGHT L P SED and LIGHT H P NOSED treatments had constant, low nitrite concentrations throughout the experiment. In contrast, nitrite concentrations in LIGHT H P SED microcosms were more variable over time. Mean nitrite concentration in the DARK H P SED treatment rose around day 50, at the same time anoxic phosphorus release from sediments was occurring, and then returned to initial low levels by day 80.

Suspended solids and volatile suspended solids

Total and volatile suspended solids measurements began on day 40 of the microcosm experiment. Mean total suspended solids concentrations in microcosm effluent of each treatment type versus time are presented in Figure 13. Mean volatile suspended solids concentrations in microcosm effluent of each treatment type versus time are presented in Figure 14 (data are in Appendix C). In general, suspended solids concentrations were greater in the LIGHT H P SED treatment compared with the LIGHT L P SED treatment. No significant differences were found to exist between overall mean volatile suspended solids concentrations in LIGHT L P SED versus LIGHT H P SED, LIGHT H P SED versus LIGHT H P NOSED, or LIGHT H P SED versus DARK H P SED treatments due, possibly, to high variability between suspended solids measurements in replicate microcosms of the same treatment and because most of the algal growth in the light microcosms was attached growth. In the LIGHT L P SED treatment, volatile suspended solids concentration and volatile suspended solids concentration over time in individual microcosms grouped by treatment are in Appendix E. Algicide treatment is denoted in parentheses on these graphs. No consistent trend between algicide application and volatile or total suspended solids concentrations is apparent.

Mean attached and suspended biomass present at experiment termination and associated standard deviations for each treatment are in Appendix F. Attached biomass was greatest in LIGHT L P SED microcosms after 80 days. Total and volatile suspended solid concentrations were much greater in the LIGHT H P SED treatment as compared to the other treatments.

Biological identifications

Dominant algae genera identified on various experiment days for the three diurnal treatments are listed in Table 14. In general, green algae genera (primarily Chlorella sp.) dominated the LIGHT H P SED and LIGHT H P NOSED treatments throughout the experiment. The LIGHT L P SED treatment was dominated by green algae until approximately day 72, when Chroococcus sp. appeared in abundance. Algae populations appeared to diversify as time progressed in terms of numbers of genera identified. Algae listed in Table 14 were identified in effluent samples and represent suspended algae populations as opposed to attached. Algicide application did not appear to alter the algae populations in terms of genera identified.

Gas accumulations

Accumulated changes in various gas constituents were derived using the FORTRAN program MICRO which considered gas production or consumption and composition. Mean accumulated change in gas volume versus time for each treatment type is presented in Figure 15. Mean accumulated change in oxygen gas volume versus time for each treatment type is presented in Figure 16 (data associated with Figures 15 and 16 and standard deviations are in Appendix G). Mean accumulated change in methane and

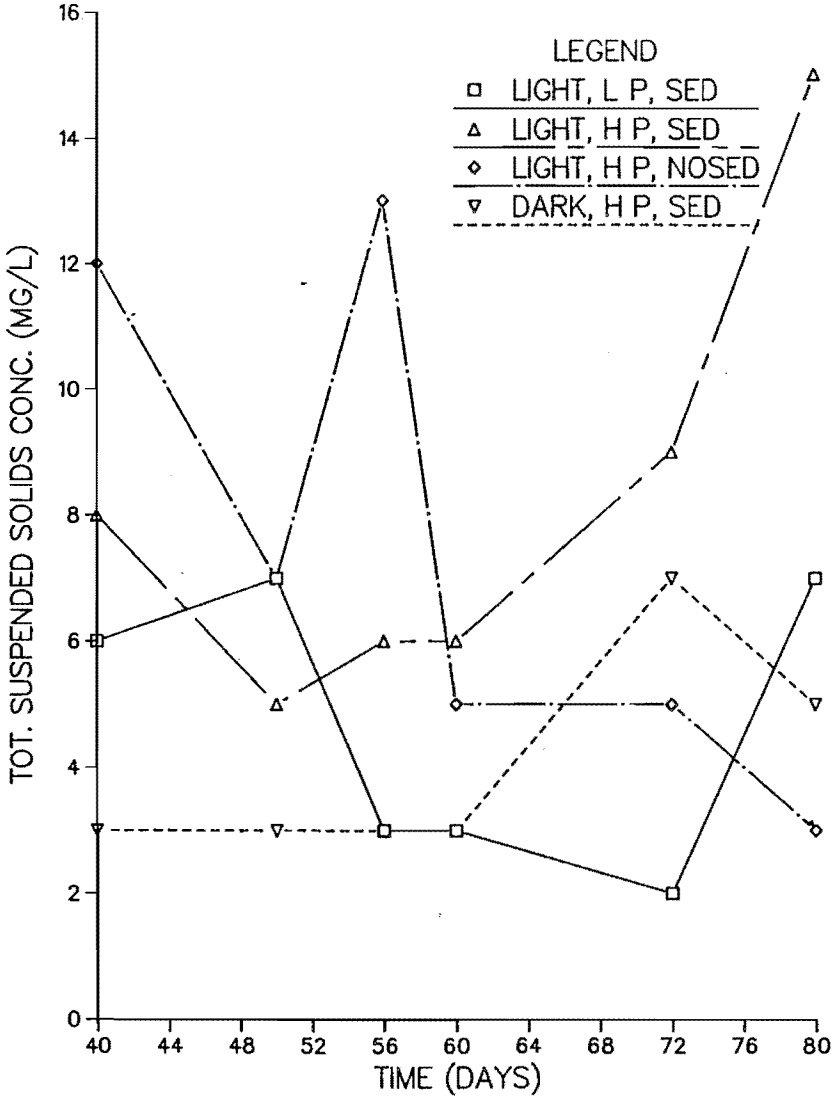

Figure 13. Mean total suspended solids concentrations in effluent of each microcosm treatment versus time. Measurements began on day 40 of the experiment.

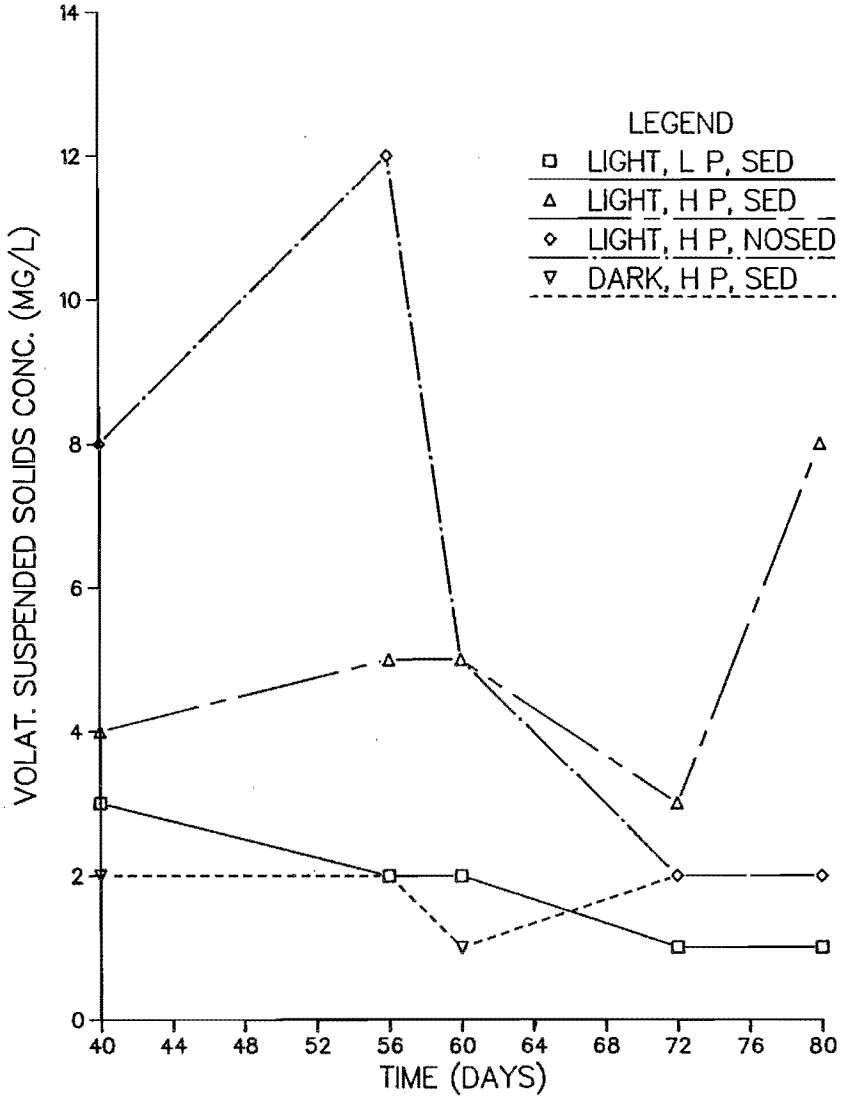

Figure 14. Mean volatile suspended solids concentrations in effluent of each microcosm treatment versus time. Measurements began on day 40 of the experiment.

Table 14. Dominant algae genera identified in the diurnal microcosm treatments.

Experiment Day	Treatment	Algae
40	LIGHT L P SED	Chlorella sp. Schroederia sp.
	LIGHT H P SED	Chroococcus sp. Schroederia sp. Chlorella sp.
	LIGHT H P NOSED	Chlorella sp.
52	LIGHT L P SED	Chlorella sp.
	LIGHT H P SED	Chlorella sp.
	LIGHT H P NOSED	Chlorella sp. Chroococcus sp. Schroederia sp.
63	LIGHT L P SED	Chlorella sp.
	LIGHT H P SED	Chlorella sp.
	LIGHT H P NOSED	Chlorella sp. Schroederia sp.
72	LIGHT L P SED	Chroococcus sp.
	LIGHT H P SED	Chlorella sp. Schroederia sp.
	LIGHT H P NOSED	Chlorella sp. Schroederia sp.
80	LIGHT L P SED	Chroococcus sp. Tabellaria sp. Schroederia sp. Chlorella sp.
	LIGHT H P SED	Chlorella sp. Fragilaria sp. Schroederia sp.
	LIGHT H P NOSED	Chlorella sp. Oscillatoria sp. Anabaena sp.

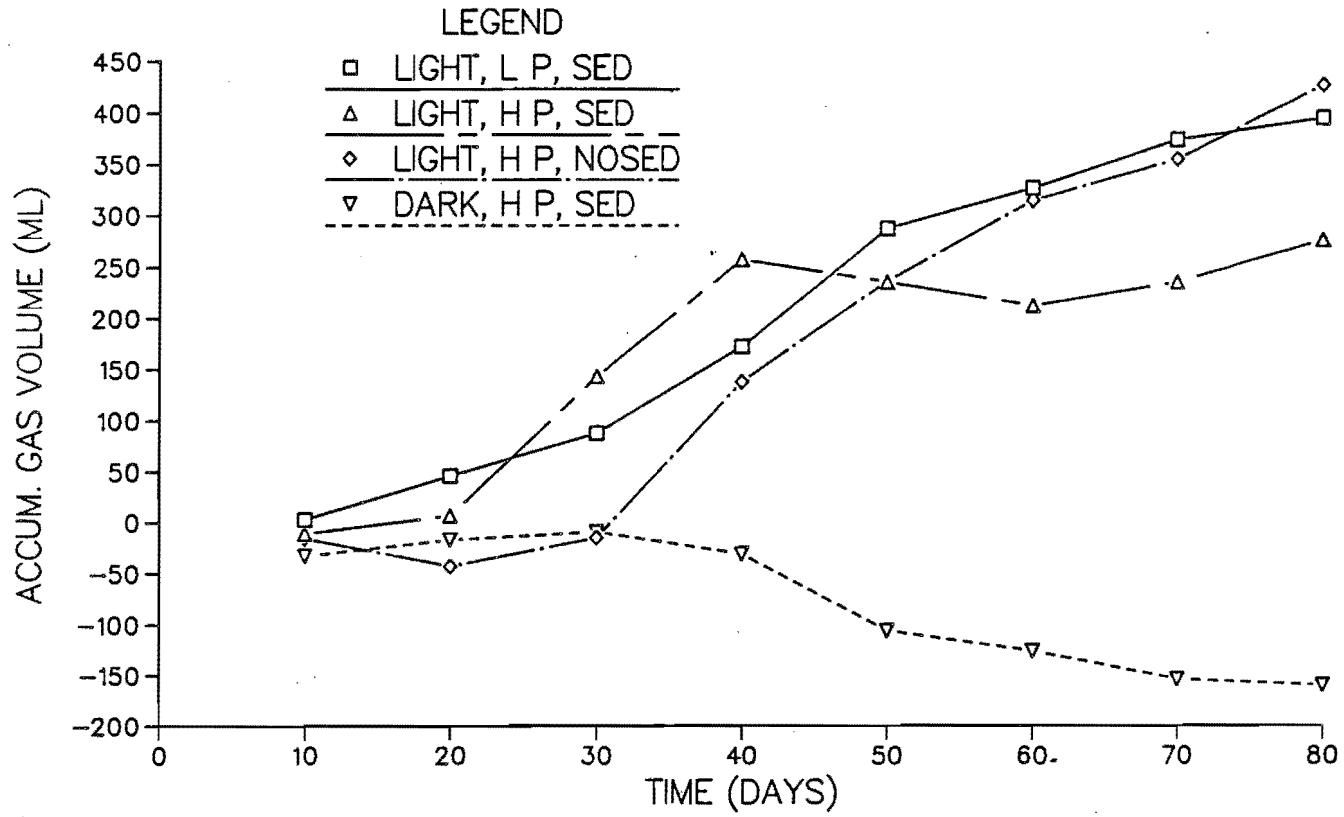

Figure 15. Mean accumulated gas volumes of each microcosm treatment versus time.

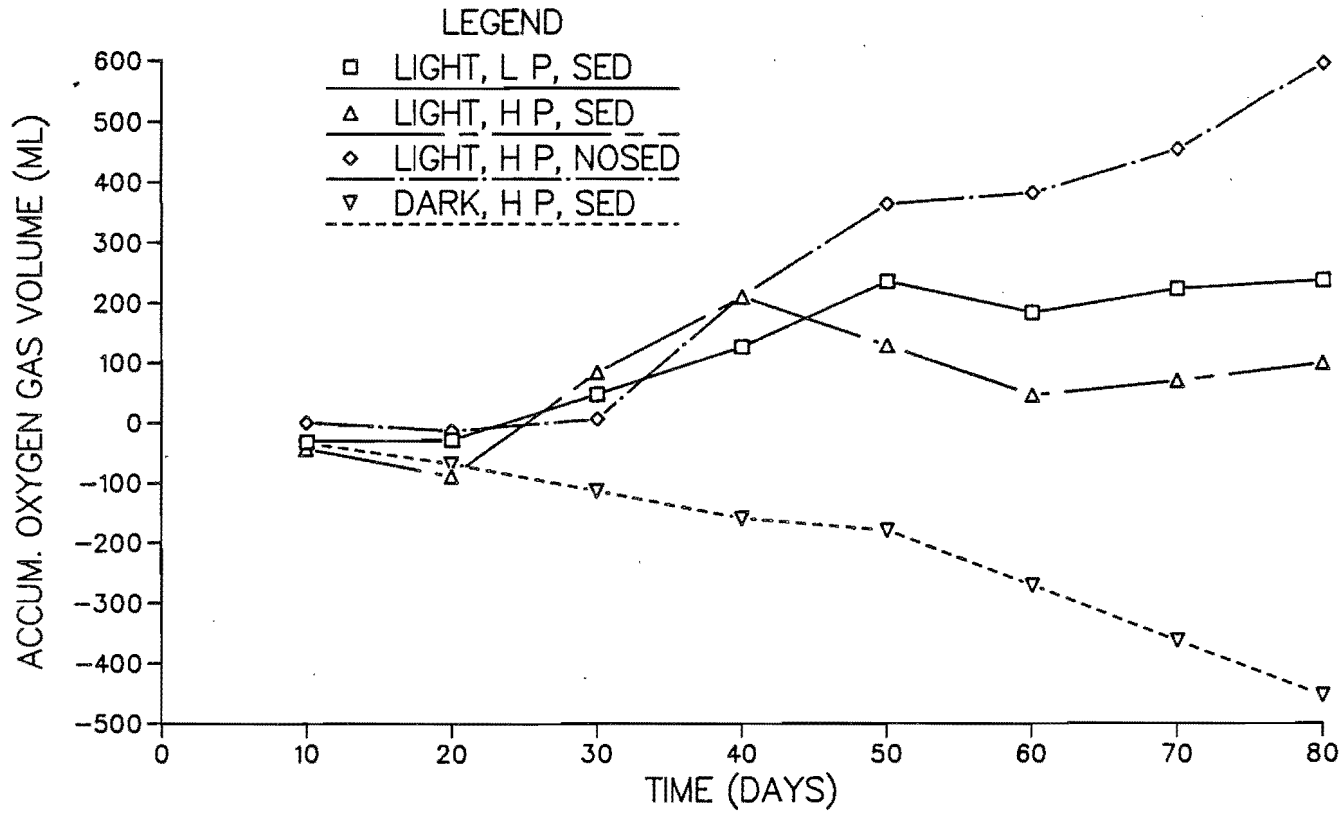

Figure 16. Mean accumulated oxygen gas volumes of each microcosm treatment versus time.

carbon dioxide volumes and associated standard deviations versus time for each treatment are presented in Appendix G. Werner (1982) documented that substantial release of carbon dioxide can occur when high alkalinity medium is of a pH lower than the microcosm aqueous phase. In this experiment, fresh medium had an overall mean pH of 7.9 while mean effluent pH values were 8.2, 8.3, 8.7, and 7.8 for LIGHT L P SED, LIGHT H P SED, LIGHT H P NOSED, and DARK H P SED treatments respectively. Differences in pH of media and LIGHT L P SED, LIGHT H P SED, and LIGHT H P NOSED treatment effluents created the potential for large carbon dioxide releases. This made the analysis of carbon dioxide fluctuations difficult.

According to Werner (1982) and Porcella et al. (1975), in ecosystems with positive net production there is an accumulation of gases. Mean accumulated change in gas volume of the LIGHT L P SED treatment was positive for each 10 day interval after day 20. Oxygen was utilized during the first 10 days due to decay of material before algae growth began. Accumulated change in gas volumes were generally positive in the LIGHT H P SED treatment for each 10 day interval. Although the mean value for gas volume accumulation in the light L P SED treatment was greater compared with the LIGHT H P SED treatment, no significant difference in gas volume accumulation could be proven to exist. However, overall mean accumulation of oxygen gas was significantly greater in the LIGHT L P SED treatment compared with the LIGHT H P SED treatment at the 98 percent confidence level. It is likely that algal production occurred at a rapid rate until approximately day 40 in the LIGHT H P SED treatment due to high phosphorus loading followed by general decay of the resultant algal biomass which created an oxygen demand and accounted for the disparity between oxygen gas accumulation in LIGHT L P SED compared with LIGHT H P SED treatments.

Accumulation of oxygen gas was greatest in the LIGHT H P NOSED treatment. The mean value for accumulation of oxygen gas in LIGHT H P NOSED microcosms was significantly greater than in LIGHT H P SED microcosms at the 99 percent confidence level. However, no significant difference could be proven to exist between the overall mean gas accumulation in the LIGHT H P NOSED versus LIGHT H P SED treatments. LIGHT H P NOSED microcosms did not exhibit the large initial declines in oxygen gas volume as seen in diurnal microcosms with sediment. It is clear that the presence of sediment created an oxygen demand due to sediment decomposition. In DARK H P SED microcosms, a general trend of gas consumption occurred over the 80 day experimental period.

