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TRIHALOMETHANE COMPOUNDS AND THEIR PRECURSORS IN SALT LAKE COUNTY

EVALUATION OF TRIHALOMETHANE SOURCE AND PRODUCTION

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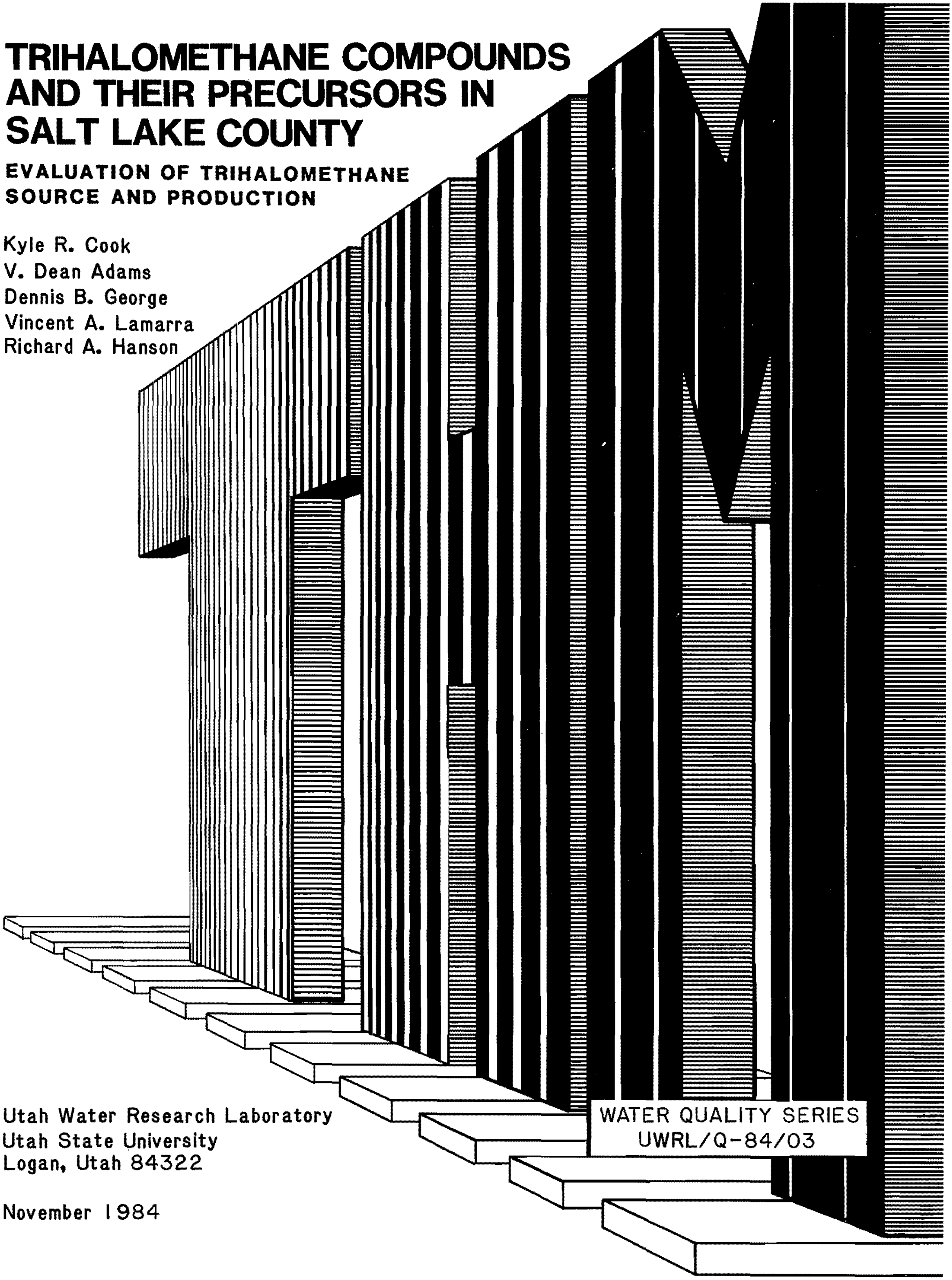

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Trihalomethane Compounds and Their Precursors in Salt Lake County

ABSTRACT

Salt Lake County, Utah, watershed streams, drinking water treatment plants, and distribution system were monitored for a period of one year or greater to determine the seasonal watershed precursor load, trihalomethane (THM) formation, and correlation between the two in the drinking water supplies. In addition, unit treatment processes were examined at Parleys, Big and Little Cottonwood water treatment plants, in the spring and late summer, to evaluate THM precursor reduction and THM formation. Additional studies were also conducted to appraise the potential contribution of natural sources to watershed THM precursor loading. Total organic carbon was used to estimate THM precursor concentrations. Instantaneous (time of sampling) and 7-day (incubated) forms of trihalomethanes were measured.

Stream THM precursor production was greatest during spring runoff; the mean precursor concentration at this time was 3.4 mg/l. Stream discharge and precursor concentration frequently exhibited a linear correlation. High streamflow, as related to precipitation events, produced greater THM formation potential. Rainfall runoff from roads and other disturbed areas provided most of the instream precursor load. Leaf litter and surface soils near streams were shown to be potentially significant sources of THM precursors (leaf litter more than soils).