Trihalomethane precursors

Mean Term TTHM concentrations in chlorinated microcosm effluent for each treatment type versus time are presented in Figure 17. Considering data from the entire experiment, mean Term TTHM concentration in chlorinated effluent from the LIGHT L P SED treatment was significantly lower, at a confidence level of 97 percent, compared with the LIGHT H P SED treatment. Although mean Term TTHM concentrations, on individual sampling days, were always lower in the LIGHT L P SED treatment compared with the LIGHT H P SED treatment, significant differences between mean Term TTHM concentrations from individual sampling days in LIGHT L P SED versus LIGHT H P SED microcosms could not always be proven to exist. A large degree of variability in Term TTHM concentrations between microcosms within treatment types made the establishment of significant differences between means difficult for individual sampling days. However, the degree of variability compared with treatment effect was reduced substantially when Term TTHM concentrations were compared over the entire experimental period. Variability between microcosms of the same treatment with regard to Term TTHM concentration is expected due to the nature of organic formation and expected differences in

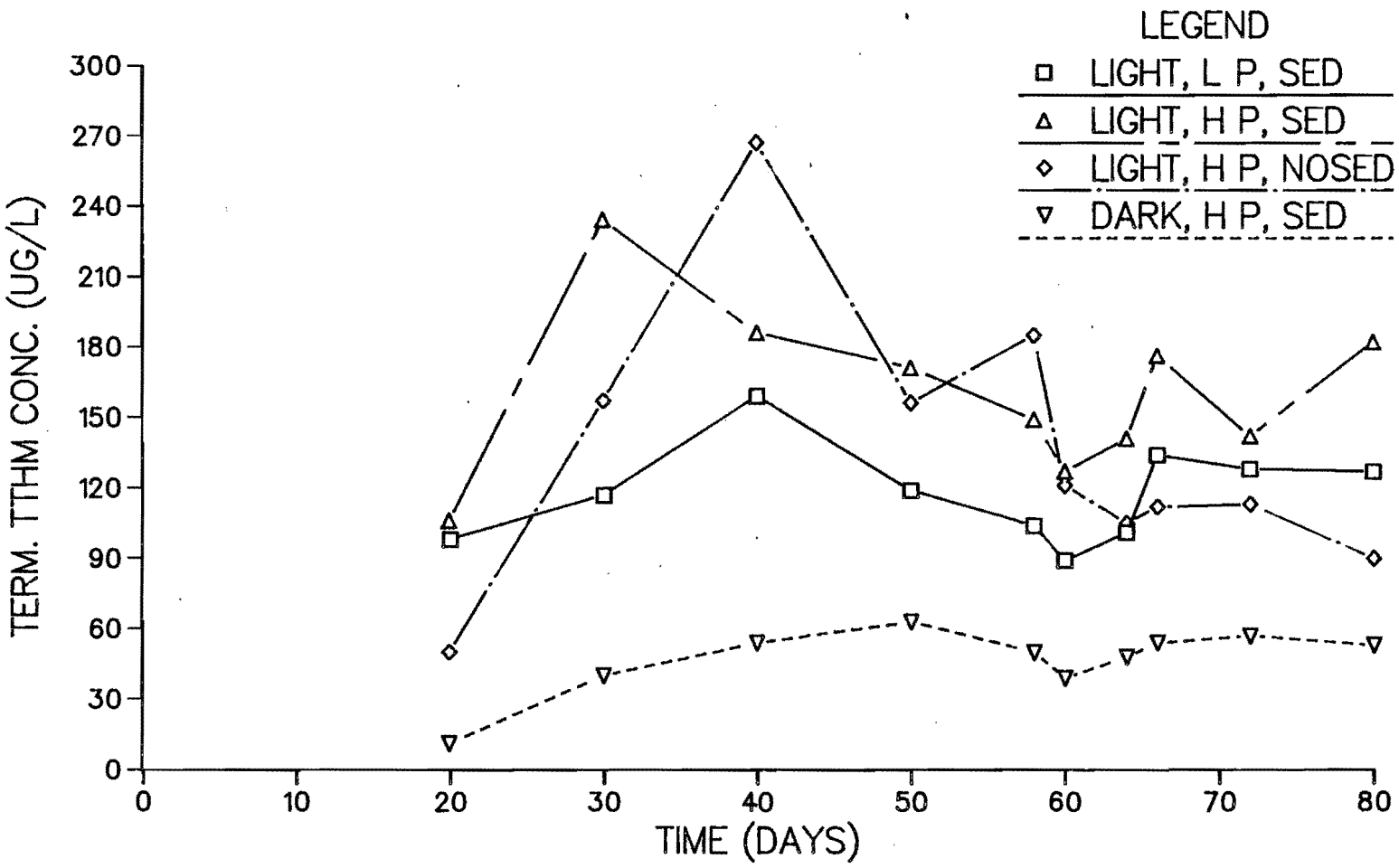

Figure 17. Mean terminal total trihalomethane concentrations of each microcosm treatment versus time.

organic composition and concentrations between replicate microcosms of each treatment. Variation in Term TTHM concentration was highest in the LIGHT H P SED treatment.

Mean Term TTHM concentration, over the entire experimental period, in samples from the LIGHT H P SED treatment was significantly greater, at the 99.9 percent confidence level, in comparison with the DARK H P SED treatment. Therefore, the difference between Term TTHM concentrations in chlorinated samples from microcosms with active algae growth and those without algae growth was profound. Since Term TTHM concentration is a measure of precursor concentration, the above result indicates algae growth products (cells and/or ECPs) were the primary precursor sources for THM production in chlorinated microcosm samples. This result is also consistent with the finding that precursor concentrations (as evaluated by Term TTHM analyses) were greater in LIGHT H P SED microcosms compared with LIGHT L P SED microcosms. Algae biomass was determined to be greater in LIGHT H P SED microcosms compared with LIGHT L P SED microcosms by examining total phosphorus concentration, suspended solids and volatile suspended solids data from days 40 through 80 of the experiment, and by qualitative (visual) observations.

Term TTHM concentration in chlorinated samples from DARK H P SED microcosms rose to a mean high value of 59 µg/l on day 50 and oscillated around 50 µg/l thereafter. The background Term TTHM concentration in the media varied from 10 to 35 µg/l. The portion of Term TTHM concentration above background levels is most probably due to precursors resulting from bacterial biomass and extracellular products in addition to released organic chemicals from the sediment phase which have the potential for reaction with chlorine to form THMs. Renk (1977) found relatively high concentrations of acetone in the interstitial water from sediments of Hyrum Reservoir in Utah. Acetone has been demonstrated to be a trihalomethane precursor by Rook (1976). The relative importance, in terms of THM production upon chlorination, of these two sources cannot be discerned. The bacterial component, in terms of biomass, in dark microcosms is not expected to be as important as in diurnal microcosms since active algae growth results in a substrate for bacterial growth.

Mean Term TTHM concentration in chlorinated samples from the LIGHT H P SED treatment was found to be higher, at the 87 percent confidence level, as compared with the mean Term TTHM concentration in the LIGHT H P NOSED treatment when data over the entire experiment was considered. The 87 percent confidence level cannot be considered significant, therefore no difference between mean Term TTHM concentrations in the LIGHT H P SED and LIGHT H P NOSED treatments over the entire experimental period can be considered to exist. Mean Term TTHM concentrations were greater (although not significantly) in the LIGHT H P SED compared with the LIGHT H P NOSED treatment group on all analysis days except for days 40 and 58 where mean concentrations were greater in LIGHT H P NOSED microcosm samples. Experiment days 40 and 58 also correspond to the only two analysis days when mean suspended solids concentrations in the LIGHT H P NOSED treatment exceeded those in the LIGHT H P SED treatment. These results indicate that the release of THM precursor compounds from the sediment is of relative unimportance to the overall production of THMs in chlorinated microcosm samples as compared with algae growth. Using split plot analysis of variance, it was determined that concentrations of Term TTHM in the four treatment types did not vary uniformly through time.

Soluble Term TTHM measurements began on experiment day 58. Mean percent soluble Term TTHM concentration to total Term TTHM concentration and corresponding standard deviation for

each treatment group on various sampling days are presented in Table 15 (data are in Appendix C). LIGHT H P NOSED microcosms consistently exhibited the smallest proportion of soluble precursor concentrations to total precursor concentrations compared with the other treatment types. Ratio of the soluble to total precursor component in LIGHT L P SED treatment was consistently greatest as compared with other treatment types.

As can be seen in Table 15, the soluble THM precursor fraction typically contributed over half of the total THM precursor concentration present for all treatment types. This result indicates a substantial portion of the precursor concentrations were soluble. If this apparent result is accurate, then it can be hypothesized that, in diurnal microcosms, algal extracellular products were the predominant precursor material as compared with non-filterable algal biomass. This conclusion would substantiate experimental results reported by Hoehn et al. (1980) but conflict with those reported by Briley et al. (1980). In dark microcosms, where algal growth was considered insignficant and therefore production of algal ECPs did not occur, the soluble fraction of Term TTHMs was probably due to background medium concentrations, bacterial ECPs, and soluble organic constitutents released from the sediment phase. Preparation of a sample for soluble Term TTHM analysis involved filtration of the sample and therefore potentially increased the probability of organically contaminating the sample.

Chloroform, over the entire experiment, composed approximately 94.5, 96.0, 98.2, and 89.3 percent of the TTHMs

Table 15. Mean percent soluble to total Term TTHM concentration for each microcosm treatment on four sampling days. Standard deviations are in parentheses.

Experiment Day	Treatment	Mean Percent Soluble to Total Term TTHM
58	LIGHT L P SED	59 (4.9)
	LIGHT H P SED	40 (6.4)
	LIGHT H P NOSED	22 (1.4)
	DARK H P SED	43 (5.2)
64	LIGHT L P SED	91 (7.1)
	LIGHT H P SED	62 (25)
	LIGHT H P NOSED	50 (14)
	DARK H P SED	82 (2.5)
66	LIGHT L P SED	91 (5.3)
	LIGHT H P SED	65 (11)
	LIGHT H P NOSED	63 (4.9)
	DARK H P SED	79 (5.8)
80	LIGHT L P SED	82 (11)
	LIGHT H P SED	62 (16)
	LIGHT H P NOSED	40 (7.2)
	DARK H P SED	65 (7.6)

(standard deviations were 1.0, 1.3, 1.8, and 3.0) for LIGHT L P SED, LIGHT H P SED, LIGHT H P NOSED, and DARK H P SED treatments respectively. The primary brominated species was bromodichloromethane. Dibromochloromethane was of secondary importance and bromoform was rarely encountered. Microcosms without sediment consistently had the smallest proportion of brominated THMs to total THMs. In addition, as the experiment progressed, concentrations of brominated THMs decreased in these microcosms (Appendix C). It is likely, therefore, that bromide was provided to the aqueous phase of the microcosms by the sediment, and initially, by the 1 ℓ of reservoir water added to each microcosm at the experiment startup. Arguello et al. (1979) reported the ratio of brominated THMs to chloroform is related to the concentration of bromide in the water. By examination of the ratio of brominated THMs to chloroform, the percentage of brominated THMs contributing to the TTHM concentration increases as chloroform concentration decreases. Similar results were obtained by Luong et al. (1982).

Soluble Term TTHM concentrations (beginning on experiment day 58) were composed primarily of chloroform. Mean chloroform concentrations to TTHM concentrations in soluble samples were 94.1, 94.6, 98.5, and 88.1 percent (standard deviations were 1.1, 1.4, 0.8, and 2.5) for LIGHT L P SED, LIGHT H P SED, LIGHT H P NOSED, and DARK H P SED treatments respectively. Overall proportions of chloroform to TTHMs decreased slightly for all treatment types except for the LIGHT H P NOSED treatment in chlorinated soluble Term TTHM samples compared with total Term TTHM samples. These results and examination of data in Appendix C indicate bromide present in samples was largely soluble since brominated THM concentrations were not reduced much, if at all, and in some cases actually increased in soluble THM samples as compared with total THM samples.

Figure 15 illustrates that the most rapid period of oxygen gas accumulation occurred between days 30 and 50, 20 and 40, and 30 and 50 for LIGHT L P SED, LIGHT H P SED, and LIGHT H P NOSED treatments respectively. Concurrent examination of Figures 15 and 16 illustrates that the greatest concentrations of Term TTHMs were measured in the middle of this rapid oxygen gas accumulation period and, therefore, the rapid algal growth period. In addition, accumulated oxygen gas volumes in the period from day 50 to 60 decreased or increased only slightly in diurnal microcosms due, most likely, to declines in the viable algal population. This period corresponded to a dip in Term TTHM concentrations in chlorinated samples from all diurnal microcosms. These declines in Term TTHM concentration could be due to declines in readily biodegradable extracellular products exuded by viable algae. Additionally, dead algae may have settled to the lower regions of the microcosms and been excluded from effluent samples. It appears that the rate of algae growth does affect the concentrations of Term TTHMs.

Synthesis of the oxygen gas accumulation data and Term TTHM data for each treatment type indicates that THM precursor production due to algae growth was greatest when the fastest rate of active algae growth occurred. Term TTHM concentrations declined after algae populations were established indicating short term decay products were not as important a THM precursor source as viable algal biomass and ECPs.

Term TTHM concentrations in chlorinated samples from each microcosm, grouped by treatment, versus time are in Appendix H. No general trends between type of algicide treatment and Term TTHM concentration after application is evident. It appears insufficient amounts of either potassium permanganate or copper sulfate were added to microcosms to significantly affect algae growth.

Correlation testing was performed on total organic carbon and Term TTHM concentration for each microcosm over the 80 day experimental period. In addition, correlation between total organic carbon and Term TTHM concentrations was tested for all microcosms on data from individual sampling days. Finally, correlation was tested on total organic carbon and Term TTHM data from all microcosms over the entire experiment period. No significant correlation could be found to exist between total organic carbon and Term TTHM concentrations.

Sediment

Total phosphorus, total organic carbon, and total nitrogen concentrations in Deer Creek Reservoir sediment used for the microcosm study are in Table 16. Total phosphorus concentrations measured in Deer Creek Reservoir sediment are considerably higher than those reported by Messer et al. (1984). This difference may be accounted for by spatial variability of sediment phosphorus concentration in the reservoir. Total phosphorus and total organic carbon concentrations at three depths in microcosm sediments at experiment termination are in Table 17. No general trend between total phosphorus or total organic carbon concentrations and treatment or depth is apparent in these data. Total phosphorus concentrations of Deer Creek Reservoir sediment and microcosm sediments were similar. The sediment phosphorus analysis employed was not precise enough to detect changes of the magnitude which occurred during the experiment.

By comparing total organic carbon concentrations in Tables 16 and 17, it is evident that total organic carbon concentrations in sediments declined over the course of the experiment. This indicates the oxidation of organic material in the sediments occurred over the experimental period. Of the three microcosm treatments with sediment, total organic carbon concentrations were greatest in the DARK H P SED treatment which is probably due to the oxygen limiting environment which existed in this treatment over most of the experiment and would result in lower oxidation rates of the sediment organic material.

Mean total nitrogen concentration present in microcosm sediment at experiment termination for each treatment is in Table 18. Comparison of Tables 16 and 18 indicates that nitrogen content in sediment declined over the experimental period. It appears nitrogen was released to the aqueous phase of the microcosms. Total nitrogen concentrations in microcosm sediments from different treatments is similar.

Term TTHM concentrations in chlorinated interstitial water from microcosm sediments are in Table 19. Concentrations were quite low and consistent between treatments. Since total organic carbon concentrations in sediments declined over the experimental period, it is possible that THM forming potential of sediment interstitial water also declined. However, sediment presence could not be proven to affect THM precursor concentrations in the microcosm experiment, therefore it is possible that interstitial water in sediments has low THM precursor concentrations over the entire experiment.

Tributary and Reservoir Study

Flow

Flow in tributaries of Deer Creek Reservoir was approximately 22 percent above normal during the period from May 1983 to December 1983 due to above normal precipitation (Kooklard 1984). Stratification of Deer Creek Reservoir, during the summer of 1983, did not occur due to the high flow conditions (Messer 1984). Flow in tributaries of Deer Creek Reservoir and in the reservoir outflow for each sampling day are presented in Appendix I. Mean contributions to total flow in the Provo River, Main Creek, and Daniels Creek

Table 16. Concentration of total nitrogen, total organic carbon and total phosphorus in Deer Creek Reservoir sediment used for microcosm experiment.

	Deer Creek Reservoir Sediment*
TN (g N/100 g SED)	0.47
TOC (g C/100 g SED)	7.1
TP (µg P/g SED)	2460

*Mean of two samples.

Table 17. Mean total phosphorus and total organic carbon concentration in microcosm sediment. Standard deviations are in parentheses.

Treatment	Sediment Depth (cm)	Total Phosphorus Concentration* (µg P/g SED)	Total Organic Carbon Concentration** (g C/100 g SED)
LIGHT L P SED	0-2	2410 (116)	5.28 (0.59)
	2-6	2400 (140)	5.51 (1.0)
	>6	2600 (229)	5.13 (0.39)
LIGHT H P SED	0-2	2330 (204)	5.71 (0.77)
	2-6	2470 (136)	5.70 (0.46)
	>6	2500 (195)	6.39 (0.78)
DARK H P SED	0-2	2300 (103)	6.65 (0.67)
	2-6	2520 (128)	6.61 (0.87)
	>6	2320 (91)	6.59 (0.94)

*Mean of 6 measurements.
**Mean of 9 measurements.

Table 18. Mean total nitrogen concentration in microcosm sediment. Standard deviations are in parentheses.

Treatment	Total Nitrogen Concentration* (g N/100 g SED)
LIGHT L P SED	0.44 (0.004)
LIGHT H P SED	0.44 (0.01)
DARK H P SED	0.42 (0.005)

*Mean of 6 measurements.

Table 19. Mean terminal total trihalomethane concentration in chlorinated interstitial water samples from microcosm sediments. Standard deviations are in parentheses.

Treatment	Number of Samples	Mean Term TTHM Concentration (µg/l)
LIGHT L P SED	2	26 (1)
LIGHT H P SED	3	32 (18)
DARK H P SED	2	34 (11)

over the sampling period were approximately 86, 9, and 4 percent respectively. The above normal contribution of Main Creek and Daniels Creek to total flow was undoubtedly due to above normal precipitation.

Chemistry

Total phosphorus concentrations in tributaries to Deer Creek Reservoir and the outflow versus time are presented in Figure 18 (data are in Appendix I). The Lower Charleston Canal was sampled only periodically to assess the impact of this flow's water quality on Daniels Creek. Agricultural activity is the primary land use, as previously described, on all tributaries. Mean total phosphorus concentrations were 59, 116, 205, and 139 µg/l with standard deviations of 24, 94, 50, and 27 for the Provo River, Main Creek, Daniels Creek, and the Lower Charleston Canal, respectively, between May and December 1983. Extreme variability existed in tributary total phosphorus concentrations from different sampling days. Total phosphorus concentrations entering the reservoir were highest during the spring snowmelt and runoff period due to nutrient flushing. Total phosphorus analysis conducted on filtered and unfiltered samples in May indicated approximately 90 percent of total phosphorus entering the reservoir was in particulate form during the spring runoff event.

Although there was a wide differential between mean total phosphorus concentrations in the different tributaries sampled, no significant difference could be proven to exist between the mean concentrations in the tributaries. A longer sampling period would probably reveal significantly higher total phosphorus concentrations in the heavily agriculturalized smaller tributaries such as Main Creek and Daniels Creek compared with the Provo River. As can be seen in Figure 18, total phosphorus concentrations exiting the reservoir were generally lower than tributary concentrations. This is expected as lake systems generally act as phosphorus traps (Nurnberg 1984).

Orthophosphorus concentrations in tributaries of and outflow from Deer Creek Reservoir over time are presented in Figure 19 (data are in Appendix I). By comparison of Figures 18 and 19, it can be seen that total phosphorus entering the reservoir was largely available. Orthophosphorus analysis conducted in May on filtered and unfiltered samples indicated approximately 67 percent of the orthophosphorus entering the reservoir during the spring runoff period was in particulate form.

Mean total phosphorus concentrations in reservoir samples from different sites at three depths over time are presented in Table 20. Data, including sites samples, are in Appendix

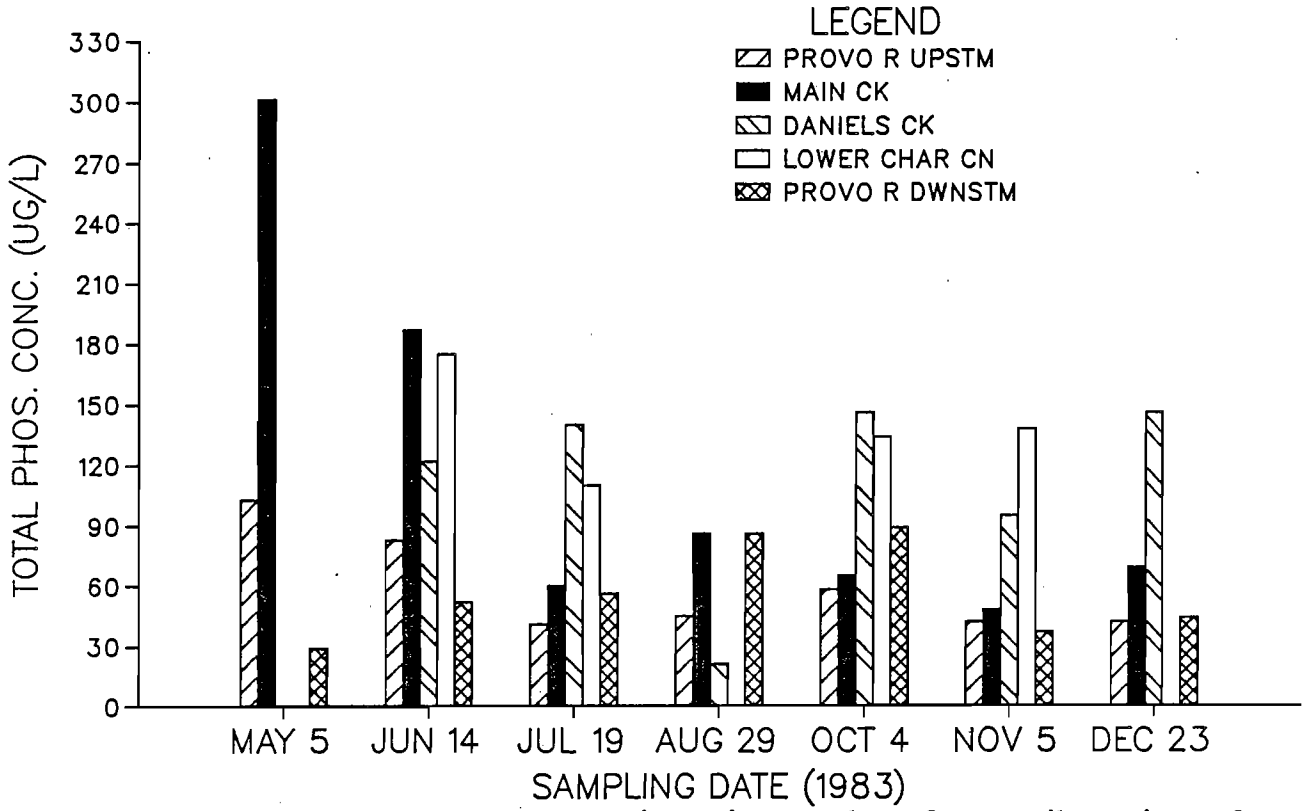

Figure 18. Total phosphorus concentrations in samples from tributaries of Deer Creek Reservoir over time (not illustrated here is the total phosphorus concentration of 762 µg/l measured in the Daniels Creek sample collected May 5).