THM formation at all water treatment plants peaked during March to June and September to October, corresponding to increased runoff in the spring, and precipitation, reservoir turnover, algal blooms, and leaf-fall in the autumn. Utilities using reservoir water had greater (approximately 60 percent) mean annual effluent THM concentrations than those using solely stream water. THMs at all distribution stations averaged less than 40 μg/l (greater than water treatment plants) during 1981. Groundwater had a comparatively small THM formation potential. The USEPA maximum contaminant level of 100 μg/l was never exceeded at any utility or distribution station.

The water treatment plants normally reduced the influent organic precursor concentration by about 30 percent, principally by sedimentation and filtration. Instantaneous THMs generally increased with process time. Precursor and chlorine concentrations governed THM formation after water treatment. Recommendations for long term control of THM formation include source control of surface water organics and nutrients, improving treatment plant efficiency, and minimizing chlorine dosages.

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

INTRODUCTION

Nature of the Problem

Public water supplies have been disinfected prior to distribution in the United States for many years. Chlorine is the most commonly used disinfectant; however, chlorination has come under attack because chlorine can react with organic materials in the water to form trihalomethanes (THMs) and other halogenated organic compounds that laboratory studies have shown to increase the risk of cancer. USEPA promulgated regulations require communities of population 75,000 (and eventually 10,000 or greater) to monitor their water and meet a maximum contaminant level (MCL) of 100 μg/l for total THMs. The available treatment methods, using granular activated carbon filtration or biologically activated carbon, are expensive. Possible less costly methods include alternative disinfectants, improved clarification, altering the point of chlorination, and seasonal use of powdered activated carbon. The best method depends on the local situation.

Salt Lake County, Utah, obtains drinking water from both surface water and groundwater sources. Low turbidity surface water, the major source, originates from mountain streams and is stored in reservoirs. Because their montoring of THM concentrations (Peters 1981) indicated a minor THM problem, County officials, concerned that the USEPA might lower the MCL for THMs, and desiring to deliver a high quality drinking water, wanted a study identifying THM organic precursors and quantifying THM formation between the water source and the consumer tap. They wanted to know the magnitude of the THM problem, the methods best suited for reducing the THM concentration in Salt Lake County's finished water, and what monitoring procedures should be followed in continued observation of precursor loading to protect the public.

Objectives

The research plan to answer these questions was designed to:

1. Determine the seasonal variation of THM precursor concentrations from five Salt Lake County watersheds and two groundwater sources over a 12-month period.

2. Determine the THM formation potential of precursors originating from selected leaf litter and debris and soil samples in the riparian zone.

3. Estimate the contribution to raw water precursor loading from rain and snow events.

4. Continuously monitor and analyze levels of THM compounds in the drinking water supplied to Salt Lake County residents for one year.

5. Correlate the formation of total THMs in finished water with raw water sources and with treatment practices for the major water utilities in Salt Lake County.

LITERATURE REVIEW

Historical Aspects

Studies on New Orleans drinking water by the USEPA in 1972 and 1974 detected traces of suspected carcinogens in the form of THMs. Charges were made (Harris and Breecher 1974) that New Orleans residents were being subjected to a hazard that could cause cancer. The results of the National Organics Reconnaissance Survey (NORS) (Symons et al. 1975) and the National Organics Monitoring Survey (NOMS) (USEPA 1978) also showed widespread occurrence of THMs in chlorinated water supplies. The primary reaction product measured was chloroform. The National Cancer Institute (1976) found chloroform to be a carcinogen to rats and mice under laboratory test conditions.

The result was promulgation by USEPA of regulations on November 29, 1979, limiting the permissible level of THMs in drinking water. A maximum contaminant level (MCL) of 0.10 mg/l (100 μg/l) was established for total THMs (TTHMs), defined as the sum of the concentrations of chloroform ($CHCl_3$), bromodichloromethane ($CHBrCl_2$), dibromochloromethane ($CHBr_2Cl$), and bromoform ($CHBr_3$). Compliance was to be accomplished within 2 years by community systems serving populations greater than 75,000, and within 4 years for populations between 10,000 and 75,000 (Federal Register 1979, 1980).

The available epidemiological evidence was not conclusive, but it did suggest a human health risk. The epidemiological work continued. In a review of the experimental and epidemiologic studies, Kraybill (1981) concluded that, while potential hazards were suggested, cancer causality was not conclusively established. More recently, the American Water Works Association agreed with the USEPA to propose procedures that a community might follow for obtaining and maintaining a variance from the TTHM standard (AWWA Mainstream 1982). The objective was to minimize potentially disruptive but unnecessary economic effects of the TTHM standard on water utilities.

Forming Halogenated Organics

Chemical Reactions

Haloforms (halogenated organic compounds) have long been known to form from acetone and other ketones. Booth and Saunders (1950) reported that haloforms are also formed from such other compounds as substituted quinones, catechol, and resorcinol. THM formation in drinking water was first documented by Rook (1974) and Bellar et al. (1974). According to Rook, THMs produced from chlorination of the humic substances found in natural waters are likely to cause adverse physiological effects.

Rook (1974) found a good correlation between chloroform and water color intensity. The coloration was thought to come from such humic substances of plant decay as macromolecules, the condensation products of quinones and polyhydroxybenzenes with substituent NH_2-groups. Rook's thesis was that the polyhydroxybenzene building blocks of natural color molecules were responsible for the haloform reaction.

Later, Rook (1976) suspected that the organic precursor for the haloform reaction was a substance such as fulvic acids, a component of aquatic humus. He determined that minor amounts of chlorine were substituted into the humic substances. Experiments indicated that the hydroxylated benzene moieties were the most active fulvic acid sites and readily underwent a haloform type of reaction when treated with aqueous chlorine (Rook 1977). Rook hypothesized reaction mechanisms for haloform production from fulvic acids and resorcinol.

A simplified structure of the humus molecule (Trussell and Umphres 1978) was an amorphous mass of polyhetero condensate with certain functional groups (metahydroxy aromatic rings, mono ketone moieties, compounds with or producing acetyl groups) protruding from the surface to react with aqueous chlorine to form THMs. An accepted haloform reaction sequence consisted of alternate hydrolysis and halogenation steps with the first ionization being rate determining. The functional groups mentioned are more rapidly ionized in the first reaction step, which is rate determining, except for the mono ketone moiety--a well-established mechanism in the traditional haloform reaction.

Reinforcing the above ideas, Dore et al. (1982) stated that organic precursors were compounds bearing acetyl groups or those susceptible to forming such groups by oxidation. The beta-diketones and m-polyhydroxybenzenes were excessively reactive precursors for chlorine in the neutral treatment pH range.

THMs have the general form CHX_3, where X can be any one of the halogens, chlorine, bromine, or iodine (Edzwald 1979). Chlorinated forms are the most common but brominated forms also occur. Some researchers have observed that the presence of bromide increased the yield of TTHMs (millimole TTHM/mole total organic carbon) for a given chlorine dose (Trussell and Umphres 1978). Dore et al. (1982), however, did not find the yield to increase. It is generally agreed that the higher molecular weight humic acid fraction results in a greater yield of chloroform ($CHCl_3$) than an equivalent amount of fulvic acid (Babcock and Singer 1979; Peters et al. 1980), but aquatic humus is more commonly present as fulvic acid than as humic acid (Trussell and Umphres 1978).

By examining humic material from various aqueous environments and from laboratory microbial cultures, Oliver and Visser (1980) determined that the major chloroform precursors in aquatic humic materials were the low molecular weight (less than 30,000) fulvic acid fractions and that the chloroform concentration decreased with increasing molecular weight (above 20,000-30,000) for the humic acids. In contrast to these findings, an analysis of Iowa River water showed that 75 percent of the THMs were derived from organics with molecular weights of less than 3000 (humic and fulvic acid fractions) (Schnoor et al. 1979). Oliver and Visser (1980) observed that the most active precursors among the fulvic acids for both river and lake environments was the 1000-10,000 molecular weight fraction. Additionally, in a specific molecular weight fraction, seasonal variations and changing aqueous environments had little effect on chloroform concentrations. Veenstra (1979) concluded from his work on the Iowa River that seasonal variations in the nature of the precursors were the predominant factor in determining the concentration of TTHMs.

Sources of THM precursors include natural organics (aquatic humus), algae, and agricultural runoff. Algal biomass and extracellular products, when chlorinated at relatively high doses (20-50 mg/l), react readily with chlorine to produce THMs (Hoehn et al. 1980) as was also found in studies with cultured algae and natural samples under chlorination conditions more representative of conventional drinking water disinfection (Oliver and Shindler 1980). Finally, algae and extracellular products from culture produced THM concentrations comparable to yields observed from humic and fulvic acids, with maximum concentrations produced during algae growth phases (Briley et al. 1980). Periods of high agricultural runoff in Iowa surface waters were distinctly associated with peaks in THMs (Morris and Johnson 1976). A direct correlation between turbidity and chloroform production was established.

In aqueous chlorination, the competitive reactions for hypochlorous acid, HOCl, are disinfection, production of chloramines, oxidation of reduced inorganics, and formation of THMs or chlorinated by-products (Edzwald 1979). Mass balance studies have shown that most of the added chlorine is consumed in oxidation processes rather than in disinfection and that only minor amounts of chlorine appear to be substituted into the organic precursors (Cotruvo 1981; Rook 1976). THM forms over several days until either the free chlorine is consumed or the precursor material has reacted (Edzwald 1979).

Physiochemical Parameters

The important physicochemical parameters influencing the formation of THMs are pH, temperature, chlorine dose, bromide ion, contact time, and the concentrations and types of organic precursors (Snoeyink and Jenkins 1980; Edzwald 1979). The THM formation rate increases with pH because of the base-catalysis of the haloform reaction (Stevens and Symons 1977) wherein THM can form in the absence of a chlorine residual (Morris and Baum 1978). The chlorinated intermediates that form at low pH hydroloyze to form THMs at higher pH values. Rook (1976) found the reaction rate to be greater at pH 8 to 10 than around pH 7.