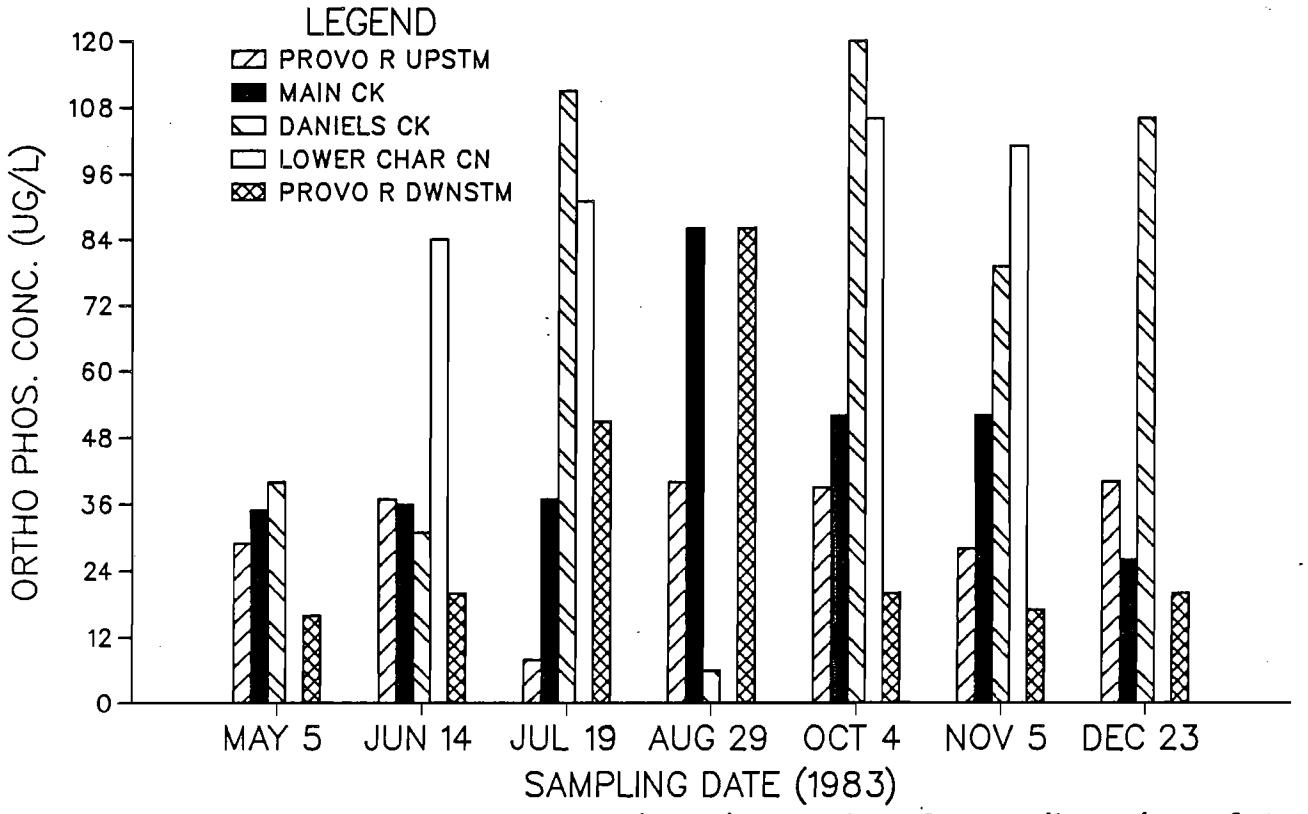

Figure 19. Ortho phosphorus concentrations in samples from tributaries of Deer Creek Reservoir over time.

Table 20. Mean total phosphorus concentration in Deer Creek Reservoir samples.*

Sampling Date	Total Phosphorus Concentration (µg/l)		
	Surface	Middle	Deep
6/14/83	60	58	107
7/21/83	25	27	42
8/29/83	5	11	17
10/4/83	14		
11/5/83	24		
12/23/83	21		

*Means are based on 2-5 observations.

I. Mean total phosphorus concentration in reservoir samples from all depth samples was determined to be significantly lower, at the 99.9 percent confidence level, compared with the mean tributary concentration. Again, this indicates assimilation of phosphorus in the reservoir sediments. Mean orthophosphorus concentrations in reservoir samples at various depths over time are presented in Table 21 (data are in Appendix I).

Total organic carbon concentrations in tributaries of and outflow from Deer Creek Reservoir versus time are presented in Table 22 (data are in Appendix I). Mean total organic carbon concentrations over the sampling period in the Provo River above the reservoir, Main Creek, and Daniels Creek were 4.2, 4.5, and 9.2 mg/l with standard deviations of 2.1, 1.1, and 10.3 respectively. In general, total organic carbon concentrations were high which is most likely the result of argicultural activity on land surrounding tributaries. Total organic carbon concentration in the Daniels Creek sample from May was extremely high (30 mg/l). This elevated concentration occurred just after spring runoff had begun and is probably the result of organic material from agricultural activity entering the channel with the high runoff.

Mean total organic carbon concentrations in reservoir samples at various depths over time are presented in Table 23. Data, including sites sampled, are in Appendix I. Overall, mean total organic carbon concentrations in surface, middle, and deep reservoir samples were 5.1, 5.2, and 5.5 mg/l with standard deviations of 1.4, 1.0, and 1.0 respectively. These mean values indicate total organic carbon concentrations were relatively constant with depth in the water column of Deer Creek Reservoir. By comparing Tables 22 and 23, similarity in total organic carbon concentrations between tributaries and reservoir samples is evident.

Nitrate, nitrite, and ammonia concentrations in tributaries of and outflow from Deer Creek Reservoir over the sampling period are presented in Appendix I. Extremely high nitrate and nitrite concentrations were present in samples from the Lower Charleston Canal. Mean nitrate, nitrite, and ammonia concentrations in Deer Creek Reservoir at three sampling depths over time are also presented in Appendix I. Additional parameters analyzed on tributaries, reservoir, and outflow samples over time included calcium, magnesium, total nitrogen, total kjeldahl nitrogen, alkalinity, pH, total suspended solids, volatile suspended

Table 21. Mean ortho phosphorus concentration in Deer Creek Reservoir samples.*

Sampling Date	Total Phosphorus Concentration (µg/l)		
	Surface	Middle	Deep
6/14/83	16	22	22
7/21/83	4	13	23
8/29/83	<2	4	<2
10/4/83	12		
11/5/83	16		
12/23/83	14		

*Means are based on 2-5 observations.

Table 22. Total organic carbon concentration in samples from tributaries of and outflow from Deer Creek Reservoir.

Sampling Date	Total Organic Carbon Concentration (mg/l)				
	Provo River Upstream	Main Creek	Daniels Creek	Lower Charleston Canal	Provo River Downstream
5/5/83	5.2	5.2	30		3.0
6/14/83	5.2	5.9	7.6	5.0	5.3
7/19/83	7.6	4.7	5.1	5.7	4.7
8/29/83	2.6	4.8		3.6	4.4
10/4/83	2.9	3.2	5.0	5.8	4.1
12/23/83	1.9	3.0	3.8		1.0

Table 23. Mean total organic carbon concentrations in Deer Creek Reservoir samples.*

Sampling Date	Total Organic Carbon Concentration (mg/l)		
	Surface	Middle	Deep
6/14/83	5.2	5.0	6.4
7/21/83	6.9	5.4	6.1
8/29/83	4.4	4.6	4.4
10/4/83	4.0		
12/23/83	3.2		

*Means are based on 2-5 observations.

solids, sulfate, and chloride. These data are in Appendix I.

Biological identification

Algal identifications were made on reservoir samples collected August 21, 1983 (data are in Appendix I). In surface samples, bluegreen algae were dominant, particularly Oscillatoria sp. and Chroococcus sp. In addition, surface samples contained the golden alga Cyclotella sp. and diatoms. One surface sample contained an abundance of the green alga Chlorella sp. in addition to bluegreen species. Samples taken from the middle portions of the Deer Creek Reservoir water column consisted primarily of the green alga Chlorella sp. Oscillatoria sp. was identified in two of the four middle samples in quantities 1 percent as large as Chlorella sp. Diatoms were noted in all samples collected from the middle of the water column.

Trihalomethane precursors

Term TTHM concentrations in tributaries of and outflow from Deer Creek Reservoir over time are presented in Figure 20 (data are in Appendix I). Although, as can be seen in Figure 20, concentrations of Term TTHMs in chlorinated samples from the Provo River above the reservoir were generally lower than those measured in Main Creek and Daniels Creek samples, the Provo River is considered the most important tributary supplier of THM precursors to Deer Creek Reservoir since it contributes an average of 94 percent of the total flow to the reservoir. Mean Term TTHM concentrations in the Provo River, Main Creek, and Daniels Creek during the study period could not be proven to differ significantly. A longer sampling period may allow the differentiation of Term TTHM concentrations in the tributaries to be proven.

Weighted mean concentrations of THM precursors as evaluated by Term TTHM concentrations which entered the reservoir over time are listed in Table 24. These values were derived using the contribution to total flow and Term TTHM concentration of each tributary. This estimation of THM precursors entering Deer Creek Reservoir indicates the largest tributary contribution to precursor loading occurred during late spring (June) and declined as summer progressed to a low in November. Mean concentrations of Term TTHM in tributaries of Deer Creek Reservoir were found to vary significantly, above the 95 percent confidence level, by sampling period and by season. Seasonal variations in THM precursor concentrations seen in this study are similar to those reported by Veenstra and Schnoor (1980). High concentrations of Term TTHMs measured in late spring probably resulted from entry of organic material from surrounding areas into streams through the process of snowmelt and transport down the river by subsequent high flows. Precursors present in tributaries are believed to be largely composed of humic and fulvic acids based on results of other stream studies (Rook 1977; Christman et al. 1983; Stevens et al. 1976; Babcock and Singer 1979).

Mean Term TTHM concentrations in chlorinated reservoir samples versus time are presented in Table 25. Data, including sites sampled, are in Appendix I. Mean concentrations of Term TTHMs in samples from the three sampling depths could not be proven to differ statistically. However, on two of the three sampling days when deep samples were collected, mean Term TTHM concentrations in the deep chlorinated samples were somewhat higher compared to surface and middle samples.

Reservoir chlorophyll-a data, collected by the Bureau of Reclamation, were available for the period between April and September 1982 for three sampling depths within the reservoir at a site near the dam. These data are presented in Table 26. Although no chlorophyll-a data from the

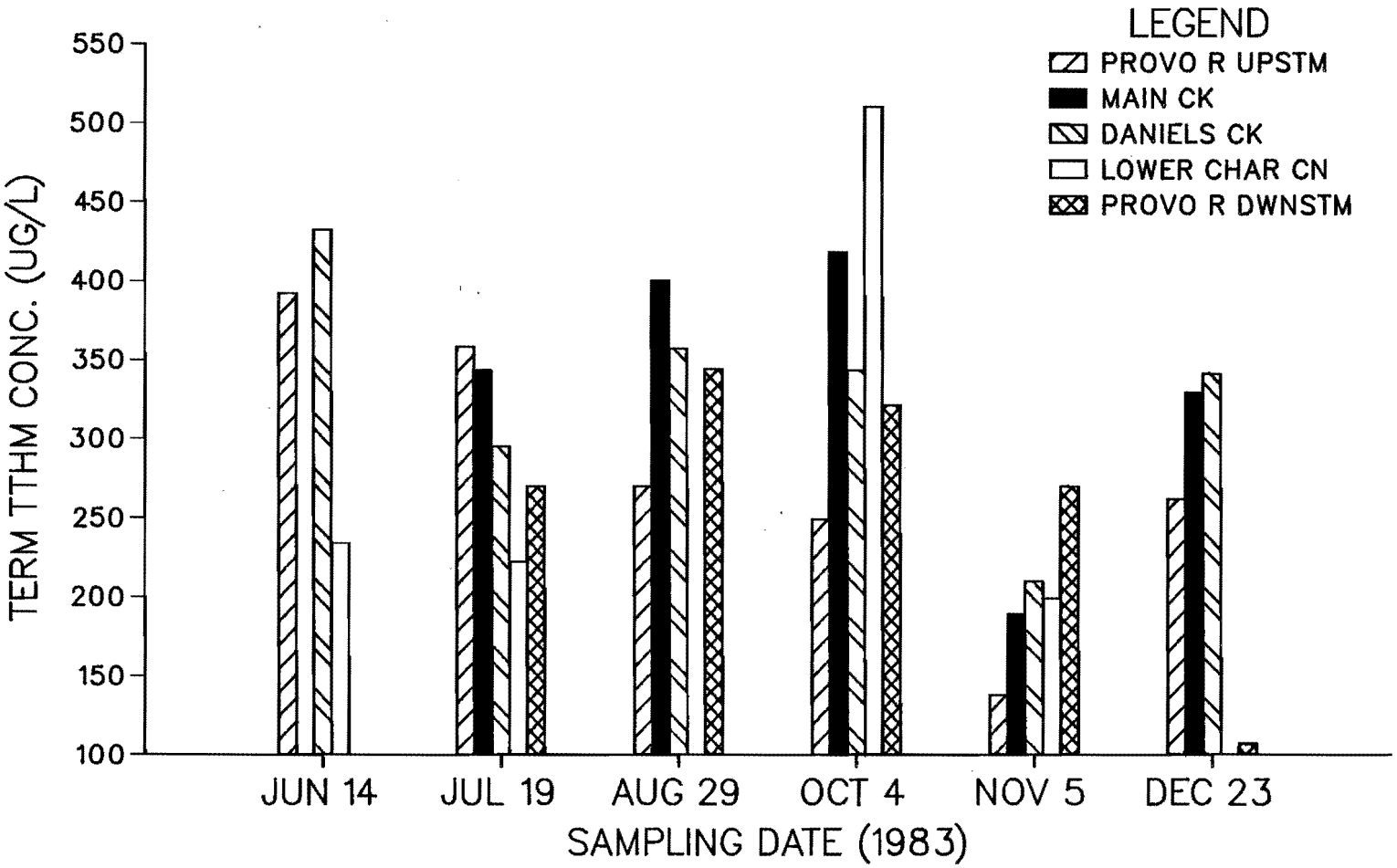

Figure 20. Terminal total trihalomethane concentrations in chlorinated samples from tributaries of Deer Creek Reservoir over time (Main Creek sample collected June 14 was mishandled).

Table 24. Trihalomethane precursor concentration entering Deer Creek Reservoir on different sampling days as evaluated by tributary terminal total trihalomethane concentration and flow.

Sampling Date	THM Precursors Entering Deer Creek Reservoir (µg/l as THMs)
6/14/83	386
7/19/83	354
8/30/83	279
10/4/83	267
11/5/83	146
12/23/83	268

Table 25. Mean terminal total trihalomethane concentration in chlorinated Deer Creek Reservoir samples.*

Sampling Date	Mean Terminal TTHM Concentration (µg/l)		
	Surface	Middle	Deep
6/14/83	328	263	232
7/21/83	339	319	446
7/29/83	396		
8/29/83	288	321	329
10/4/83	349		
11/5/83	250		

*Means are based on 2-5 observations.

Table 26. Chlorophyll-a concentration in samples from three depths in Deer Creek Reservoir between April and September 1983 (Truman 1984).

Month	Chlorophyll-a Concentration (mg/l)		
	Surface	Middle	Deep
Apr	19.4	15.4	15.8
May	3.6	2.8	2.2
Jun	5.5	5.7	5.6
Jul	4.1	4.8	3.9
Aug	6.4	10.0	8.5
Sep	5.8	7.5	7.9

reservoir are available for 1983, data from 1982 are used for comparative purposes between chlorophyll-a concentrations at different depths in the water column since the hydrologic characteristics of 1982 and 1983 were similar. As can be seen in Table 26, the concentration of chlorophyll-a and hence algae in the deep section of the reservoir is comparable to middle and surface sections of the water column. This result is due to mixing of the reservoir which occurs when stratification does not exist. Since stratification of the reservoir did not occur during 1983, concentrations of algae, ECPs, and humic and fulvic acids were probably similar at all depths sampled. High Term TTHM concentrations in deep samples may also be due, in part, to release of organic decay products such as acetone which produce THMs upon chlorination (Adams et al. 1975; Rook 1976).

Soluble Term TTHM concentrations in chlorinated tributary, reservoir, and outflow samples are in Appendix I. Percent soluble to total Term TTHM concentrations in chlorinated samples from tributaries to and outflow from Deer Creek Reservoir on August 29, October 4, and November 5, 1983, are presented in Table 27. Soluble Term TTHM measurements on other sampling days were either not made or sample contamination resulted in the elimination of data. By examination of Table 27, variability in the soluble precursor component over time is evident but it is clear that most precursor material is soluble. Mean percent soluble to total Term TTHM concentrations for surface samples from July 29, October 4, and November 5, 1983, and all three depths from August 29, 1983, are in Table 28. In the reservoir as in tributaries, precusors were predominantly of a soluble nature.

Total Term TTHM concentrations in the reservoir and proportion of total to soluble THM precursors were quite variable but this is not surprising given the dynamics of the reservoir system. Attempts were made to collect reservoir and tributary samples at approximately the same time of day. However, Hoehn et al. (1984) reported THM forming potential, in a diurnal study conducted on a reservoir in August, was maximum at 8 a.m. and declined approximately 75 µg/l between 8 and 12 a.m. and 300 µg/l between 12 and 4 p.m. In a second diurnal study, the maximum THM forming potential occurred at 9 a.m. followed by a 150 µg/l decline during the daylight period. Nighttime levels decreased to 350 µg/l below the maximum daytime concentration. In both these studies, conducted on the identical water source, the maximum THM forming potential was approximately 700 µg/l.

Hoehn et al. (1984) reported maximum ECP liberation occurred in the early morning coincident with the time maximum THM forming potential was noted. In the Deer Creek Reservoir study, sampling was usually conducted between 12 and 2 p.m. Therefore, if Deer Creek Reservoir behaved similarly to the reservoir studied by Hoehn et al. (1984), it is possible that Term TTHM levels were higher before the sampling time and lower after sampling occurred. It is also possible that small differences in the time samples were taken on different sampling days may have accounted for some variation among Term TTHM concentrations from different sampling days. However, variations in algae growth over time, precursor loading changes, and spatial variability were probably more important as opposed to time of day sampling occurred to overall variation in Term TTHM concentrations measured on different sampling days in the reservoir.

The contribution of each THM species to total Term TTHM concentrations in tributary and reservoir samples are presented in Appendix I. Concentrations of brominated species in chlorinated tributary and reservoir samples were relatively constant over the sampling period except on the June 14,

Table 27. Percent soluble to total terminal total trihalomethane concentration in samples from tributaries to and outflow from Deer Creek Reservoir on three sampling days.

Sampling Date	Percent Soluble to Total Terminal TTHM Concentration				
	Provo River Upstream	Main Creek	Daniels Creek	Lower Charleston Canal	Provo River Downstream
8/29/83	76	82	75		100
10/4/83	85	64	90	34	78
11/5/83	63	76	92	79	82

Table 28. Mean percent soluble to total terminal total trihalomethane concentration in Deer Creek Reservoir samples from four sampling dates.*

Sampling Date	Mean Percent Soluble to Total Terminal TTHM Concentration		
	Surface	Middle	Deep
7/29/83	90		
8/29/83	78	99	94
10/4/83	93		
11/5/83	97		

*Means are based on 2-5 observations.

1983, sampling day when brominated THM concentrations were particularly low in tributary samples. It is evident that the source of bromide to streams, which has been shown to control the proportion of brominated THMs, was constant over time and therefore dilution of this constant bromide input during the high runoff period resulted in low concentrations of brominated THM species in June. For the period sampled, chloroform composed 89, 89, and 93 percent of the TTHMs with standard deviations of 6.2, 5.7, and 2.7 in samples from the Provo River, Main Creek, and Daniels Creek respectively.

Concentrations of Term TTHM in chlorinated tributary and reservoir samples could not be statistically differentiated when all tributary and reservoir data were considered. This result indicates similarity between precursor concentrations in Deer Creek Reservoir and tributaries. Tributaries, therefore, appear to be very important in providing THM precursors to the reservoir system.

No correlation was found to exist between Term TTHM and total organic carbon concentrations in tributary or reservoir samples. This was evaluated by considering data from individual sampling days in addition to the entire sampling period. Furthermore, no correlation was found between soluble total organic carbon and soluble Term

TTHM concentrations. Apparently, total organic carbon concentration cannot be used as an indicator of THM precursor concentration in tributaries of Deer Creek Reservoir or the reservoir itself.

Sediment

Term TTHM concentrations in interstitial water of Deer Creek Reservoir sediment collected August 29, 1983, were 138 and 311 µg/l for sampling points 1 and 2 respectively (Figure 6). The relatively high concentrations of Term TTHMs measured in these chlorinated sediment interstitial water samples were probably the result of sediment organic decay products released to the aqueous phase as previously described. The large discrepancy between the two values could be due to spatial variability of sediment characteristics within the reservoir and/or differences in the separation of solid and liquid phases after centrifugation.

Comparison of Microcosm Study and Tributary and Reservoir Study

Trihalomethane precursor sources

Similarity between Term TTHM concentrations in chlorinated reservoir and tributary samples initially indicates that tributaries are the primary sources of THM precursors to Deer Creek Reservoir. This would presuppose algae and their ECPs contribute insignificantly to the reservoir's THM precursor pool. However, in light of the microcosm experiment, it is clear that algae growth does result in substantial production of THM precursors. Therefore, it is possible that a portion of the incoming THM precursors from tributary sources becomes inactive to reaction with chlorine to form THMs in the reservoir and outflow either by removal from the system (settling and incorporation into sediments) or chemical alteration. Alternatively, a portion of precursors due to algae growth in the reservoir may become inactive by similar mechanisms. In the microcosms, Term TTHM concentrations were, generally, not as high as those measured in chlorinated tributary and reservoir samples. Therefore, it appears both tributaries (most likely humic and fulvic acids) and in-reservoir generation (algal biomass and ECPs) contribute significantly to THM precursors in Deer Creek Reservoir.

Interstitial water

From the microcosm study, it appears sediment is not an important contributor of THM precursors to the reservoir water column. However, it is possible the sediment collected for the microcosm study was not representative of sediment throughout the reservoir. Term TTHM concentrations were much lower in chlorinated interstitial water from microcosm sediments as compared to reservoir sediment collected August 29, 1983. Microcosm sediment was collected in late spring and placed in a microcosm environment for 80 days before interstitial water was extracted. Differences in time of sediment collection, place of sediment collection, and the time lapse between sediment collection and interstitial water extraction may have all contributed to the differential in Term TTHM concentrations measured in reservoir and microcosm interstitial water samples. However, since Term TTHM concentration in chlorinated interstitial water of microcosm sediment was not analyzed previous to experiment startup, any explanation is speculative.

Phosphorus

By examination of the tributary sampling data, it is clear that tributaries are transporting significant quantities of phosphorus to the reservoir. Results of the microcosm study indicated the reduction of total phosphorus loading to the reservoir system would reduce algae growth and thereby reduce THM precursor concentrations. However, the comparison used to develop this conclusion was between LIGHT L P

SED and LIGHT H P SED microcosms, neither of which developed anoxic conditions. In Deer Creek Reservoir, anoxic conditions usually develop when stratification occurs. This condition may result in anoxic phosphorus release as seen in the dark anoxic microcosms. Under circumstances of anoxic phosphorus release, the influence of reduced phosphorus loading to the reservoir may not result in reduced algal growth and therefore reduced THM precursors.

Algicide treatment

The affect of algicide application in the reservoir on THM precursor concentrations could not be completely evaluated since inadequate applications of both copper sulfate and potassium permanganate were made to microcosms. Application of 50 µg/l copper sulfate as Cu^{+2} and 0.2 mg/l potassium permanganate did not differentially affect Term TTHM concentrations or oxygen accumulation as compared to the control microcosm in each treatment group which was not treated with algicide. Variability naturally existent between microcosm groups made the comparative study of differential algicide application difficult.

CONCLUSIONS

Microcosm Study

A microcosm experiment was conducted in which the affect of the following parameters on THM precursor concentration was studied: phosphorus loading, algae growth, sediment presence, and algicide application. THM precursor concentrations were evaluated by Term TTHM analysis. The following conclusions are based on this study:

1. When data over the entire experiment were considered, no significant difference in mean THM precursor concentration or mean total phosphorus concentration was found to exist between LIGHT H P SED and LIGHT H P NOSED treatments. Therefore, the presence of sediment did not significantly affect THM precursor concentrations or total phosphorus concentrations.

2. Mean THM precursor concentration was significantly higher (at the 99 percent confidence level) in effluent from the LIGHT H P SED versus DARK H P SED treatments. Therefore, algae growth produced THM precursors to a significant degree.

3. Mean THM precursor concentration was significantly greater (at the 97 percent confidence level) in effluent from the LIGHT H P SED versus LIGHT L P SED treatments. This was most likely due to increased algae growth in the LIGHT H P SED versus LIGHT L P SED microcosms.

4. The highest THM precursor concentrations of each diurnal treatment were encountered during the period of greatest oxygen gas accumulation. Short term algal decay products did not appear to have the THM forming potential of active algal growth products.

5. The rate of algae growth appeared to affect THM precursor concentrations.

6. No correlation between total organic carbon concentration and Term TTHM concentration was found to exist.

7. Application of 0.3 mg/l potassium permanganate or 50 µg/l copper sulfate as Cu^{+2} did not appear to affect THM precursor, total phosphorus, total suspended solids, or volatile suspended solids concentrations.

8. Term TTHM concentration in chlorinated interstitial water from microcosm sediments at experiment termination was low (mean of 27 µg/l for all treatments).

9. Chloroform composed over 90 percent of the TTHMs measured in chlorinated samples from all microcosm treatments. However, the proportion of brominated THM species in samples from microcosms without sediment was lower compared to those with sediment.

10. THM precursors were predominantly soluble as measured by a 0.45 micron filter.

Tributary and Reservoir Study

Monitoring of Deer Creek Reservoir, its tributaries, and outflow was performed between May and December 1983. The following conclusions are based on the results of this study:

1. Phosphorus loading from tributaries was substantial. Mean total

phosphorus concentrations were 49, 116, 205, and 139 µg/l for the Provo River, Main Creek, Daniels Creek and the Lower Charleston Canal. Total phosphorus concentrations were extremely variable in tributaries over time.

2. Concentrations of THM precursors in tributaries were greatest in June and lowest in November. THM precursor concentrations in tributaries were found to vary significantly by season.

3. THM precursors in tributary and reservoir samples were predominantly soluble as measured by 0.45 micron filters.

4. Mean Term TTHM concentrations in chlorinated tributary and reservoir samples could not be statistically differentiated.

5. Chloroform was the dominant THM species encountered in chlorinated tributary and reservoir samples indicating bromide concentration in the tributaries and reservoir does not significantly elevate THM yield.

6. Term TTHM concentrations of chlorinated Deer Creek Reservoir sediment interstitial water samples were 138 and 311 µg/l for 2 sampling points in the reservoir.

7. No correlation between Term TTHM and total organic carbon concentrations was found to exist in either tributary or reservoir samples.

RECOMMENDATIONS

1. Based on microcosm study results, decreased phosphorus loading to the reservoir system was shown to decrease THM precursor concentration. However, phosphorus release from sediment can occur when stratification creates an anoxic environment in the lower region of the reservoir. Research is currently being conducted by J. Messer at Utah State University in which the extent of phosphorus release from Deer Creek Reservoir sediment under anoxic conditions is being studied. Results of this research should indicate whether reduced phosphorus loading from tributaries would lower phosphorus levels in the reservoir. If it is determined that reduction in phosphorus loading from tributaries would reduce phosphorus concentrations in the reservoir, land management practices to decrease phosphorus pollution of tributaries should be implemented. This would probably necessitate control of agricultural phosphorus inputs. If anoxic phosphorus release from sediments is shown to override any tributary phosphorus loading reductions, destratification or hypolimnetic aeration in combination with tributary phosphorus loading reduction would be a possible solution for reduction of phosphorus concentrations in the reservoir.

2. Since individual microcosms of the same treatment exhibited substantial variability with regard to certain parameters, the study of algicide or oxidant application on THM precursor concentration would be facilitated by the application of chemicals to subsamples of one microcosm's effluent. This would enable direct comparison of results. Another approach would be application of chemicals to subsamples of a reservoir sample taken from an algal bloom area. In either case, concentrations of copper sulfate and potassium permanganate should be increased above those used in this study.

3. Currently, chlorination of Deer Creek Reservoir water occurs as water enters the 32 mi aqueduct leading to the Little Cottonwood Metropolitan water treatment plant. Use of an alternative oxidant (i.e., potassium permanganate) at this point would prohibit the formation of THMs before the water is treated. Chlorination should be delayed until the coagulation/flocculation process is completed. In previous studies, the coagulation/flocculation process has been shown to greatly reduce the THM forming potential of a water through precursor removal (Kavanaugh 1978; Davis and Gloor 1981; Blanck 1979; Stevens et al. 1976; Briley et al. 1980).

4. Tributaries were shown to be significant contributors of THM precursors to Deer Creek Reservoir. It is unlikely that the high Term TTHM concentrations measured in chlorinated tributary samples are due primarily to background levels of THM precursors. Therefore, it is most probable that THM precursor loading to the reservoir could be reduced by implementation of land management practices. The primary management strategy should be exclusion of animal and plant wastes, derived from agricultural activity, from the channels.

5. Term TTHM concentrations in tributary and reservoir samples were statistically undifferentiable. However, since the microcosm study indicated algae growth resulted in a substantial concentration of THM precursors, the primary contributor (if a

primary contributor exists) of THM precursors to the reservoir is not readily apparent. Fractionation of THM precursors in the reservoir may allow the identification of dominant precursor types and, consequently, sources.

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Appendix A

Techniques Used in Sediment Analyses

Table 29. Techniques used in sediment chemical analyses.

Parameter	Technique	References
Total Phosphorus	Acid-Persulfate Digestion	APHA (1980)
Total Organic Carbon	Wet Combustion-Infrared	Menzel and Vaccaro (1964)
Total Nitrogen	Micro-dumas	Coleman Total Nitrogen Analyzer Manual

Appendix B

Visual Observations of Microcosms

7/10/83 (DAY 21)

LIGHT L P SED (#1) - Slightly turbid (green).

LIGHT L P SED (#2) - More turbid (green) than #1 with strands of algae near surface.

LIGHT L P SED (#3) - Most turbid (green) of LIGHT L P SED treatment. Many strands of algae were seen all the way through the water column.

LIGHT H P SED (#1) - More turbid (green) than LIGHT L P SED treatment; green algae growth on sides.

LIGHT H P SED (#2) - Turbid (green) but no large green algae growth on sides.

LIGHT H P SED (#3) - Most turbid (green) of the LIGHT H P SED microcosms; no obvious algae growth on sides.

LIGHT H P NOSED (#1, 2, 3) - Clear.

DARK H P SED (#1, 2, 3) - Clear.

7/14/83 (DAY 25)

LIGHT L P SED (#1) - Similar amount of filamentous growth as on day 21 but extending further downward through water column; brown growth on sides.

LIGHT L P SED (#2) - Filamentous growth expanding; brown growth on sides.

LIGHT L P SED (#3) - Filamentous growth expanding; less brownish growth on sides than LIGHT L P SED (#1 and #2).

LIGHT H P SED (#1) - More turbid (greenish-brown) than LIGHT L P SED microcosms; green algae colonies on sides; least turbid of LIGHT H P SED microcosms.

LIGHT H P SED (#2) - Little suspended growth; green colonies on glass.

LIGHT H P SED (#3) - Most turbid (green) of LIGHT H P SED microcosms; little suspended filamentous growth.

LIGHT H P NOSED (#1) - Mostly clear; greenish growth on inlet and outlet ports; few green algae colonies on sides.

LIGHT H P NOSED (#2) - Most turbid (green) of LIGHT H P NOSED microcosms; few brownish-green algae colonies on sides.

LIGHT H P NOSED (#3) - Mostly clear; few brownish-green algae colonies on sides.

DARK H P SED (#1, 2, 3) - Clear.

7/18/83 (DAY 29)

LIGHT L P SED (#1) - Filamentous algae present; filamentous attached algae growth on sides (green); least turbid of LIGHT L P SED microcosms.

LIGHT L P SED (#2) - Filamentous algae growth expanding.

LIGHT L P SED (#3) - Filamentous algae growth expanding; new brownish algae colonies on sides.

LIGHT H P SED (#1) - Dense filamentous algae growth in clumps through water column; greener in coloration than LIGHT L P SED microcosms.

LIGHT H P SED (#2) - Less filamentous growth than LIGHT H P SED (#1); very green.

LIGHT H P SED (#3) - Most turbid (green) of LIGHT H P SED microcosms.

LIGHT H P NOSED (#1) - Turbid (green).

LIGHT H P NOSED (#2) - Turbid (green).

LIGHT H P NOSED (#3) - Mostly clear.

DARK H P SED (#1, 2, 3) - Clear.

7/28/83 (DAY 39)

LIGHT L P SED (#1) - Long filamentous green algae growth throughout length of water column concentrated on sides; some orange colonies on sides concentrated near feed port.

LIGHT L P SED (#2) - Similar filamentous green algae growth as LIGHT L P SED (#1) but not as thick; few orange colonies.

LIGHT L P SED (#3) - Less filamentous green algae growth than LIGHT L P SED (#1 or 2); greener coloration than LIGHT L P SED (#1 or 2).

LIGHT H P SED (#1) - Dispersed green algae growth; little filamentous growth.

LIGHT H P SED (#2) - Thick filamentous algae strands.

LIGHT H P SED (#3) - Very turbid (green); little or no filamentous algae growth; small algae colonies on grass.

LIGHT H P NOSED (#1, 2, 3) - Turbid (clear to green).

DARK H P SED (#1, 2, 3) - Clear.

8/11/83 (DAY 52)

LIGHT L P SED (#1) - Algae growth on sides becoming more dense; attached orange algae growth near feed port more extensive; green algae growth forming mats.

LIGHT L P SED (#2) - Less dense green algae growth than LIGHT L P SED (#1); some filamentous green algae growth; little attached orange growth on sides.

LIGHT L P SED (#3) - Least attached growth of LIGHT L P SED microcosms; turbid (green); some attached orange growth near bottom of microcosm.

LIGHT H P SED (#1) - More of an orange coloration than LIGHT L P SED microcosms; less suspended algae growth than previously existed; attached algae growth around stir bar.

LIGHT H P SED (#2) - Sparse attached filamentous algae growth; orange-green coloration; less growth than LIGHT H P SED (#1).

LIGHT H P SED (#3) - Less attached growth than other LIGHT H P SED microcosms; green-orange coloration.

LIGHT H P NOSED (#1, 2, 3) - Turbid (green).

DARK H P SED (#1) - Slightly turbid (brown).

DARK H P SED (#2, 3) - Mostly clear; brown growth on sides and stir bars.

8/31/83 (DAY 72)

LIGHT L P SED (#1) - Attached filamentous algae growth becoming denser near bottom of microcosm; coloration brown-green.

LIGHT L P SED (#2) - More algae growth than LIGHT L P SED (#1); coloration orange-brown-green.

LIGHT L P SED (#3) - Less attached growth than other LIGHT L P SED microcosms.

LIGHT H P SED (#1) - Denser (green) growth than LIGHT L P SED microcosms; mostly dispersed algae growth.

LIGHT H P SED (#2) - Dispersed green algae growth; few strands of algae growth on sides.

LIGHT H P SED (#3) - Dense dispersed growth. Coloration orange-brown.

LIGHT H P NOSED (#1) - Clear to light green; collection of algae on bottom.

LIGHT H P NOSED (#2) - Greenest of LIGHT H P NOSED microcosms; whitish growth on sides.

LIGHT H P NOSED (#3) - Dark brown-green in color; mostly clear.

DARK H P SED (#1, 2, 3) - Mostly clear; brown growth on sides and stir bars.

Appendix C

Data Collected During the Microcosm Study

Table 30. Data collected over time in the LIGHT L P SED microcosms.

Exp. Day	Treatment	pH	Alk. (mg/l as $CaCO_3$)	OP (µg/l)	TP (µg/l)	NH_3-N (µg/l)	NO_3-N (mg/l)	NO_2-N (µg/l)	TN (mg/l)	TKN (mg/l)	TOC (mg/l)	SOL TOC (mg/l)	Ca (mg/l)	Mg (mg/l)
Microcosm 1 (LIGHT L P SED)														
1		6.9	150	52	71	1160	0.10	2					53	14
10		7.8	160	76	76	1660	0.05	2			1.4		47	15
20		8.1	156	3	41	1110	0.17	2			8.9	2.9		
30		8.2	162	18	36	1080	0.12	2			1.7		55	13
40		8.1	122	<2	26	130	0.08	2			1.1		40	13
50		8.4		12	12	25	<0.04	<2	0.21	0.18		1.3		
56	$KMnO_4$		105	12	14									
58														
60		8.4		3	10	29	<0.04	<2	0.16	0.14	9.2	<2		
64		8.4												
66		8.4												
72		7.6		<2	4	<10	0.09	<2	0.19	0.10	2.4			
80		7.7		3	12	20	<0.04	<2	0.18	0.15	4.2	2.6		
Microcosm 2 (LIGHT L P SED)														
1		6.9	138	43	44	1200	<0.04	<2					53	12
10		7.9	137	60	66	1760	0.20	2			1.9		49	10
20		8.3	152	3	26	1110	0.13	<2			5.2	2.5		
30		8.3	138	13	31	840	0.08	<2			1.8		45	13
40		8.2	130	<2	31	490	0.11	2			3.5	1.7	43	13
50		8.2		15	15	150	0.04	2	0.20	0.16		1.1		
56	CTL.		132	12	14									
58														
60		8.3		3	12	18	0.04	<2	0.18	0.14	8.0	3.1		
64		8.6												
66		8.6												
72		8.6		<2	5	<10		2	0.20		4.0	2.0		
80		7.7		3	12	<10	<0.04	<2	0.35	0.32	3.8	2.9		
Microcosm 3 (LIGHT L P SED)														
1		7.0	150	42	58		0.15	3					53	13
10		8.0	156	57	63	1650	0.05	<2			2.4		48	14
20		8.0	157	9	16	910		<2			9.7	2.1	14	10
30		8.1	125	18	18	740	0.10	2			2.0		49	13
40		8.2	109	2	43	132	0.10	3			2.1	1.0	35	
50		8.0		18	19	<10	0.04	<2	0.26	0.22		1.7		
56	$CuSO_4$		123	9	26									
58														
60		7.7		3	25	19	<0.04	<2	0.20	0.18	4.4	2.7		
64		7.7												
66		7.7												
72		8.3		<2	12	<10	0.04	<2	0.28	0.24	4.3			
80		8.3		4	14	<10	<0.04	<2	0.19	0.16	5.8	2.8		

Table 30. Continued.

$CHCl_3$ (µg/l)	SOL $CHCl_3$ (µg/l)	$CHBrCl_2$ (µg/l)	SOL $CHBrCl_2$ (µg/l)	$CHBr_2Cl$ (µg/l)	SOL $CHBr_2Cl$ (µg/l)	$CHBr_3$ (µg/l)	SOL $CHBr_3$ (µg/l)	DO (mg/l)	TSS (mg/l)	VSS (mg/l)
								6.6		
64		4		1		<1		8.0		
119		5		1		ND		7.7		
109		6		1		2		11	5	2
112		5		1		ND		11.9		
									3	2
101	63	5	4	1	<1	<1	ND			
93		4		1		ND			4	4
88		5		<1		ND				
122	113	5	5	<1	<1	ND	ND			
97		5		<1	<1	ND		9.9	3	<1
111	94	6	6	1	1	ND	ND		5	1
								6.9		
123		5		1		<1		8.3		
107		6		1		ND		9.4		
122		7		2		ND		10.7	7	2
92		5		1		ND		9.9		
									1	1
84	45	4	4	1	<1	<1				
77		4		<1		ND				
88	85	4	4	2	<1	ND	ND			
132	111	5	5	<1	<1	ND	ND			
117	102	5	4	<1	<1	<1	<1	10.2	2	2
124	85	6	5	1	1	ND	ND		10	2
								6.6		
91		5		<1		ND		7.6		
105		7		1		ND		10.1		
215		7		1		2		14.5	7	4
136		5		1		ND		12.5	7	
									5	2
109		5		2		ND				
85		4		<1		ND			3	3
109	93	5	5	1	<1	ND	ND			
131	124	5	6	1	1	ND	ND			
153	122	6	6	<1	<1	ND	ND	11.2	2	2
125	112	6	6	2	<1	ND	ND		6	1

Table 31. Data collected over time in the LIGHT H P SED microcosms.

Exp. Day	Treatment	pH	Alk. (mg/l as $CaCO_3$)	OP (µg/l)	TP (µg/l)	NH_3-N (µg/l)	NO_3-N (mg/l)	NO_2-N (µg/l)	TN (mg/l)	TKN (mg/l)	TOC (mg/l)	SOL TOC (mg/l)	Ca (mg/l)	Mg (mg/l)
Microcosm 4 (LIGHT H P SED)														
1		7.2	166	84	101	690	0.15	2					55	13
10		8.1	164	69	75	1430	0.29	<2			3.8		49	11
20		8.0	161	<2	35	280	0.35	4			8.0	2.6		
30		8.3	109	9	21	106	0.34	5			2.8		35	13
40		8.2	102	2	46	17	0.10	2			2.0	2	32	14
50		8.2		14	35	15	<0.04	<2	0.29	0.26	<2			
56	CTL.		143	3	24									
58														
60		8.2		3	25	24	<0.04	<2	0.27	0.24	<2	<2		
64		8.3												
66		8.3												
72		8.5		<2	5	<10	0.05	<2	0.27	0.22	8.4	2.1		
80		8.6		3	19	<10	<0.04	<2	0.26	0.22	4.8			
Microcosm 5 (LIGHT H P SED)														
1		7.0	168	101	121	1220	0.72	3					56	14
10		8.0	170	84	86	1430	0.34	2			1.2		50	17
20		7.4	163	7	48	640	0.44	5			10.9	2.4		
30		8.1	116	5	38	130	0.31	5			4.9	2.9	37	14
40		8.2	108	2	36	<10	0.20	4			2.1		48	
50		8.3		24	35	14	0.08	<2	0.40	0.32	2.8	2.2		
56	$CuSO_4$		145	3	31									
58														
60		8.1		4	38	<10	0.06	<2	0.37	0.31	6.8	4.9		
64		8.4												
66		8.4												
72		8.4		4	61	<10	0.12	<2	0.40	0.28	4.9	3.9		
80		8.3		5	142	40	0.11	3	0.59	0.48	10.4	11.8		
Microcosm 6 (LIGHT H P SED)														
1		7.0	165	101	123		0.73	4					55	14
10		8.0	164	76	87	1460	0.33	3			1.4		50	17
20		8.0	167	<2	41	90	0.56	2			7.5	2.6		
30		8.7	84	13	41	50	0.22	6			6.2	3.5	22	14
40		8.2	108	2	36	140	0.24	6			3	3	35	13
50		8.0		20	32	90	0.27	10	1.00	0.72		32		
56	$KMnO_4$		156	6	43									
58														
60		7.6		7	42	60	0.14	6	0.53	0.38	3.4	2.8		
64		8.6												
66		8.6												
72		8.2		3	28	30	0.07	<2	0.44	0.37	6.1	2.9		
80		8.2		4	39	30	0.06	<2	0.39	0.33	4.8	4.4		

Table 31. Continued.