More THM forms at higher temperature. Stevens and Symons (1977) reported that approximately twice as much chloroform could be produced when natural waters were chlorinated at 25°C versus 3°C.

A free chlorine residual is necessary for the chlorine to react with organic precursors to yield THMs (Stevens and Symons 1977). The amount of the free chlorine dose influences the ultimate formation of THMs and the reaction kinetics. Higher doses cause formation at a faster rate (Trussell et al. 1979).

The traditional textbook haloform reaction is zero order with respect to chlorine, but this may not hold true for more complex reactions in natural waters (Trussell and Umphres 1978). The following empirical rate equation was obtained for the rate of chlorine consumption for the reaction between chlorine residual and aquatic humus:

$$\ln[Cl_2]/[Cl_2]_o = -k_1[TOC]t$$

The chlorine was assumed not to reduce the total concentration of humic material present significantly. This reaction is first order with respect to chlorine residual (Trussell and Umphres 1978). Assuming that the rate of THM production is related to the chlorine residual to the first power, the equation obtained was:

$$\frac{d\ THM}{dt} = \frac{-d\ TOC}{dt} = k_2[Cl_2][TOC]^m$$

where m is the order of the reaction with respect to the precursor concentration.

Bromide increases the total yield of THMs for a given chlorine dose but reduces the incremental increase per unit increase in the chlorine dose (Minear and Bird 1980). Also, the THMs are more highly brominated (Trussell and Umphres 1978; Edzwald 1979; Dore et al. 1982; Minear and Bird 1980). These effects could be important for water supplies affected by salt water intrusion or withdrawn from groundwater supplies with a high bromide ion concentration.

The THM reaction is very slow in comparison to most other physicochemical processes occurring in a water treatment system. The rate varies with the chemical composition of the water (Trussell and Umphres 1978), but it can continue for days. Reaction-rate curves (THM concentrations versus time) vary with the nature of the precursor and the reaction conditions (Stevens and Symons 1977). The ultimate THM concentration is determined by the longest residence time in the distribution system.

The THM reaction continues until either the free chlorine or the organic precursor is exhausted (Babcock and Singer 1979; Stevens and Symons 1977; Rook 1976). Consequently, the total THM concentration increases with longer contact times between the free chlorine and the organic precursors. In most water treatment systems, either the free chlorine or the precursor eventually becomes limiting and THM formation levels off. Studies have shown increasing concentrations of chloroform as water travels through the distribution system (Brett and Calverley 1979; Harms and Looyenga 1977), but reaction time may not have been the only parameter responsible.

One of the easiest parameters to vary experimentally in a conventional water treatment is the concentration of organic precursor. Rook (1976) found that chloroform production increased linearly with organic matter up to 250 mg/l TOC. Babcock and Singer (1979) supported this finding for humic solutions in the presence of excess chlorine. Results obtained with resorcinol and acetone showed that the quantity of chloroform formed was proportional to the concentration of the precursor and the chlorine dose (Dore et al. 1982).

Methods for Controlling THM Concentration

Since adoption of a maximum contaminant level for THMs by the USEPA, a number of alternatives for complying have been investigated. The four approaches are: 1) altering reaction kinetics by changing the physiochemical parameters, 2) reduction of the organic precursor concentration, 3) a change in disinfectant and 4) treatment to reduce the total THM concentration. Each one can be achieved in several ways.

Altering Reaction Kinetics

Temperature cannot be controlled economically; pH can only be varied within a narrow range (6-8); and chlorine disinfectant concentrations and contact times are limited by disinfection requirements. However, chlorine applications can be set by site specific requirements and varied on a seasonal basis to keep dosages to a minimum.

Organic Precursor Reduction and Removal

Reduction of the organic precursor concentration appears to be the most promising approach (Rook 1976). Organic precursor concentrations can be reduced by adsorption, oxidation, coagulation, direct filtration, reservoir treatment, or watershed management.

Several researchers have shown that synthetic resins and activated carbon can adsorb precursors (Anderson et al. 1981; Reed and Zey 1981; Boening et al. 1980). However, these methods are expensive.

Various chemicals have been studied for precursor concentration reduction via oxidation. Shindala and Mowry (1981) found that adding potassium permanganate ($KMnO_4$) prior to chlorination did not help much. In agreement with this finding, $KMnO_4$ appeared to have a minor effect on the chlorine demand of surface waters at Chapel Hill and Durham, N.C., even at 10 mg/l, in bench-scale tests (Singer et al. 1980). It was concluded that large doses of $KMnO_4$ would be required for effective precursor reduction. In Blanck's work (1979) with full-scale plants and surface waters, $KMnO_4$ pretreatment at a dose of 0.4 mg/l produced a 76 percent THM reduction.

Other oxidants have also been used. In bench-scale experiments, humic acid was added to Kansas River water and treated with the oxidants $KMnO_4$, K_2FeO_4 (ferrate), and H_2O_2 (hydrogen peroxide) prior to chlorination (Voss et al. 1980). Treatment with H_2O_2 at pH 10.3 for 68 hrs resulted in undetectable $CHCl_3$. Untreated river water was then used with shorter contact times and chloroform was reduced by about 80 percent. The optimum pH range was 4 to 10. H_2O_2 is readily available, relatively cheap, and no sludge is produced.

The oxidation of precursors with ozone may also reduce THM formation (Carns and Stinson 1978; Barnett and Trussell 1978). Ozone has been used prior to chlorination to oxidize precursors to CO_2 and water, but the method has not been consistently effective (Rice et al. 1981). In some cases, THM levels increased. It appears that the potential for oxidation of precursors by ozone should be determined for individual water sources. This oxidation process also has the potential to form organic by-products whose health risks are yet unknown (Vogt and Regli 1981). Additionally, organics in the water may be made more biodegradable by ozonation, and this can result in higher microbiological activity in the distribution system (Symons et al. 1981).

One of the most easily implemented and economical methods of precursor reduction is by coagulation. Some research has been done on applications to surface waters. Varying water conditions were used to study the impact of operating variables on Mississippi River water taken near the Minneapolis treatment plant. Organics removal was found to be strongly dependent on the pH and alum dose. A TOC reduction of up to 50 percent was achieved at high alum doses and pH 5.0 (Semmens and Field 1980). Maximum removal required alum doses of up to 100 mg/l. The authors found that organics coagulation and removal occur through several mechanisms and that the process may be quite different under varying pH.

European practices have used a new coagulant, alkaline polyaluminum chloride (APAC), on surface waters for improved precursor removal (Knoppert et al. 1980). Kavanaugh (1978) stated that coagulation may selectively remove THM precursors but an acceptable low residual TOC level may not be achieved economically by coagulation.

Alum treatment followed by direct sand filtration of natural waters removed about two-thirds of the precursors (Oliver and Lawrence 1979). Subsequent chlorination yielded low haloform concentrations. Bench-scale pilot plant filters on synthetic humic waters and Raquette, N.Y., river water gave precursor reductions of 50-60 percent and 40 percent, respectively, as measured by 5-day chloroform formation potential (Scheuch and Edzwald 1981). Direct filtration offers low capital and operating costs and high treatment efficiency.

Watershed and reservoir management practices (drinking water quality source protection) can also reduce organic precursors. The approach is to prevent decomposing organic material from coming into contact with free flowing water and reducing the time of contact (Wilen 1977). This can be accomplished by preventing leaves and other organic material from reaching streams or controlling the organic sediments in reservoirs. The only practical method of leaf control in forested watersheds is conversion from deciduous to coniferous trees. Even this measure has severe drawbacks including soil disturbance and erosion problems from stump removal, management efforts for upkeep, prohibitive costs, and reduced water yield. It has been found that the construction of a small dam above the inlet of a reservoir, with resultant settling pools, collects organic and inorganic materials that otherwise would be transported into the reservoir (Wilen 1977). These materials can be removed with a minimum of nutrient release and without the turbidity and sediment dispersion problems caused by normal reservoir dredging. Reservoir storage capacity is also protected.

Beaver activity is a known cause of color, and thus humic and fulvic acid compounds, in natural waters (Wilen 1977). Beaver dams and/or natural debris cause pooling of stream water and a decrease in the stream gradient. This allows longer contact time between organic debris and water, resulting in greater organic water color production. In a western Massachusetts study (Wilen et al. 1974), beaver control increased the streamflow gradients and reduced organic water coloration in the study watershed.

Construction, vegetation removal, and agricultural activities near stream channels can cause erosion and create sedimentation and nutrient influx to the stream system (Satterlund 1972; Watson et al. 1979; Karr and Schlosser 1978). Many plant nutrients (especially phosphorus) are attached to sediment particles. Erosion control methods and healthy vegetation reduce these nonpoint source loadings of organic precursors and also stabilize the nitrogen:phosphorus nutrient loadings to lakes and reservoirs with the resultant reduction of algal growth, a known precursor source. Treatment of reservoir waters with algicides such as copper sulfate can also inhibit algal growth (Fitzgerald 1963) and thus decrease the amount of potential organic precursors available for THM formation.

Alternative Disinfectants

Disinfectants other than chlorine have been used to reduce THM formation, but many of them have other problems. USEPA THM regulations prohibit the use of chloramines for disinfection except as a chlorine residual for water that already meets the primary drinking water regulations (Federal Register 1979). The use of chloramines (ammoniation) has been shown to reduce THM levels. Duke et al. (1980) found that ammoniation just after prechlorination did not reduce the formation of THMs upon chlorination, but rather it increased THMs from the point of ammoniation on through the distribution system. Rice and Bolding (1981) experimented with ammoniation in advance of chlorination at a full-scale system in Dallas, Texas, and were able to reduce THM formation by 75 percent while maintaining an effluent with no more coliforms than that treated with chlorine alone. Norman et al. (1980) stated that if the chlorine residual was normally hypochlorite ion (high pH), chloramines were an equally effective disinfectant. The chloramine residual is more persistent but needs greater contact time (Trussell et al. 1979). Therefore, modest increases in capital operating costs may result.