$CHCl_3$ (µg/l)	SOL $CHCl_3$ (µg/l)	$CHBrCl_2$ (µg/l)	SOL $CHBrCl_2$ (µg/l)	$CHBr_2Cl$ (µg/l)	SOL $CHBr_2Cl$ (µg/l)	$CHBr_3$ (µg/l)	SOL $CHBr_3$ (µg/l)	DO (mg/l)	TSS (mg/l)	VSS (mg/l)
								6.6		
135		5		<1		ND		6.4		
159		6		1		ND		12.9		
178		6		1		ND		13.8	10	4
120		5		1		ND		11.1		
									8	5
105	47	4	3	2	<1	ND	ND			
101		3		<1		ND			3	3
111	78	4	4	2	<1	ND	ND			
181	136	4	4	<1	<1	ND	ND			
131		4		<1		ND		9.6	6	1
174	95	6	5	2	1	ND	ND		21	8
								7.9		
45		4		<1		ND		8.2		
262		7		1		ND		11.9		
176		6		<1		ND		11.1	7	7
236		6		1		ND		9.6	8	
									5	4
	48		4		<1	ND	ND			
150		4		1		ND			10	10
198	74	5	4	<1	<1	ND	ND			
204	107	4	4	<1	<1	ND	ND			
156		3		1		ND		7.3	8	6
212	106	7	5	2	<1	ND	ND		22	13
								7.2		
121		4		<1		ND		9.6		
257		7		1		ND				
182		7		<1		ND		15.2	6	2
136		5		2		ND		8.1	2	
									6	5
181	64	4	4	1	<1	ND	ND			
114		4		2		ND			4	3
100	81	4	4	2	<1	ND	ND			
130	86	4	4	<1	<1	ND	ND			
126		5		<1		ND		6.1	13	<1
137	110	6	5	2	<1	ND	ND		3	2

Table 32. Data collected over time in the LIGHT H P NOSED microcosms.

Exp. Day	Treatment	pH	Alk. (mg/l as $CaCO_3$)	OP (µg/l)	TP (µg/l)	NH_3-N (µg/l)	NO_3-N (mg/l)	NO_2-N (µg/l)	TN (mg/l)	TKN (mg/l)	TOC (mg/l)	SOL TOC (mg/l)	Ca (mg/l)	Mg (mg/l)
Microcosm 7 (LIGHT H P NOSED)														
1		7.9	156	59	67	<10	0.83	2					52	15
10		8.0	156	60	60	45	0.61	<2			1.3		49	16
20		7.8	156	27	48	<10	0.76	<2			10.0	2.1		
30		8.5	117	9	29	10	0.05	<2			3.3		33	14
40		8.3	85	4	49	<10	0.09	<2			10.6	5.1	39	
50		8.0		40	40	<10	0.10	<2	0.30	0.20	7.4	5.0		
56	$CuSO_4$		105	12	52									
58														
60		8.6		6	38	28	0.10	2	0.35	0.25	9.2	8.1		
64		8.6												
66		8.6												
72		8.4		9	18	<10	0.09	<2	0.28	0.19	3.4	4.2		
80		8.4		2	29	<10	0.06	<2	0.19	0.13	3.0	2.7		
Microcosm 8 (LIGHT H P NOSED)														
1		7.8	146	63	71	<10	0.94	2					55	13
10		8.0	154	67	67	25	0.62	<2			0.7		47	18
20		7.8	157	9	47	<10	0.64	<2			2.5	1.8		
30		8.5	102	12	29	10	0.05	<2			55		29	14
40		8.4	98	3	49	<10	0.11	<2			7.0		27	13
50		8.9		38	38	17	0.10	<2	0.33	0.23	6.5	5.0		
56	CTL.		101	3	48									
58														
60		8.1		9	45	50	0.11	2	0.44	0.33	22	5.9		
64		8.6												
66		8.6												
72		8.6		23	28	<10	0.07	<2	0.28	0.21	4.2	4.0		
80		8.5		3	37	<10	0.07	<2	0.24	0.17	3.8	3.1		
Microcosm 9 (LIGHT H P NOSED)														
1		7.7	150	60	65	<10	0.89	2					54	15
10		8.1	154	67	67	19	0.62	<2			0.9		47	16
20		7.4	158	58	58			<2			1.8			
30		8.2	143	8	35	<10	0.29	4			1.5		31	
40		8.2	104	3	36	<10	0.08	<2			5.3	3.2	32	12
50		8.3		34	34	18	0.09	<2	0.24	0.15	5.8	2.8		
56	$KMnO_4$		110	<2	62									
58														
60		7.1		8	52	41	0.10	2	0.44	0.34	7.6	3.9		
64		8.5												
66		8.5												
72		8.5		18	35	<10	0.08	<2	0.39	0.31	3.8			
80		8.6		5	47	18	0.08	<2	0.30	0.22	4.4	<2		

Table 32. Continued.

$CHCl_3$ (µg/l)	SOL $CHCl_3$ (µg/l)	$CHBrCl_2$ (µg/l)	SOL $CHBrCl_2$ (µg/l)	$CHBr_2Cl$ (µg/l)	SOL $CHBr_2Cl$ (µg/l)	$CHBr_3$ (µg/l)	SOL $CHBr_3$ (µg/l)	DO (mg/l)	TSS (mg/l)	VSS (mg/l)
								9.2		
43		2		<1		ND		10.2		
170		2		1		ND		11.6		
242		2		<1		ND			12	9
192		1		<1		ND		15.5	10	
									12	11
176	40	<1	<1	<1	<1	ND	ND			
									6	5
109	40	<1	<1	<1	<1	ND	ND			
113	78	<1	<1	<1	<1	ND	ND			
122		1		1		ND		2.5	5	2
66	32	<1	<1	1	<1	ND	ND		2	2
								7.7		
55		2		2		ND		10.4		
149		2		1		ND		12.9		
396		2		<1		ND		16.7	13	10
								15.2	4	
									15	14
189	38	<1	<1	<1	<1	ND	ND			
120		<1		ND		ND			5	5
96	62	<1	<1	ND	ND	ND	ND			
104	64	<1	<1	<1	<1	ND	ND			
98		<1		<1		ND		16.0	1	1
95	32	<1	<1	<1	<1	ND	ND		3	3
								8.0		
43		2		<1		ND		10.3		
143		2		<1		ND		8.8		
152		2		2		3		13.4	10	6
116		1		<1		ND		16.6	7	
									14	12
186		<1		<1		ND				
121		<1		<1		ND			5	5
109	51	<1	<1	<1	<1	ND	ND			
116	70	<1		<1	<1	ND	ND			
114		<1	<1	<1				13.0	10	1
106	40	<1	<1	<1	<1	ND	ND		3	<1

Table 33. Data collected over time in the DARK H P SED microcosms.

Exp. Day	Treatment	pH	Alk. (mg/l as $CaCO_3$)	OP (µg/l)	TP (µg/l)	NH_3-N (µg/l)	NO_3-N (mg/l)	NO_2-N (µg/l)	TN (mg/l)	TKN (mg/l)	TOC (mg/l)	SOL TOC (mg/l)	Ca (mg/l)	Mg (mg/l)
Microcosm 10 (DARK H P SED)														
1		7.6	160	79	94	810	0.83	3					53	14
10		8.0	158	86	102	1280	0.42	3			0.9		47	16
20		7.6	168	86	107	1710	0.55	<2			2.8			
30		7.9	174	67	68	1880	0.27	5			1.3		58	13
40		7.8	115	75	79	1910	0.22	2			2		59	14
50		7.6		18	66	1540	0.17	39	2.59	2.38	<2	<2		
56	$KMnO_4$		181	115	214									
58														
60		7.2		119	195	1440	0.08	50	1.16	1.04	9.9	3.3		
64		7.3												
66		7.3												
72		7.7		304	304	1490	0.05	<2	1.43	1.38	2.7			
80		7.8		243	368	1340	0.06	<2	1.50	1.44	3.7	2.7		
Microcosm 11 (DARK H P SED)														
1		7.1	161	93	101	740	0.80	2					48	18
10		7.9	158	76	88	1430	0.39	3			8.4		46	15
20		7.7	143	116	116	1570	0.48	3			6.2	2.3		
30		7.8	173	123	133	1720	0.34	<2			0.9		57	12
40		7.8	164	68	75	1940	0.26	2			1.6		53	14
50		7.8		87	119	1570	0.16	9	1.58	1.41	<2	<2		
56	CTL.		181	93	117									
58														
60		7.2		111	156	1340	0.13	12	1.41	1.27	2.2	2		
64		7.4												
66		7.4												
72		7.6		322	322	1520	0.05	37	1.62	1.53	1.1			
80		7.6		311	433	1490	0.08	<2	1.56	1.48	<2			
Microcosm 12 (DARK H P SED)														
1		7.2	149	104	111	1540	0.83	3					52	15
10		7.9	160	70	70	1320	0.39	<2			1.5		46	15
20		7.7	171	91	91	1530	0.43	2			3.7	3.0		
30		7.9	173	102	119	1740	0.33	<2			5.1		57	13
40		7.7	164	66	102	1670	0.26	<2			0.8		57	13
50		7.9		35	108	2050	0.22	3	2.09	1.87	<2	<2		
56	$CuSO_4$		183	39	68									
58														
60		7.1		57	96		0.16	22	1.48	1.30	3.3	2.8		
64		7.4												
66		7.4												
72		7.6		359	435	1580	0.06	<2	1.67	1.61	3.2			
80		7.6		303	479	1440	<0.04	<2	1.59	1.58	<2			

Table 33. Continued.

$CHCl_3$ (µg/l)	SOL $CHCl_3$ (µg/l)	$CHBrCl_2$ (µg/l)	SOL $CHBrCl_2$ (µg/l)	$CHBr_2Cl$ (µg/l)	SOL $CHBr_2Cl$ (µg/l)	$CHBr_3$ (µg/l)	SOL $CHBr_3$ (µg/l)	DO (mg/l)	TSS (mg/l)	VSS (mg/l)
								7.2		
9		1		<1		ND		7.4		
								5.5		
42		5		<1		ND		4.5	3	3
66		4		<1		<1		3.1	3	
									4	3
59	26	4	3	2	<1	ND	ND			
37		3		1		ND			3	<1
48	36	3	4	<1	<1	ND	ND			
49	42	3	3	1	<1	ND	ND			
55		4		1		ND		2.2	4	3
47	32	4	4	2	1	ND	ND		4	3
								7.8		
9		1		<1		ND		7.2		
36		6		3		ND		6.0		
56		5		2		ND		3.7	3	2
42		3		2		ND		3.2	3	
									3	2
43	18	3	3	1	<1	ND	ND			
33		2		<1		ND			6	3
43	35	2	2	<1	<1	ND	ND			
46	35	3	3	1	<1	ND	ND			
41		4		<1		ND		1.9	6	3
45	25	4	3	<1	<1	ND	ND		3	1
								5.8		
11		1		<1		ND		7.2		
30		5		2		ND		5.8		
46		5		<1		ND		5.3	5	2
54		5		2		ND		3.1	4	
									2	1
34	12	3	2	2	<1	ND	ND			
37		3		1		ND			<1	<1
43	35	4	3	1	<1	ND	ND			
54	40	3	3	<1	<1	ND	ND			
61		4		<1		ND		1.5	12	<1
51	37	4	4	2	<1	ND	ND		8	2

Appendix D

Total Phosphorus Concentrations in Each Microcosm Versus Time

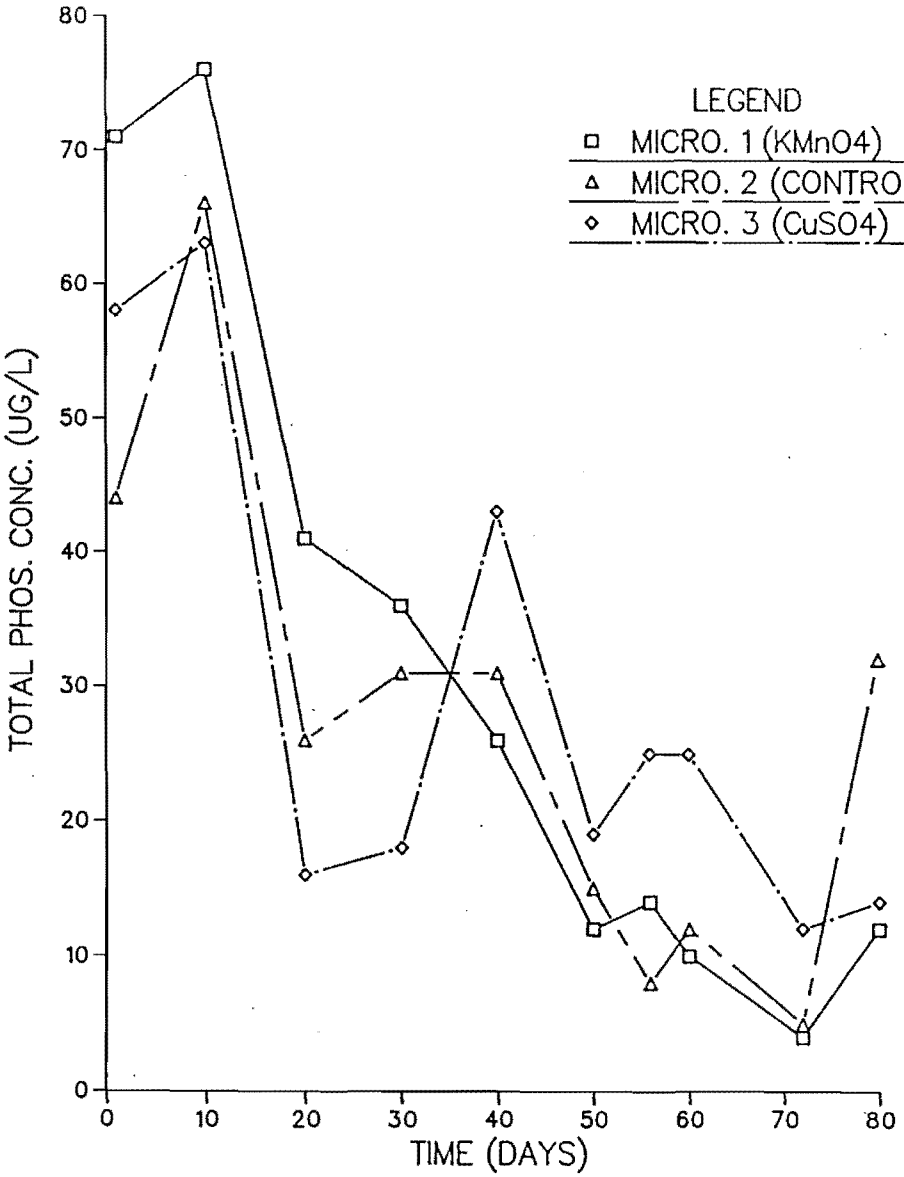

Figure 21. Total phosphorus concentrations for each microcosm of the LIGHT L P SED treatment versus time. Algicide applications on day 58 of the experiment are noted in parentheses in the legend.

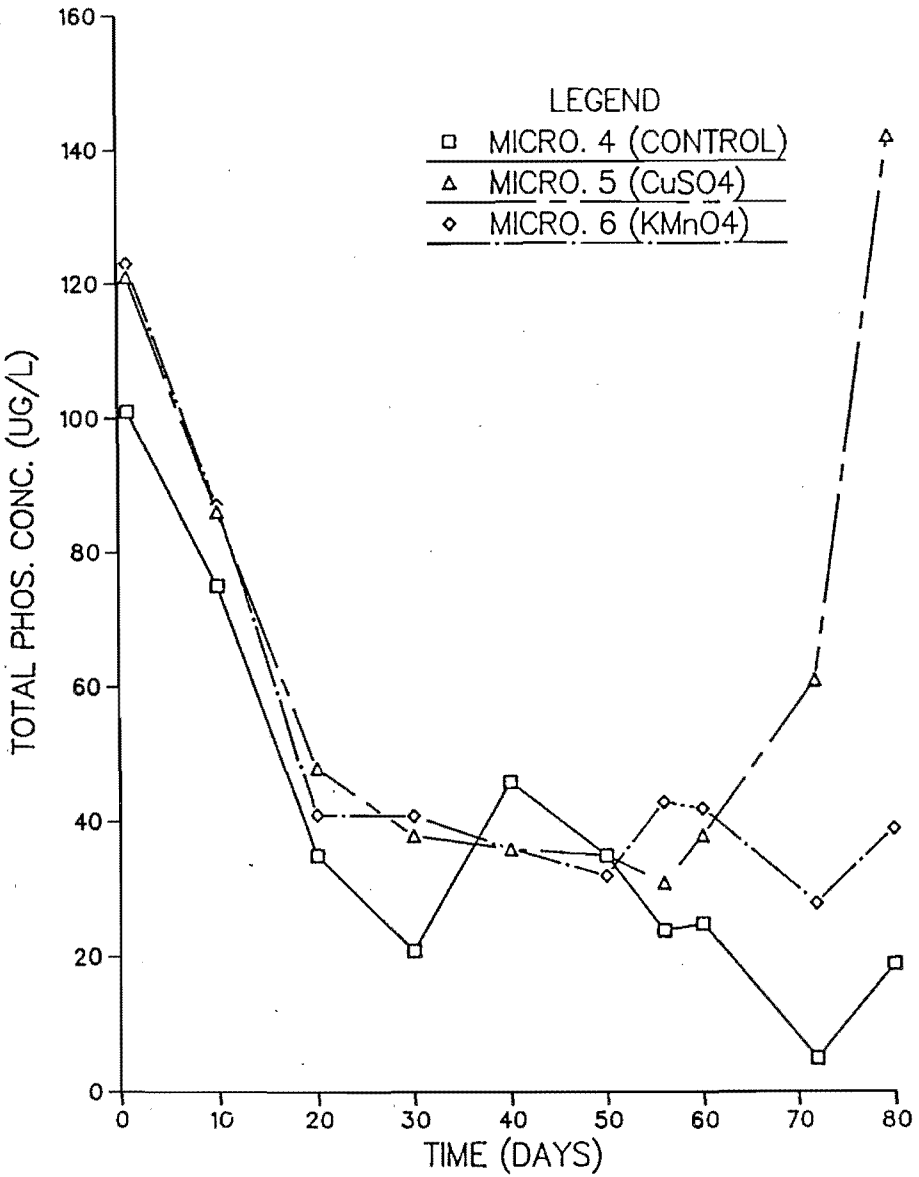

Figure 22. Total phosphorus concentrations for each microcosm of the LIGHT H P SED treatment versus time. Algicide applications on day 58 of the experiment are noted in parentheses in the legend.

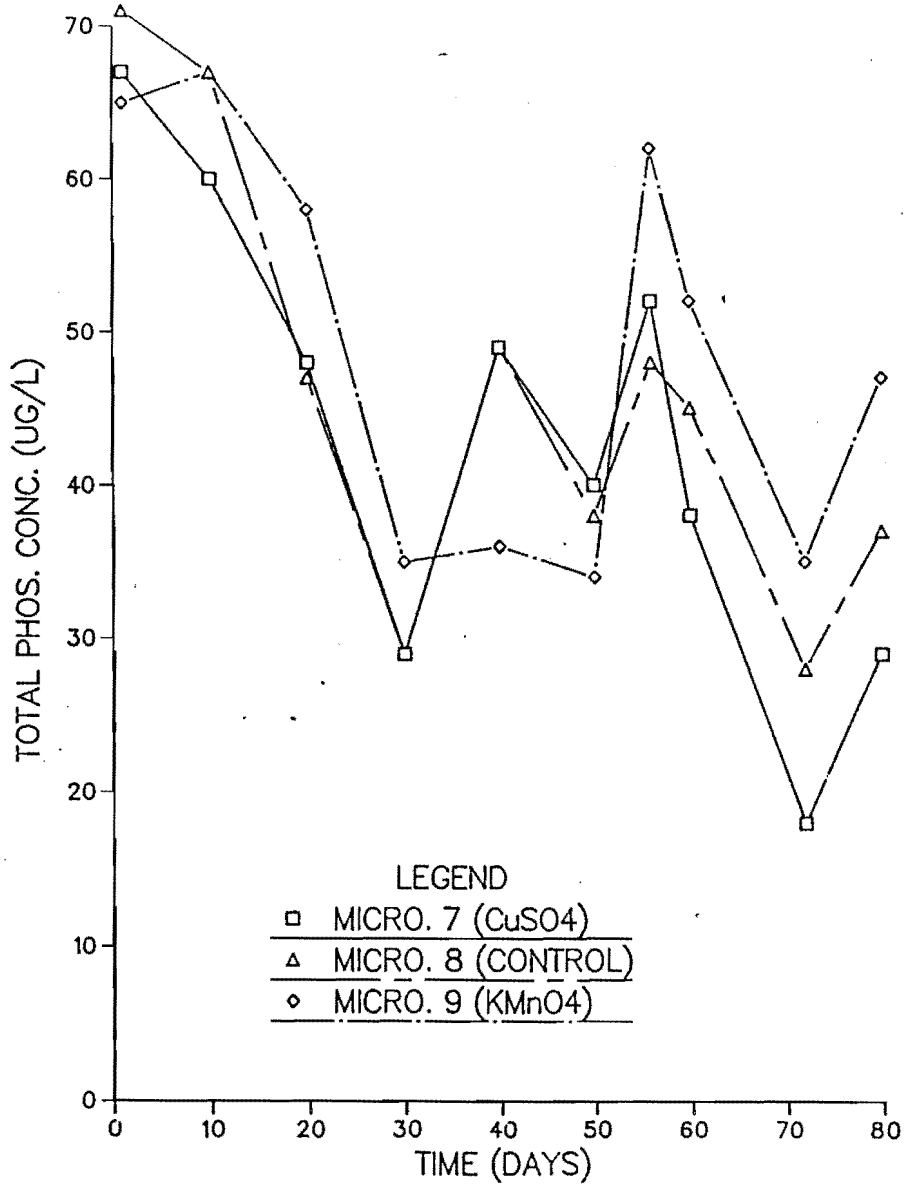

Figure 23. Total phosphorus concentrations for each microcosm of the LIGHT H P NOSED treatment versus time. Algicide applications on day 58 of the experiment are noted in parentheses in the legend.