Chlorine dioxide (ClO_2) and ozone (O_3) are two disinfectants which do not produce THMs (providing no chlorine is present from the generation of ClO_2). ClO_2 has good biocidal activity over the normal treatment pH range; it can be generated and applied readily; and it produces a residual that can persist through the distribution system (Symons et al. 1981). There are concerns over the possible toxicity of chlorite and chlorate (Edzwald 1979), and the USEPA has recommended that the sum of the residual concentrations of chlorine dioxide, chlorite, and chlorate be limited to 0.5 mg/l in drinking water (Federal Register 1979, 1980). This may preclude ClO_2 use in some cases.

Ozone is an excellent biocide but does not provide residual disinfection protection (Symons et al. 1981; Edzwald 1979). Thus chlorine may be needed to provide a residual for the distribution system. Ozone must be produced at the point of application and the generation equipment is more elaborate than when chlorine is used. It is generally agreed that ozonation of drinking water does not produce THMs (Yapijakis 1978; Kühn et al. 1978). But once produced, THMs are highly resistant to oxidation, even by ozone, one of the most powerful chemical oxidants available (Rice et al. 1981). A major drawback to ozone usage in existing and potential water treatment plants is the high capital costs for ozone installations (Rice et al. 1981).

Trihalomethane Reduction and Removal

Granular activated carbon (GAC) has been shown to adsorb both precursors and THMs in pilot scale operation (Love 1976). In evaluating the treatment of river and reservoir surface waters in full-scale plants, it was found that GAC reduced THMs by 23 to 60 percent but was not cost effective (Blanck 1979). GAC was effective for THM control for short periods of time when treating river water using a filtration/adsorption sequence at two sites (Feige and DeMarco 1980). For longer periods of time, carbon reactivation would be necessary.

Recent work by Anderson et al. (1981) indicated that a powdered activated carbon (PAC) (21.6 mg/l dosage) formulated for precursor adsorption was successful in reducing THM formation to an order of magnitude less than the levels reported by the USEPA. Up to 56 percent less THMs and 54 percent less TOC were obtained at the Kanawha Valley Water Treatment Plant in Charleston, W. Va. Good results require an adequate contact time before prechlorination. An economic analysis was not presented. Sludge disposal was necessary.

Resins have also been studied for THM removal. Symons et al. (1981) reported that both activated carbon and the synthetic resin Ambersorb XE-340 were much more effective for adsorbing the bromine-containing THMs than for chloroform. The resin was more effective for THM removal overall. Other research has also shown the XE-340 resin to have better adsorptive capacity than GAC in raw and finished waters; however, an IRA-904 resin appeared to enhance the reaction of free chlorine with precursors to form haloforms. It is generally agreed that pretreatment should be utilized to reduce organic matter prior to treatment with an adsorbent.

Aeration after chlorination has removed 90 percent of chloroform formed during water treatment (Siemak et al. 1979). Waters high in the bromine-containing THMs were difficult to treat by aeration because of a less favorable Henry's Law constant (Symons et al. 1981). Aeration has traditionally been used for taste and odor control as well as iron and manganese oxidation. To be effective for the removal of volatile organics, the air:water volume ratio must be considerably greater, 20:1 to 30:1 (Edzwald 1979). To remove THMs, aeration would have to follow chlorination. One possibly serious drawback would be the continued reaction of free chlorine residual with precursors, in the distribution system, to form additional THMs (Siemak et al. 1979). Precursors are not removed by the aeration process. Some studies have indicated that the air stripping process may be considerably less expensive than GAC treatment (Symons et al. 1981; Kim and Stone 1979). Ari and Crittenden (1981) however, maintain that GAC treatment costs could be lowered considerably through the use of various configurations of multistage adsorbers.

The point of chlorination can be adjusted to lessen THM formation. Shindala and Mowry (1981) found that post-chlorination of Pearl River, Miss., water reduced THMs at the plant, but the 7-day THMs were still high. At the Huron water treatment plant in South Dakota, Harms and Looyenga (1977) concluded that post chlorination reduced the amount of chlorine used and possibly ultimate THM formation. Chlorination after settling reduced, but did not eliminate, THMs (Trussell et al. 1979) because they can still form in the distribution system. When raw water was transported from the reservoir to the treatment plant, the chlorine dose could be reduced to 1 mg/l. The lower dose reduced THMs and still controlled organism growth (Knoppert et al. 1980).

RESEARCH PROCEDURES

Watershed Characteristics

The City Creek, Red Butte, Parleys Canyon, and Big and Little Cottonwood Creek watersheds supply water to Salt Lake County. Figure 1 shows the locations of the watersheds and their respective water treatment plants. The Deer Creek Reservoir watershed, also supplying culinary water to the Little Cottonwood Water Treatment Plant, was not included in the study because of travel and budget constraints.