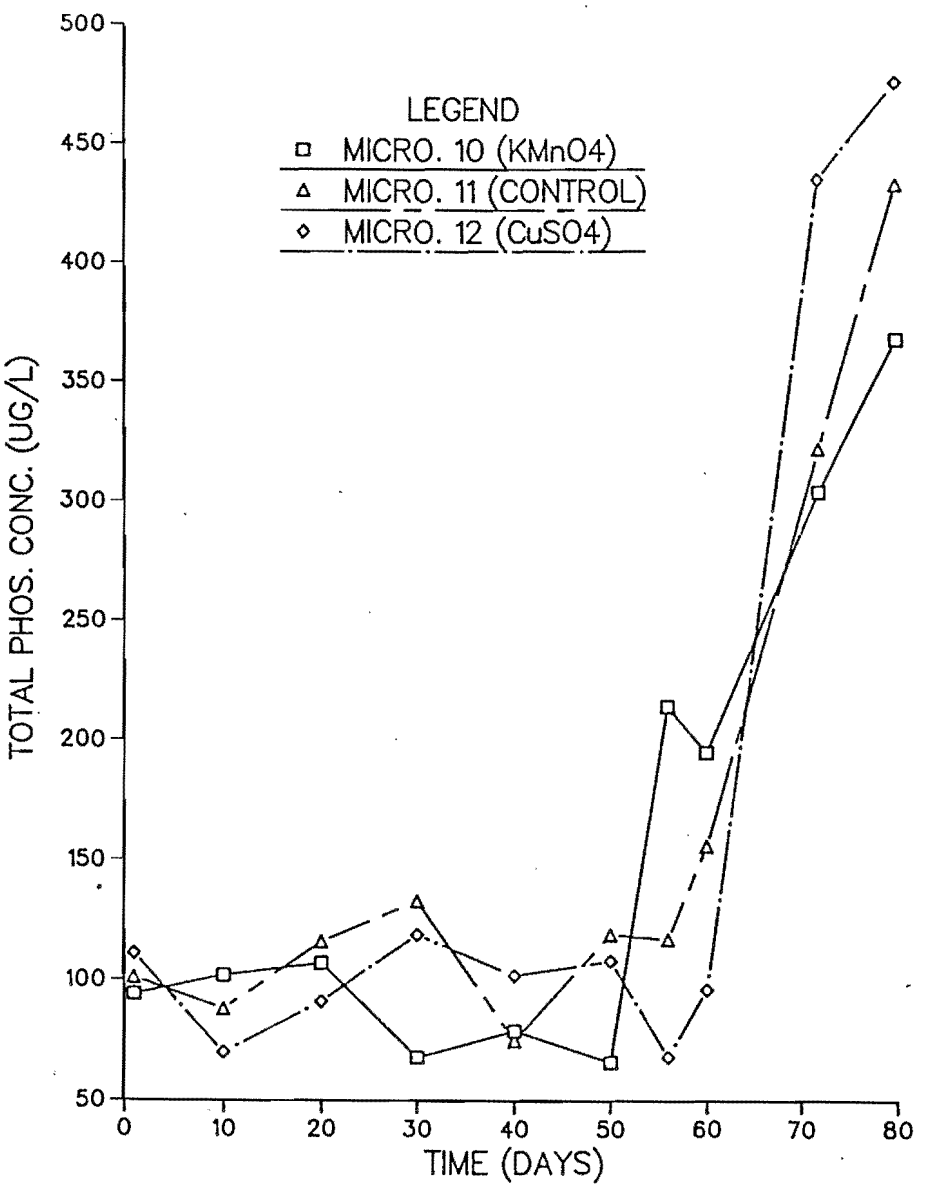

Figure 24. Total phosphorus concentrations for each microcosm of the DARK H P SED treatment versus time. Algicide applications on day 58 of the experiment are noted in parentheses in the legend.

Appendix E

Total and Volatile Suspended Solids Concentrations in Each Microcosm Versus Time

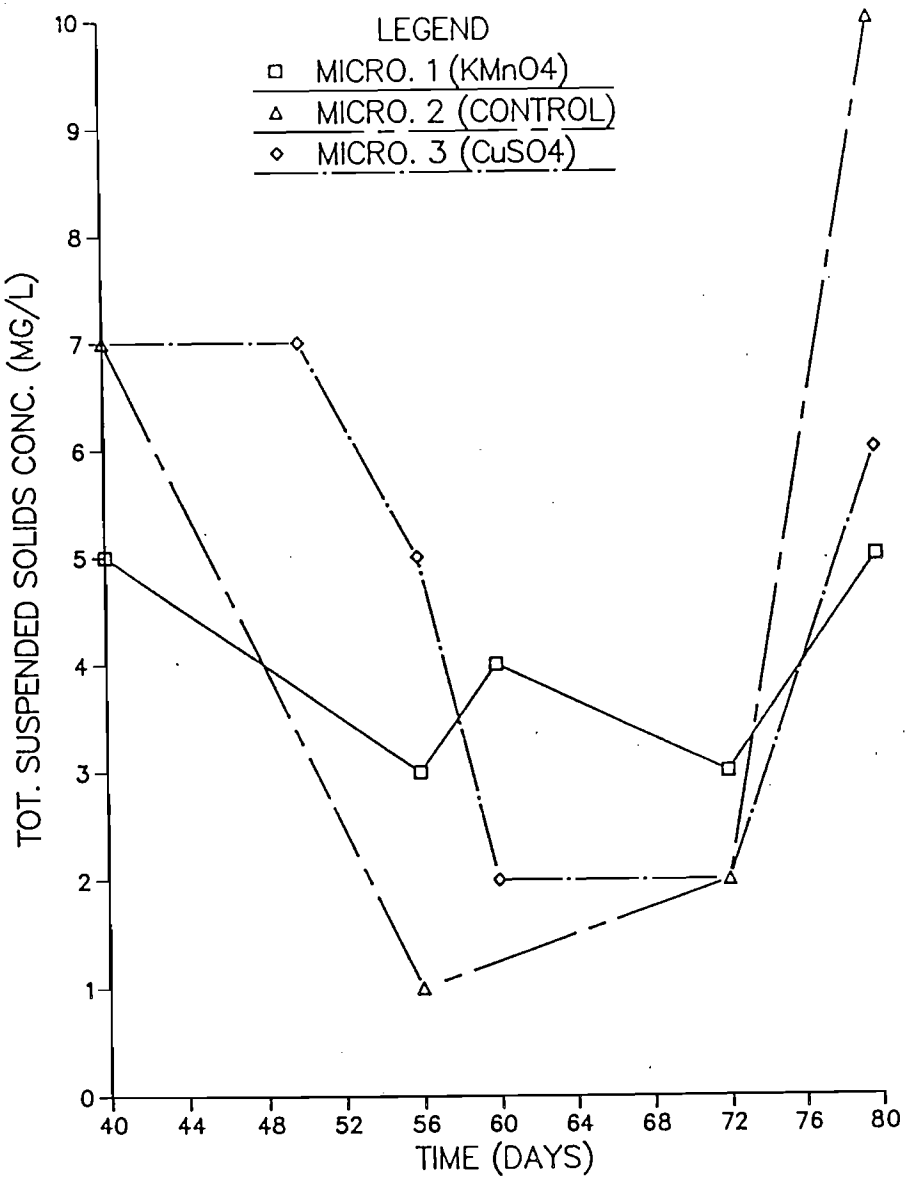

Figure 25. Total suspended solids concentrations for each microcosm of the LIGHT L P SED treatment versus time. Algicide applications on day 58 of the experiment are noted in parentheses in the legend.

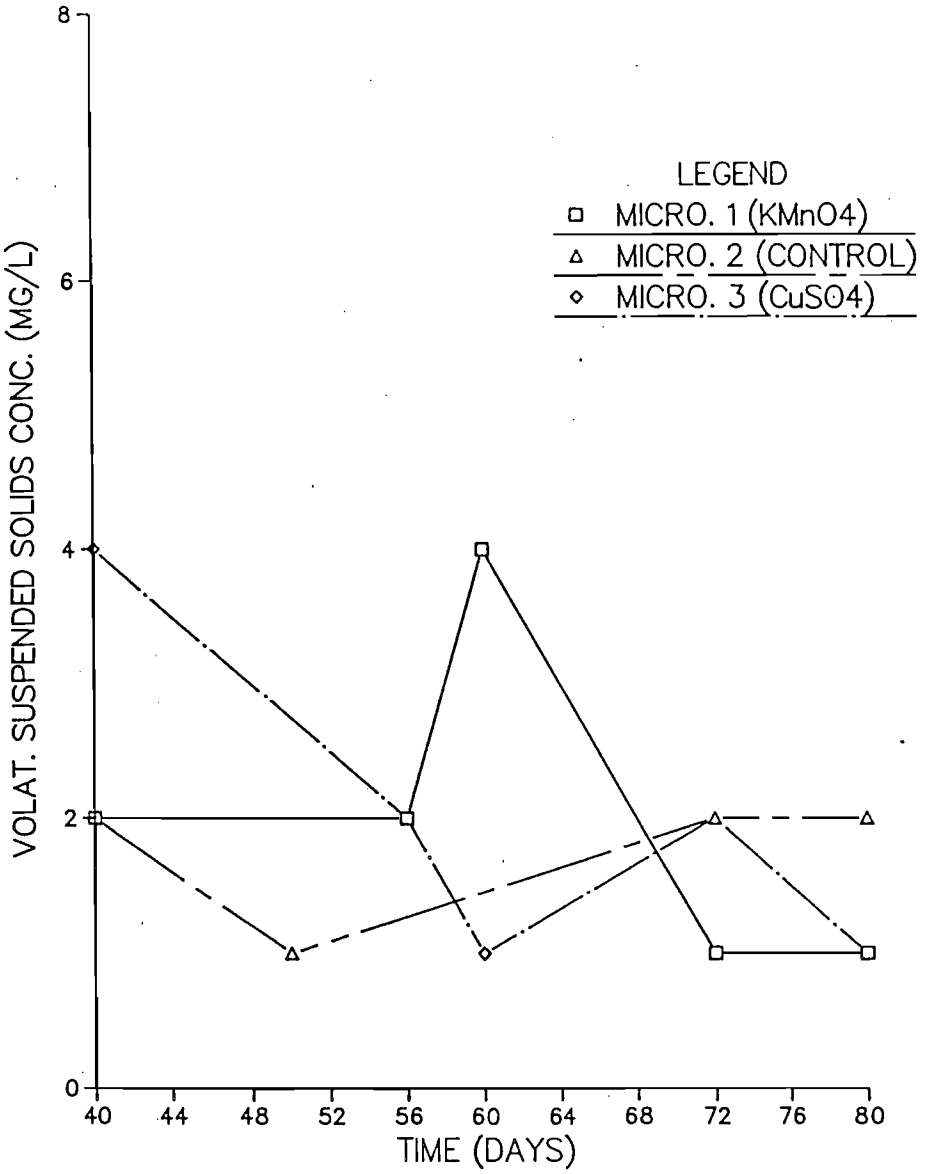

Figure 26. Volatile suspended solids concentrations for each microcosm of the LIGHT L P SED treatment versus time. Algicide applications on day 58 of the experiment are noted in parentheses in the legend.

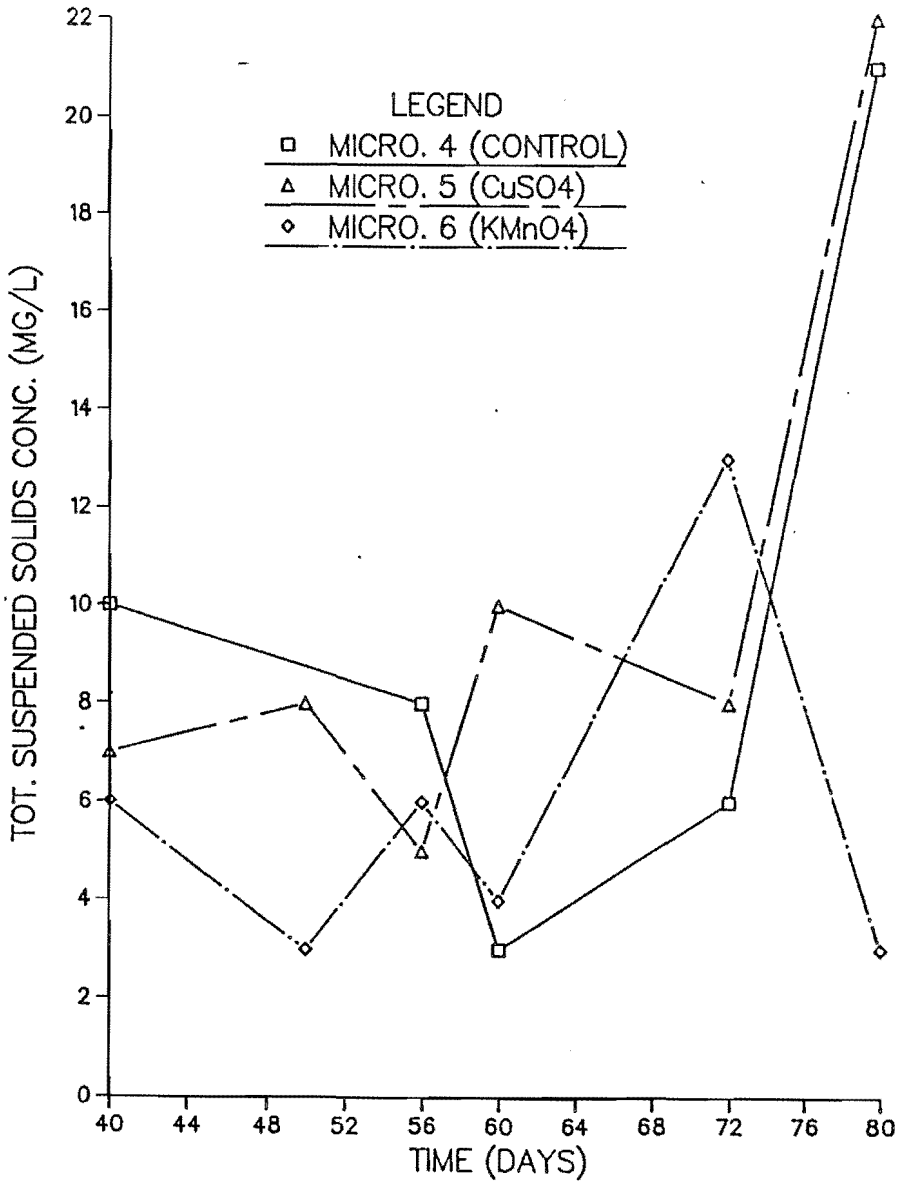

Figure 27. Total suspended solids concentrations for each microcosm of the LIGHT H P SED treatment versus time. Algicide applications on day 58 of the experiment are noted in parentheses in the legend.

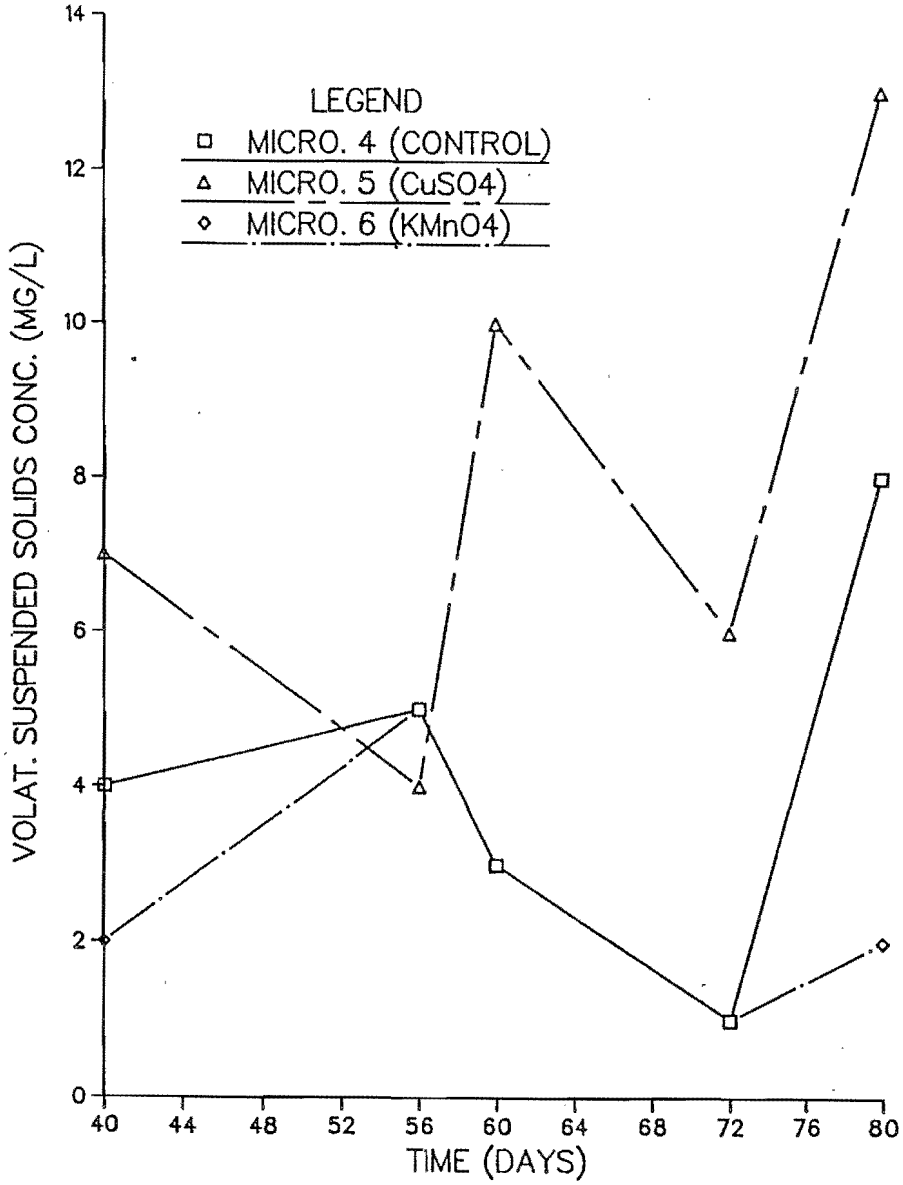

Figure 28. Volatile suspended solids concentrations for each microcosm of the LIGHT H P SED treatment versus time. Algicide applications on day 58 of the experiment are noted in parentheses in the legend.

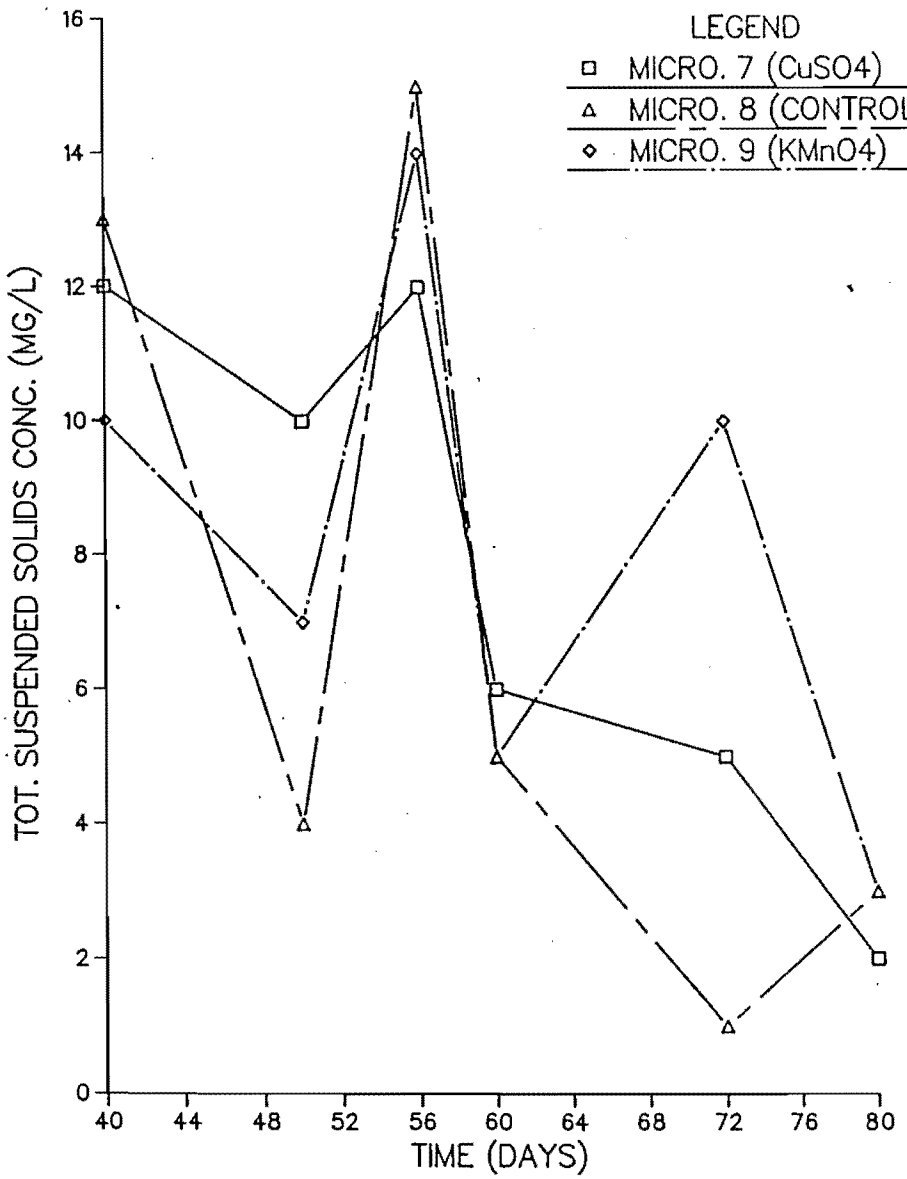

Figure 29. Total suspended solids concentrations for each microcosm of the LIGHT H P NOSED treatment versus time. Algicide applications on day 58 of the experiment are noted in parentheses in the legend.

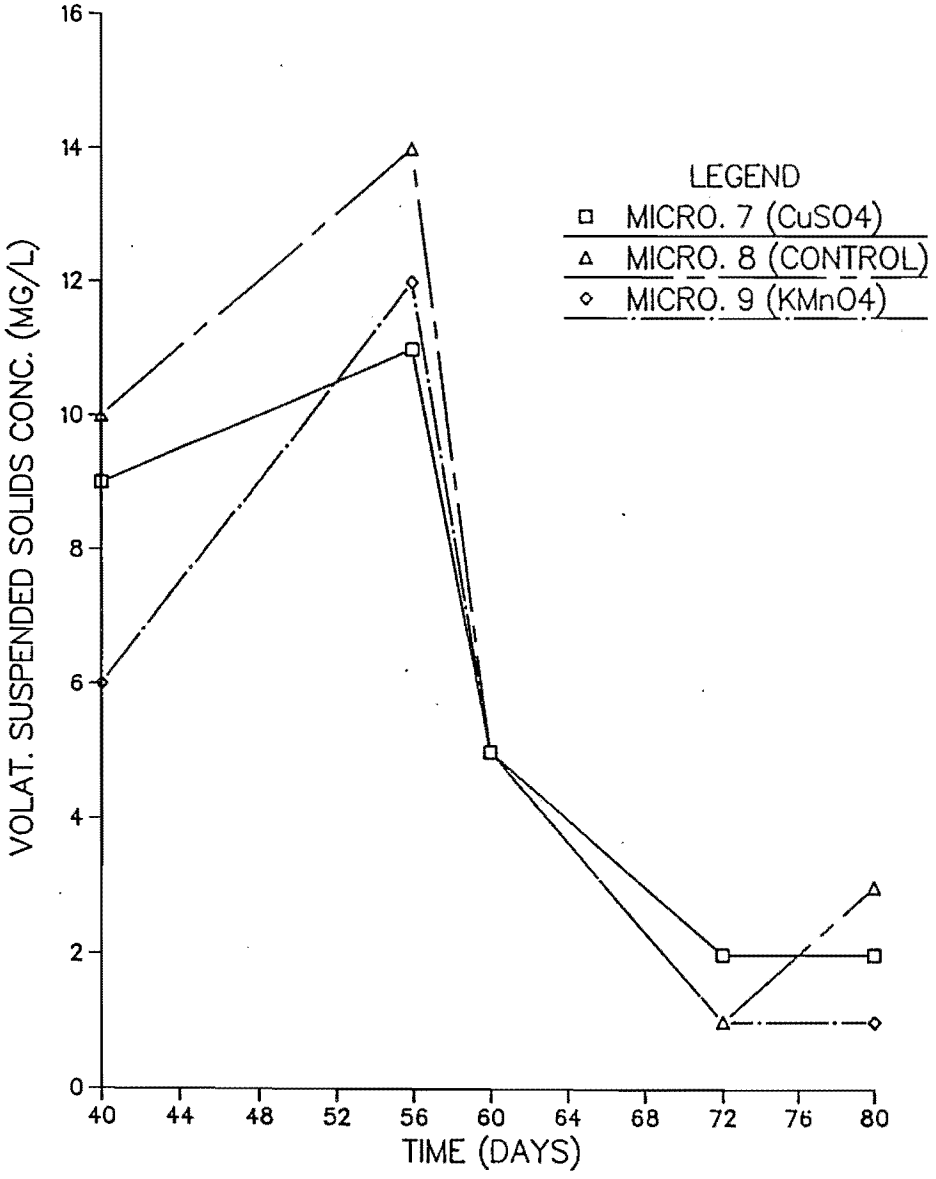

Figure 30. Volatile suspended solids concentrations for each microcosm of the LIGHT H P NOSED treatment versus time. Algicide applications on day 58 of the experiment are noted in parentheses in the legend.

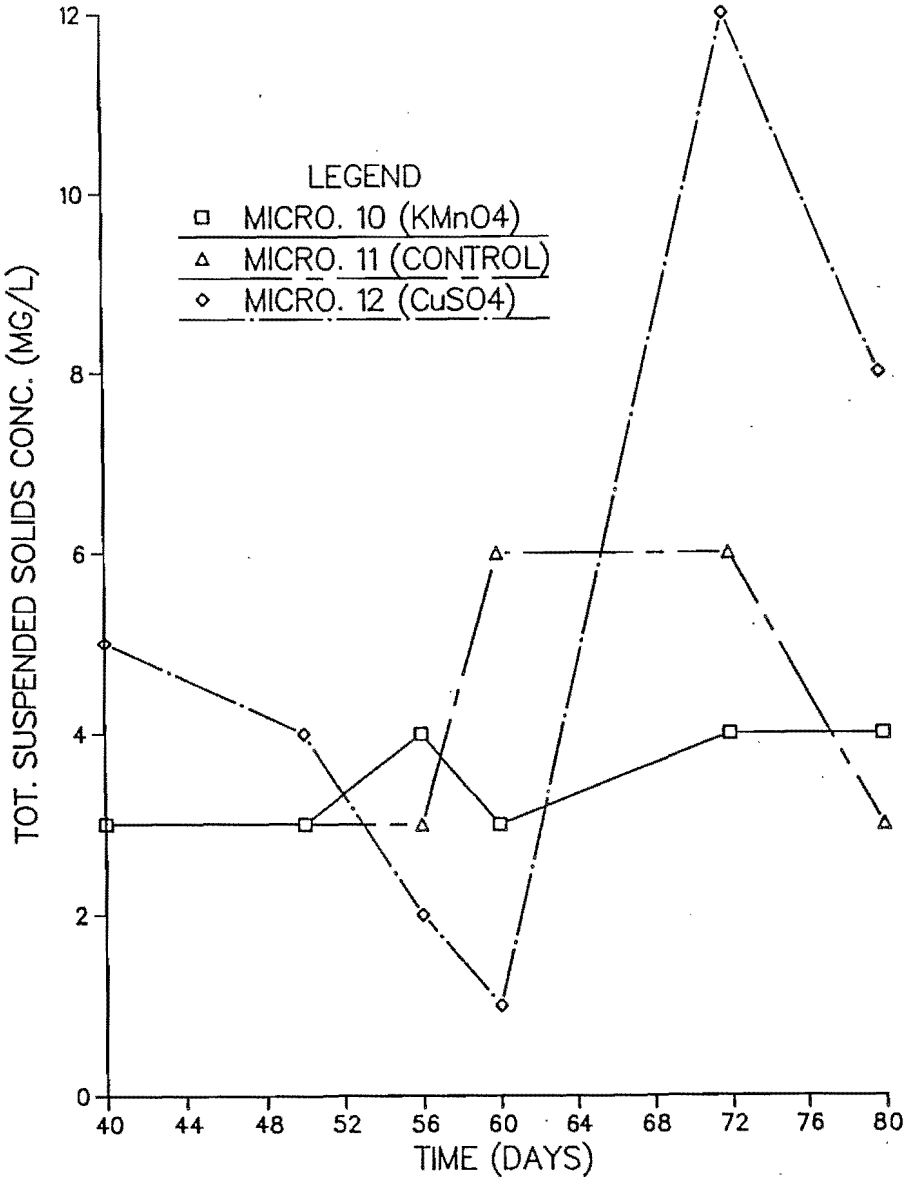

Figure 31. Total suspended solids concentrations for each microcosm of the DARK H P 3ED treatment versus time. Algicide applications on day 58 of the experiment are noted in parentheses in the legend.

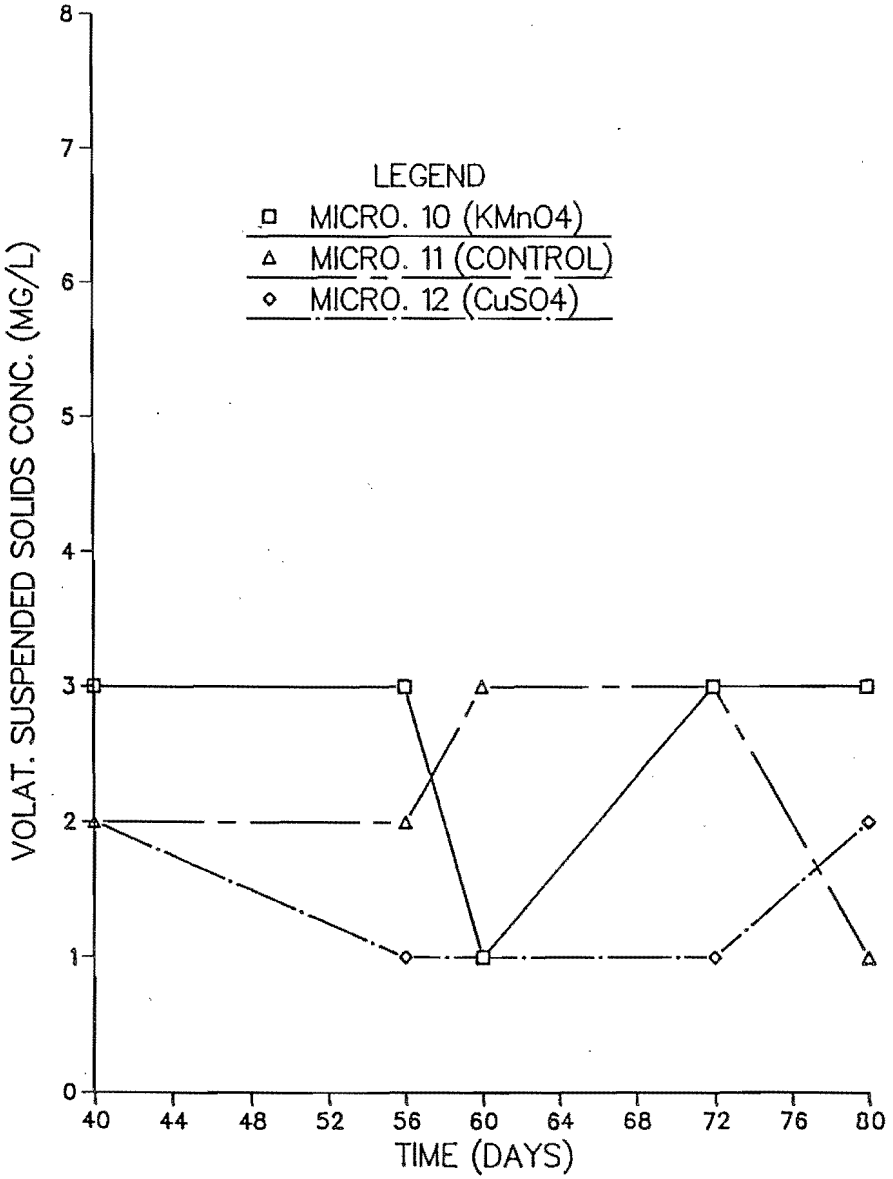

Figure 32. Volatile suspended solids concentrations for each microcosm of the DARK H P SED treatment versus time. Algicide applications on day 58 of the experiment are noted in parentheses in the legend.

Appendix F

Mean Attached and Suspended Biomass Present at Microcosm Experiment Termination and Associated Standard Deviations for Each Treatment

Table 34. Mean attached and suspended biomass present at experiment termination for each microcosm treatment. Standard deviations are in parentheses.

Treatment	Mean Attached Biomass (g)	Mean Suspended Biomass (mg/l)
LIGHT L P SED	2.6 (0.80)	6.9 (2.8)
LIGHT H P SED	1.8 (0.43)	15 (10)
LIGHT H P NOSED	1.6 (0.47)	2.7 (0.66)
DARK H P SED	<1	5.0 (2.3)

Appendix G

Mean Accumulated Change in Gas, Oxygen, Methane, and Carbon Dioxide Volumes and Associated Standard Deviations of Each Treatment Over Time

Table 35. Mean accumulated change in gas volume over time for each microcosm treatment and associated standard deviations.*

	LIGHT L P SED		LIGHT H P SED		LIGHT H P NOSED		DARK H P SED	
Exper. Day	Mean (ml)	Std. Dev.	Mean (ml)	Std. Dev.	Mean (ml)	Std. Dev.	Mean (ml)	Std. Dev.
10	3.3	2.9	-11	15	-16	8.2	-33	23
20	46	24	7.0	24	-43	16	-17	23
30	88	22	140	71	-15	43	-8.7	24
40	170	37	260	49	140	76	-31	30
50	290	100	230	54	240	110	-110	21
60	330	130	210	46	314	120	-130	16
72	370	140	240	111	353	97	-150	26
80	394	140	280	95	426	83	-160	23

*Means and standard deviations were derived using data from the three replicate microcosms in each treatment.

Table 36. Mean accumulated change in oxygen gas volume over time for each microcosm treatment and associated standard deviations.*

	LIGHT L P SED		LIGHT H P SED		LIGHT H P NOSED		DARK H P SED	
Exper. Day	Mean (ml)	Std. Dev.	Mean (ml)	Std. Dev.	Mean (ml)	Std. Dev.	Mean (ml)	Std. Dev.
10	-33	44	-44	2.0	0	2.5	-34	8.0
20	-29	53	-90	2.9	-14	9.5	-69	8.7
30	47	67	83	35	6.0	32	-114	7.0
40	130	59	210	54	210	89	-160	5.5
50	240	80	130	29	360	110	-180	37
60	180	100	45	41	380	110	-270	150
72	220	66	69	77	450	98	-360	140
80	240	100	99	85	590	81	-450	133

*Means and standard deviations were derived using data from the three replicate microcosms in each treatment.

Appendix H

Terminal Total Trihalomethane Concentrations in Each Microcosm Versus Time

Table 37. Mean accumulated change in carbon dioxide gas volume over time for each microcosm treatment and associated standard deviations.*

	LIGHT L P SED		LIGHT H P SED		LIGHT H P NOSED		DARK H P SED	
Exper. Day	Mean (ml)	Std. Dev.	Mean (ml)	Std. Dev.	Mean (ml)	Std. Dev.	Mean (ml)	Std. Dev.
10	2.1	33	48	28	-29	0.60	49	9.5
20	6.8	43	110	64	-71	0.60	100	12
30	-26	38	-3.4	36	-110	6.3	150	14
40	-69	49	-40	38	-160	1.1	180	38
50	-92	59	-48	42	-200	1.0	200	64
60	-150	100	-100	12	-312	2.0	180	81
72	-180	120	-90	43	-350	3.6	240	82
80	-190	150	-75	110	-390	2.5	280	80

*Means and standard deviations were derived using data from the three replicate microcosms in each treatment.

Table 38. Mean accumulated change in methane gas volume over time for each microcosm treatment and associated standard deviations.*

	LIGHT L P SED		LIGHT H P SED		LIGHT H P NOSED		DARK H P SED	
Exper. Day	Mean (ml)	Std. Dev.	Mean (ml)	Std. Dev.	Mean (ml)	Std. Dev.	Mean (ml)	Std. Dev.
10	ND		ND		ND		ND	
20	ND		ND		ND		ND	
30	ND		ND		ND		ND	
40	15	9.6	21	7.4	ND		2.4	4.1
50	34	22	14	2.2	ND		6.6	6.1
60	37	22	20	5.8	ND		11	2.3
72	46	12	21	16	ND		15	3.6
80	54	14	36	26	ND		19	8.1

*Means and standard deviations were derived using data from the three replicate microcosms in each treatment.

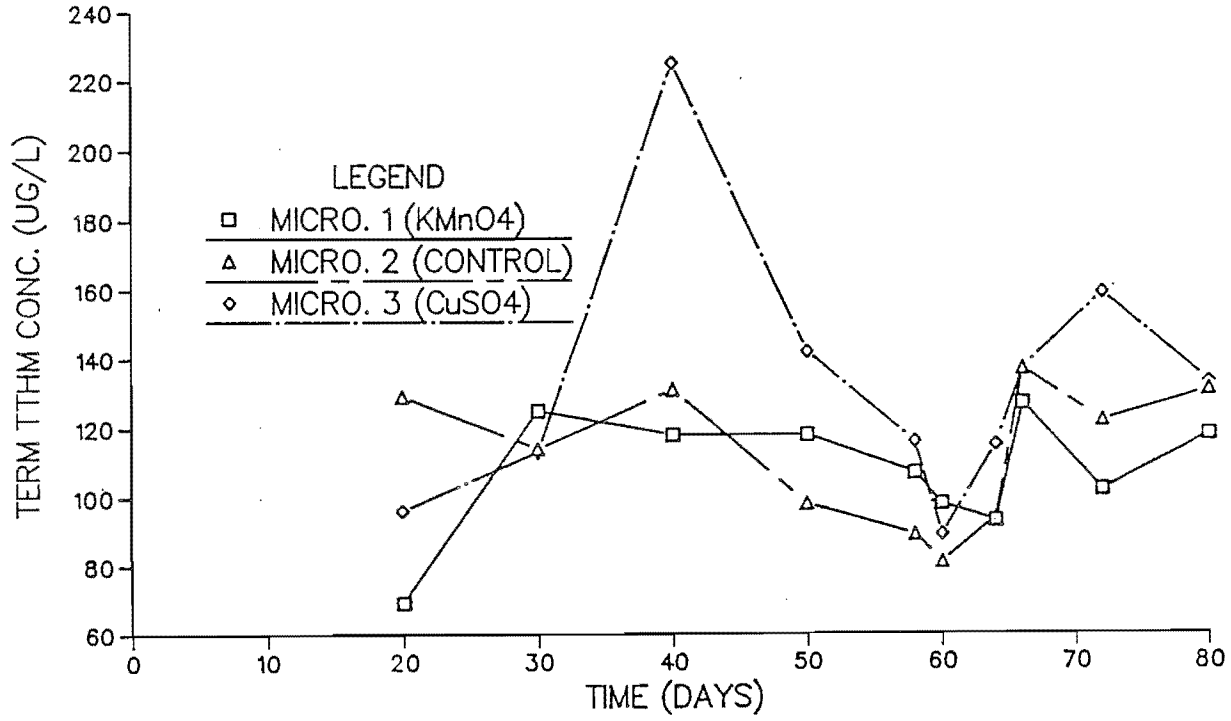

Figure 33. Terminal total trihalomethane concentrations for each microcosm of the LIGHT L P SED treatment versus time. Algicide applications on day 58 of the experiment are noted in parentheses in the legend.

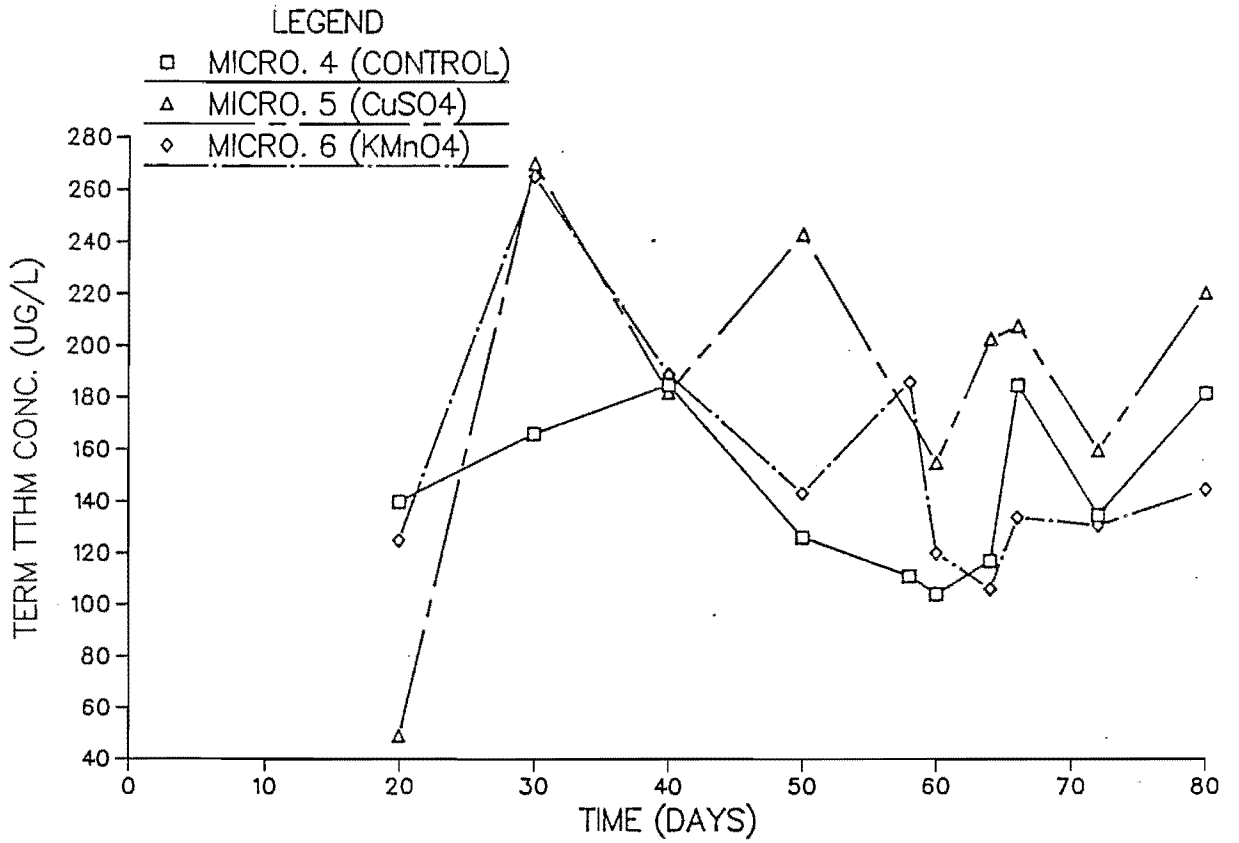

Figure 34. Terminal total trihalomethane concentrations for each microcosm of the LIGHT H P SED treatment versus time. Algicide applications on day 58 of the experiment are noted in parentheses in the legend.