Most of the runoff from these watersheds occurs during the spring and early summer as a result of melting winter snowpacks. Low flows occur during late summer, fall, and winter (U.S. Forest Service 1979). All five streams are generally well within the State of Utah water quality classification of Class C water (irrigation, stock, fish culture, recreation except swimming, industrial, and municipal after complete treatment). Their chemical characterizations, however, vary widely. Water in Little and Big Cottonwood Canyons is soft to moderately hard and the water in the remaining three streams is classified as hard. Little and Big Cottonwood Canyons are producers of waters with low concentrations total dissolved solids (120 to 187 mg/l) while the others produce higher concentrations (272 mg/l in City Creek). Stream pH varies from about 7.4 in Big Cottonwood Creek to 8.0 in Red Butte.

Bacteriological characteristics also vary widely from stream to stream because of differences in land uses. All five streams have low levels of total coliforms, primarily because of strict waste disposal practices. People in the watersheds are required to use vault storage for sanitary wastes other than kitchen and shower wastes (Hydroscience 1976). Water quality, hydrologic, and land use characteristics for the watersheds are given in Tables 1 to 4, respectively.

The geologic structure of the study area in the Wasatch Mountains is extremely complex. The rock formations are, for the most part, sedimentary strata which have been subjected to thrust faulting, folding, and complex faulting. There are also igneous rock intrusions.

City Creek Canyon

City Creek Canyon is a mountainous watershed with a moderately peaked hydrograph (significant soil contact time). It is forested with a mix of coniferous and deciduous trees. The canyon contains outcrops of poorly consolidated sandstone, limestone, and water-laid tuff. City Creek is a primary water supply for the Salt Lake City Water Department (SLCWD). No cabins, overnight camping, or permanent residences are allowed. Public use of the canyon is restricted to hiking, picnicking, and hunting. The public has unrestricted summer use of the lower portion of the canyon (cars by permit). The watershed is closed to the public during the remainder of the year for all uses except hiking and limited vehicular access during hunting season. The flow is a low turbidity, pristine water suitable for drinking. In recent times, the microbiological quality of the canyon waters has been deteriorating. Increased levels of coliforms have been associated with periods of heavy use and construction activities.