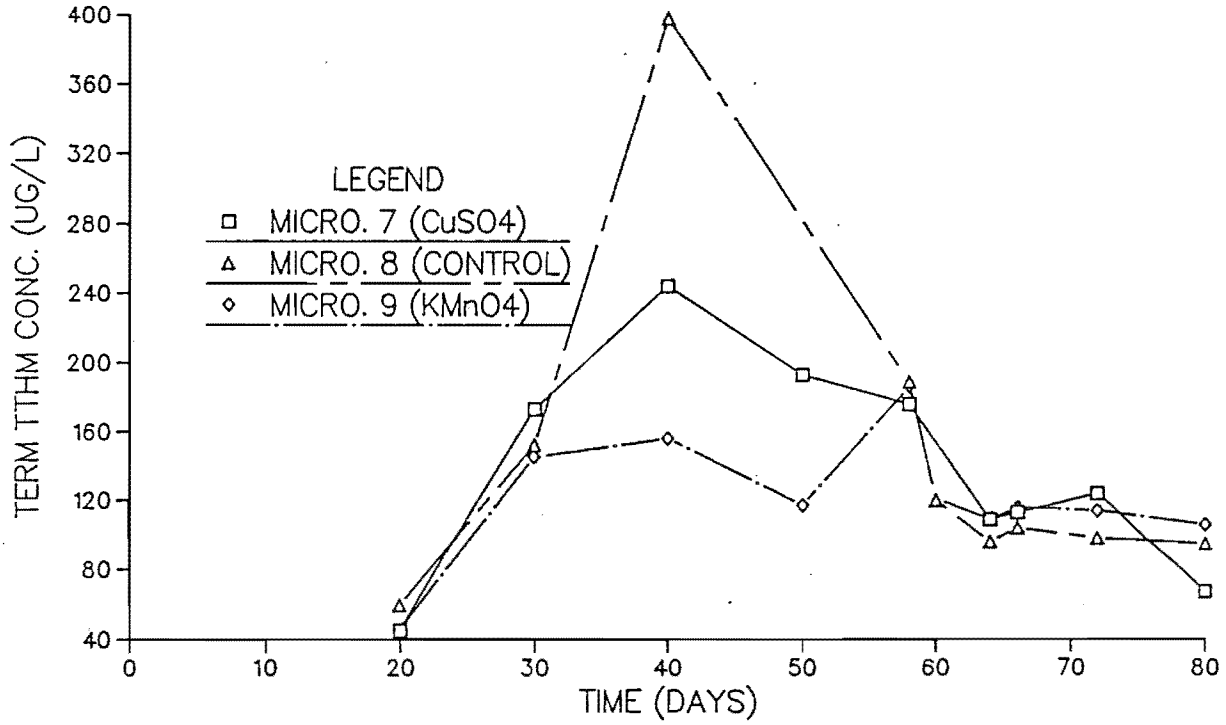

Figure 35. Terminal total trihalomethane concentrations for each microcosm of the LIGHT H P NOSED treatment versus time. Algicide applications on day 58 of the experiment are noted in parentheses in the legend.

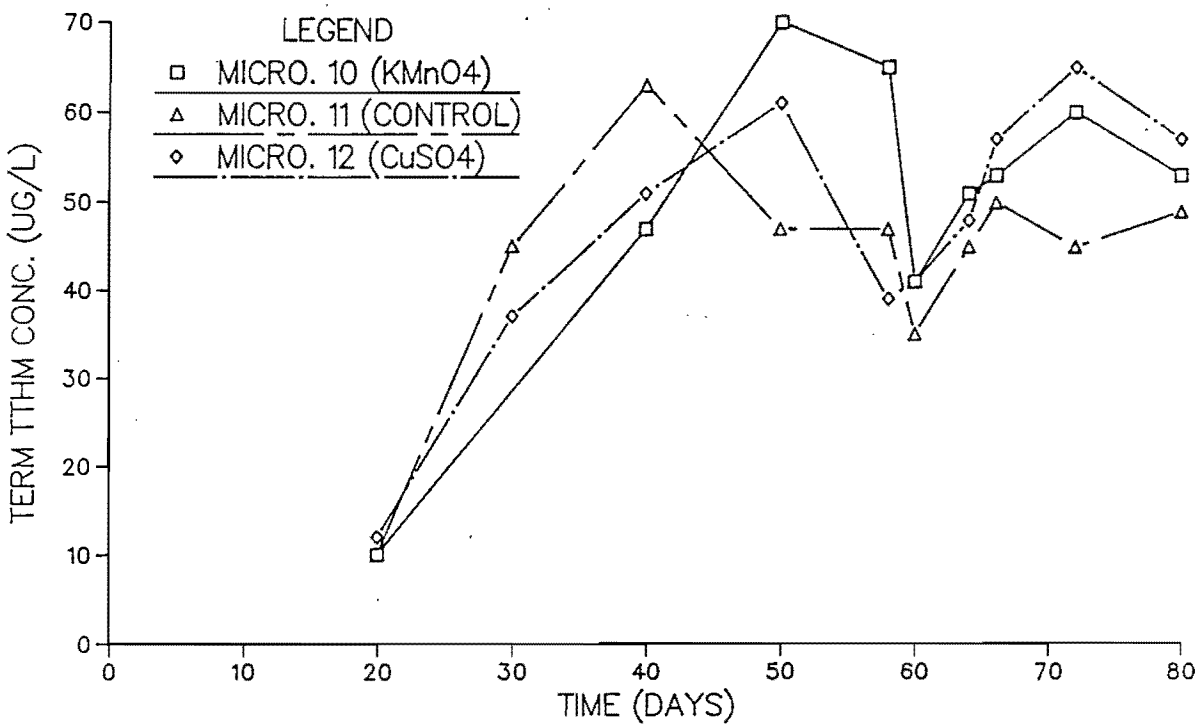

Figure 36. Terminal total trihalomethane concentrations for each microcosm of the DARK H P SED treatment versus time. Algicide applications on day 58 of the experiment are noted in parentheses in the legend.

Appendix I

Data Collected During Tributary and Reservoir Study

Location	Site	Flow (cfs)	Alk. (mg/l as $CaCO_3$)	OP (µg/l)	TP (µg/l)	NH_3-N (µg/l)	NO_3-N (mg/l)	NO_2-N (mg/l)	TN (mg/l)	TKN (mg/l)	TOC (mg/l)	SOL TOC (mg/l)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)
Sampling Date: 5/5/83															
Provo R. Upstream		610	118	29	103	11	0.66	18	1.1	0.41	5.2	3.5	7	44	12
Main Ck.		235	124	35	301	23	0.19	17	1.0	0.82	5.2	4.3	5	40	7
Daniels Ck.		40	131	40	762	18	0.32	19	2.0	1.7	30	4.1	15	40	9
Deckers Ck.		3	230	36	103	<10	0.49	<2	0.91	0.42	4.4	2.8	8	70	26
Provo. R. Downstream		615	157	16	29	40	0.24	13	0.78	0.53	3.0		11	58	2
Sampling Date: 6/14/83															
Provo R. Upstream		1425	81	37	82	<10	0.81	4	3.2	2.3	5.2			30	24
Main Ck.		113	95	36	187	<10	0.25	4	0.73	0.48	5.9			32	24
Daniels Ck.		96	86	31	122	10	0.28	4	0.71	0.43	7.6			30	22
Lower Charleston Canal		13	179	84	175	24	1.4	12	3.2	1.8	5.0	3.3		62	46
Provo R. Downstream		2079	83	20	52	17	0.21	5	0.54	0.32	5.3			33	27
DCR (surf)	2		86	16	60	20	0.26	7	0.57	0.30	5.2			32	26
DCR (mid)	2		105	22	58	36	0.27	7	0.53	0.25	5.0			35	26
DCR (deep)	2		118	22	107	41	0.29	6	0.54	0.24	6.4			34	34
DCR (composite)															
Sampling Date: 7/19/83															
Provo R. Upstream		162	129	8	41	<10	0.23	10	0.78	0.56	7.6	5.1		51	8
Main Ck.		14	242	37	60	<10	0.30	5	1.04	0.74	4.7			81	11
Daniels Ck.		3	127	111	140	<10	0.80	5	2.47	1.67	5.1			56	6
Lower Charleston Canal		2	191	91	110	13	1.9	23	2.64	0.71	5.7	3.8		72	7
Provo R. Downstream		465	119	51	56	<10	0.39	2	0.57	0.18	4.7			56	8
Sampling Date: 7/21/83															
DCR (surf)	1		101	5	21	27	0.23	4			7.0			40	5
DCR (surf)	2		109	3	24	14	0.19	11			7.5			41	5
DCR (mid)	2		105	4	21	17	0.23	11			7.0			42	6
DCR (deep)	2		103	29	46	17	0.35	11			6.0			46	5
DCR (surf)	4		107	3	30	24	0.18	11			6.3			42	5
DCR (mid)	4		120	22	33	74	0.35	18			4.9			43	5
DCR (deep)	4		107	17	37	33	0.32	16			6.3			48	6

Location	$CHCl_3$ (µg/l)	SOL $CHCl_3$ (µg/l)	$CHBrCl_2$ (µg/l)	SOL $CHBrCl_2$ (µg/l)	$CHBr_2Cl$ (µg/l)	SOL $CHBr_2Cl$ (µg/l)	$CHBr_3$ (µg/l)	SOL $CHBr_3$ (µg/l)	TSS (mg/l)	VSS (mg/l)	TDS (mg/l)	pH	DO (mg/l)	Temp. (°C)	Chloride (mg/l)	Sulfate (mg/l)
Sampling Date: 5/5/83																
Provo R. Upstream									29	5	195		10.9	10.1	6	27
Main Ck.									264	41	158		8.4	8.3	5	6
Daniels Ck.									1050	134	200		9.3	9.6	26	5
Deckers Ck.									61	11	298		8.8		7	37
Provo. R. Downstream									2	1	257		9.3	6.3	11	53
Sampling Date: 6/14/83																
Provo R. Upstream	383		9		<1		<1		36	4	153		9.4	8.0	3	14
Main Ck.									152	17	155		8.2	8.0	4	7
Daniels Ck.	418		13		<1		<1		173	23	174		9.4	8.0	10	5
Lower Charleston Canal	221		12		<1		<1		60	16	283		8.0	14.0	62	16
Provo R. Downstream									4	<1	185		9.0	12.5	5	25
DCR (surf)	246		16		<1		<1		6	1	189		7.6	14.0	7	25
DCR (mid)	204		25		<1		<1		12	4	185		6.9	10.0	6	31
DCR (deep)	418		13		3		<1		5	2	216		7.4	8.4	35	25
DCR (composite)	333		16		<1		<1									
Sampling Date: 7/19/83																
Provo R. Upstream	334		23		1		ND					8.4	8.5	22		1
Main Ck.	301		37		5		<1					8.0	9.2	19		1
Daniels Ck.	275		19		1		ND					8.4	8.8	20		1
Lower Charleston Canal	207		14		1		ND					8.1	12	19		1
Provo R. Downstream	251		18		1		ND					7.5	6.4	11		8
Sampling Date: 7/21/83																
DCR (surf)	301		16		1		ND		7			7.5				12
DCR (surf)	319		17		1		ND					8.1				
DCR (mid)	327		18		3		ND					8.2				<1
DCR (deep)	563		17		1		ND					7.5				2
DCR (surf)	343		17		1		ND		6			8.2				<1
DCR (mid)	271		19		1		ND					8.0				<1
DCR (deep)	291		18		2		ND					8.1				2

ND = none detected.

Location	Site	Flow (cfs)	Alk. (mg/l as $CaCO_3$)	OP (µg/l)	TP (µg/l)	NH_3-N (µg/l)	NO_3-N (mg/l)	NO_2-N (mg/l)	TN (mg/l)	TKN (mg/l)	TOC (mg/l)	SOL TOC (mg/l)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)
Sampling Date: 7/29/83															
DCR (surf)	1														
DCR (surf)	2														
DCR (surf)	3														
DCR (surf)	4														
DCR (surf)	5														
Sampling Date: 8/29/83															
Provo R. Upstream		295	209	40	45	13	0.62	5	0.75	0.12	2.6				
Main Ck.		11	276	86	86	13	0.93	10	0.77		4.8				
Daniels Ck.		1	149	6	21	27	0.92	11	1.1	0.18	3.6				
Provo R. Downstream		443	109	86	86	<10	0.50	5	0.73	0.23	4.4				
DCR (surf)	2		133			<10	0.09	2	0.40	0.31	4.8				
DCR (mid)	2		130	<2	16	<10	0.06	4	0.42	0.36	4.7				
DCR (deep)	2		141	2	21	40	0.28	8	0.56	0.27	4.7				
DCR (surf)	4		131	<2	5	<10	0.06	6	0.35	0.28	3.9				
DCR (mid)	4		127	6	6	12	0.17	6	0.47	0.29	4.5				
DCR (deep)	4		122	<2	13	<10	0.44	4	0.65	0.21	4.1				
Sampling Date: 10/4/83															
Provo R. Upstream		294		39	58	<10		5	1.1	0.44	2.9	2.2			
Main Ck.		26		52	65	<10	0.44	6	0.62	0.17	3.2	3.1			
Daniels Ck.		6		120	146	171	0.85	11	0.85		5.0	3.7			
Lower Charleston Canal		11		106	134	62	2.7	20	2.7		5.8	2.4			
Provo R. Downstream		543		20	89	75	0.24	11	0.65	0.40	4.1	4.1			
DCR (surf)	1			9	14	<10	0.26	5	0.45	0.19	3.8	3.8			
DCR (surf)	2			14	14	<10	0.09	5	0.22	0.13	3.8	3.5			
DCR (surf)	3			16	17	<10	0.14	5	0.29	0.15	4.8	4.8			
DCR (surf)	4			9	14	<10	0.14	5	0.28	0.14	3.8	3.5			

Location	$CHCl_3$ (µg/l)	SOL $CHCl_3$ (µg/l)	$CHBrCl_2$ (µg/l)	SOL $CHBrCl_2$ (µg/l)	$CHBr_2Cl$ (µg/l)	SOL $CHBr_2Cl$ (µg/l)	$CHBr_3$ (µg/l)	SOL $CHBr_3$ (µg/l)	TSS (mg/l)	VSS (mg/l)	TDS (mg/l)	pH	DO (mg/l)	Temp. (°C)	Chloride (mg/l)	Sulfate (mg/l)
Sampling Date: 7/29/83																
DCR (surf)	374	341	20	19	8	2	ND	ND	7	4						
DCR (surf)	346	327	19	18	1	1	ND	ND	4	2						
DCR (surf)	350	348	21	19	8	1	ND	ND	4	2						
DCR (surf)	394		19		1		ND		6	2						
DCR (surf)	390	311	20	18	6	1	ND	ND	12	3						
Sampling Date: 8/29/83																
Provo R. Upstream	230	166	35	31	6	6	<1	ND	6	1		9.4	7.2	19		
Main Ck.	342	285	51	45	7	5	<1	ND	4	<1		8.0	6.7	18		
Daniels Ck.	332	243	23	21	2	2	<1	ND	4	2		9.4	6.2	20		
Provo R. Downstream	326		17		1		<1		17	5		8.0	3.4	8		
DCR (surf)	266	230	21	21	2	2	ND	ND	3	<1		9.6	10.2	23		
DCR (mid)	272		22		2				7	3		8.5	6.1	15		
DCR (deep)	260	241	23	23	2	2	ND	ND	7	2		9.1	4.1	10		
DCR (surf)	263	181	22	15	3	1	ND	ND	4	<1		8.1	8.2	23		
DCR (mid)	318		25		2		<1		6	<1		8.5	6.3	14		
DCR (deep)	351		22		1		ND	ND	5	<1		8.8	4.3	11		
Sampling Date: 10/4/83																
Provo R. Upstream	218	178	27	27	4	4	ND	ND	8	4		7.7	9.8	13		
Main Ck.	390	222	26	26	2	2	<1	<1	3	2		8.0	10.0	12		
Daniels Ck.	323	287	19	19	1	1	ND	ND	5	2		8.2	9.4	11		
Lower Charleston Canal	491	149	17	17	2	1	ND	ND	4	3		7.7	8.6	14		
Provo R. Downstream	295	224	24	24	2	2	ND	ND	12	6		7.6	5.0	16		
DCR (surf)	284	270	25	25	2	2	ND	ND	<1	<1		7.9	9.1	13		
DCR (surf)	375	329	29	29	3	2	<1	ND	2	2		8.5	8.6	14		
DCR (surf)	320	300	29	28	2	2	<1	<1	3	3		8.2	8.7	12		
DCR (surf)	299	339	27	27	2	2	ND	ND	<1	<1		8.3	8.7	12		

ND = none detected.

Location	Site	Flow (cfs)	Alk. (mg/l as $CaCO_3$)	OP (µg/l)	TP (µg/l)	NH_3-N (µg/l)	NO_3-N (mg/l)	NO_2-N (µg/l)	TN (mg/l)	TKN (mg/l)	TOC (mg/l)	SOL TOC (mg/l)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)
Sampling Date: 11/5/83															
Provo R. Upstream		276		28	42	<10	0.67	5	0.79	0.12					
Main Ck.		28		26	48	<10	0.73	5							
Daniels Ck.		6		79	95	<10	0.94	6	1.07	0.13					
Lower Charleston Canal		4		101	138	32	2.4	25	2.6	0.19					
Provo R. Downstream		386		17	37	57	0.28	7	0.48	0.19					
DCR (surf)	1			15	26	33	0.26	8	0.48	0.22					
DCR (surf)	3			12	24	26	0.19	7	0.88	0.69					
DCR (surf)	4			21	21	22	0.21	8	0.42	0.21					
Sampling Date: 12/23/83															
Provo R. Upstream		282		40	42	26	0.75	4			1.9				
Main Ck.		30		39	69		0.79	5	0.90	0.11	3.0				
Daniels Ck.		8		106	146	22	0.85	6	1.04	0.19	3.8				
Provo R. Downstream		610		20	44	19	0.64	3			1.0				
DCR (surf)	~ 2			14	21	<10	0.30	2	0.32	0.23	3.2				

Location	$CHCl_3$ (µg/l)	SOL $CHCl_3$ (µg/l)	$CHBrCl_2$ (µg/l)	SOL $CHBrCl_2$ (µg/l)	$CHBr_2Cl$ (µg/l)	SOL $CHBr_2Cl$ (µg/l)	$CHBr_3$ (µg/l)	SOL $CHBr_3$ (µg/l)	TSS (mg/l)	VSS (mg/l)	TDS (mg/l)	pH	DO (mg/l)	Temp. (°C)	Chloride (mg/l)	Sulfate (mg/l)
Sampling Date 11/5/83																
Provo R. Upstream	110	66	23	17	6	5	<1	<1	7	3		7.9	9.6	12		
Main Ck.	152	109	30	26	7	7	ND	ND	9	<1		8.3	9.2	13		
Daniels Ck.	187	170	20	20	3	3	ND	ND	5	1		8.4	9.0	10		
Lower Charleston Canal	180	138	17	17	3	3	ND	ND				7.7	8.5	14		
Provo R. Downstream	243	195	24	24	4	4	ND	ND	11	2		7.8	5.3	14		
DCR (surf)	209	209	24	24	4	3	ND	ND	5	3		7.9	9.1	12		
DCR (surf)	228	215	26	26	4	4	ND	ND	4	3		7.9	9.0	11		
DCR (surf)	230	223	23	23	3	3	ND	ND	4	1		7.9	9.2	11		
Sampling Date: 12/23/83																
Provo R. Upstream	231		21		6		3		9	2						
Main Ck.	295		26		8		ND		31	5						
Daniels Ck.	317		20		4		ND		18	3						
Provo R. Downstream	75		20		9		4		<1	<1						
DCR (surf)																

ND = none detected.

Appendix J

Algal Identification on Samples From Deer Creek Reservoir

Collected August 21, 1983

Table 39. Algal identification on Deer Creek Reservoir samples taken August 21, 1983.

Reservoir Sampling Site	Depth	Algae Genera Present
2	Surface	Chroococcus sp. Oscillatoria sp. Cyclotella sp.
	Middle	Chlorella sp. Centronella sp.
3	Surface	Chlorella sp. Oscillatoria sp. Fusiform diatom Lyngbya
	Middle	Chlorella sp. Oscillatoria sp. Fusiform diatom
4	Surface	Blue/Green Short Filamentous Oscillatoria sp. Cyclotella sp.
	Middle	Chlorella sp. Oscillatoria sp. Centronella sp.