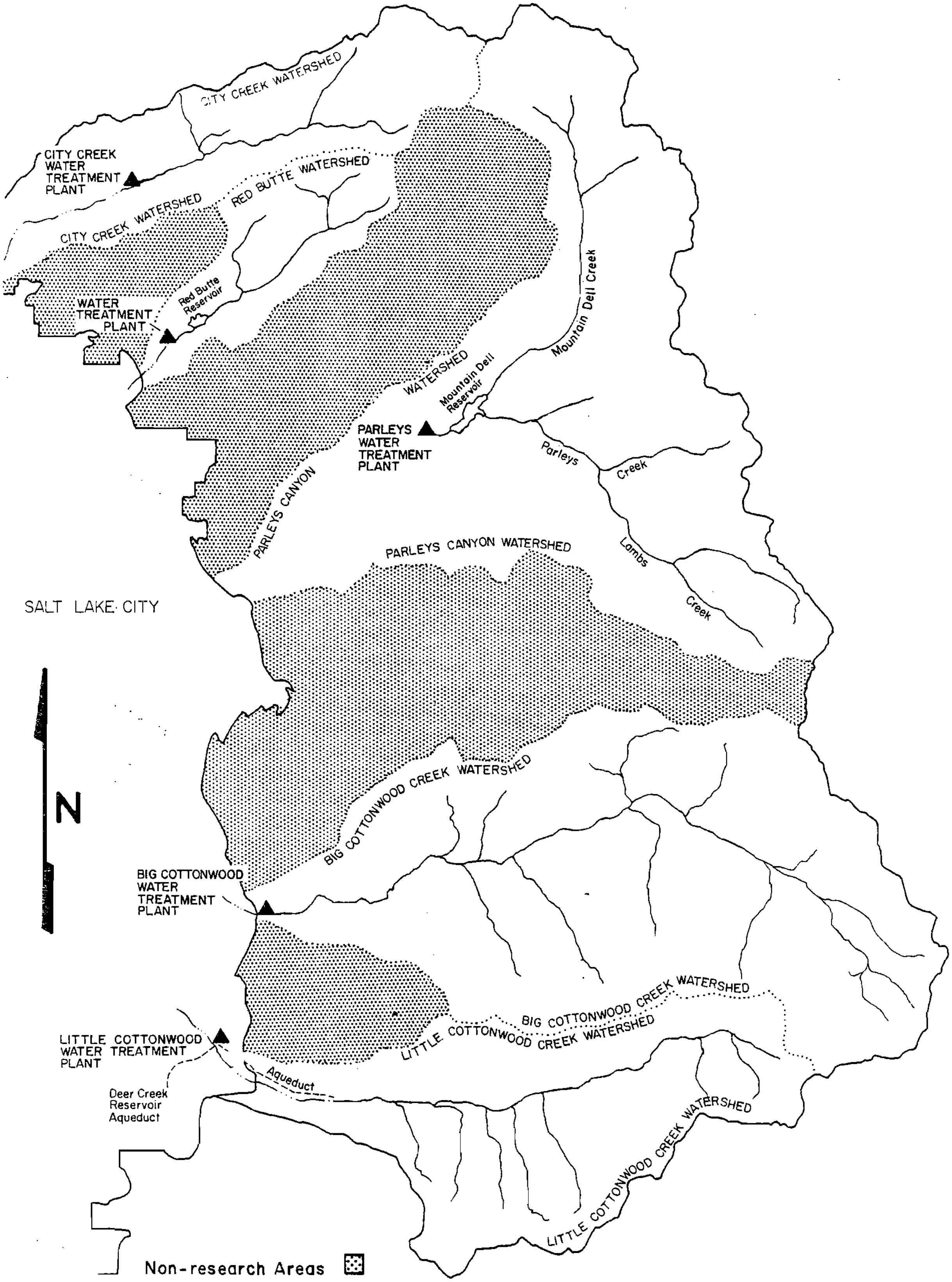

Figure 1. Location of Salt Lake County watersheds and water treatment plants.

Table 1. Chemical quality of water from seven Wasatch streams, 1964-68 water years (U.S. Forest Service 1979).

	Little Cottonwood Creek	Big Cottonwood Creek	Mill Creek	Parleys Creek	Emigration Creek	Red Butte Creek	City Creek
Mean discharge, in cubic feet per second	67.8	73.8	13.6	13.5	6.14	3.34	6.01
Silica (SiO_2) (mg/l)	6.4	6.7	8.3	12	15	11	11
Calcium (Ca) (mg/l)	27	40	82	79	90	76	66
Magnesium (Mg) (mg/l)	5.8	13	26	24	27	28	18
Sodium (Na) (mg/l)	6.6	6.9	7.2	26	30	22	12
Bicarbonate (HCO_3) (mg/l)	77	142	231	263	287	286	263
Sulfate (SO_4) (mg/l)	30	36	120	80	107	94	17
Chloride (Cl) (mg/l)	7.5	10	9.1	38	38	14	23
Nitrate (NO_3) (mg/l)	0.8	0.4	0.3	1.2	0.9	0.4	0.1
Dissolved Solids (mg/l)	120	187	380	401	464	393	272
Tons per acre-foot	0.16	0.25	0.52	0.54	0.63	0.53	0.37
Tons per day	21.5	36.6	14.0	14.5	7.67	3.51	4.41
Hardness as $CaCO_3$							
Calcium, Magnesium (mg/l)	91	153	312	296	334	305	239
Noncarbonate (mg/l)	28	37	122	80	100	70	23
Sodium adsorption ratio	0.3	0.2	0.2	0.6	0.7	0.5	0.3
Specific conductance, in micromhos per centimeter at 25°C	202	319	576	647	727	621	481
pH	7.4	7.8	7.8	7.7	7.8	8.0	7.6

Notes: Sampling points are at canyon mouths, except for Red Butte Creek where the sampling point is above Red Butte Reservoir.

Discharge: Combined flow (creek channel and diversion) for Little Cottonwood, Big Cottonwood, and Mill Creeks; and residual flow (excluding diversions to Salt Lake City water supply) for Parleys, Emigration, and City Creeks.

Sodium and potassium: Calculated and reported as sodium.

Dissolved solids: Determined as residue on evaporation at 180°C.

Table 2. Bacteriological analysis of seven Wasatch streams for the years 1965 to 1976 (U.S. Forest Service 1979). (Total coliform/100 milliliters of water.)

Month	City Creek		Red Butte		Emigration		Parleys		Mill Creek		Big Cottonwood		Little Cottonwood	
	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range
January	3.60	0-240.0	6	--	1190	660-2260	20.4	0-920.0	138.9	0-2400	42.97	0-240	21.22	0-240
February	39.5	0-240.0	1	--	1827	430-7900	22.3	0-540	141.8	5-1600	29.88	0-130	15.47	0-130
March	38.5	0-350	-	--	1197	200-4200	38.6	0-540	117.1	2-1600	39.27	0-240	35.32	0-240
April	63.6	0-540	21	--	623	320-1000	36.5	0-540	310.5	2-3500	48.06	0-540	33.33	0-540
May	72.0	0-920	-	--	425	210-780	46.8	0-920	436.1	2-9200	63.47	0-540	32.6	0-240
June	51.9	0-240	25	--	983	250-1910	19.8	0-920	503.4	8-5400	69.87	0-1600	27.42	0-350
July	201.7	0-2400	80	--	1903	1050-3120	5.9	0-130	1169.9	27-16000	74.7	0-1600	34.99	0-540
August	304.6	0-1600	96	--	3483	860-6200	2.2	0-49	1125.3	30-16000	125.27	0-2400	37.11	0-240
September	167.2	2-1600	32	--	2413	240-6800	0.7	0-23	599.5	8-4600	45.44	0-540	31.42	0-240
October	123.5	0-430	10	--	1365	60-4300	1.9	0-43	325.3	4-2400	47.45	0-930	30.23	0-240
November	85.9	0-430	60	--	1100	190-2950	1.4	0-20	215.4	6-2400	43.0	0-240	42.02	0-920
December	43.8	0-1600	29	--	1195	90-3500	2.9	0-23	134.4	2-2400	39.5	0-280	26.25	0-240
Average	102.4	4.1-355.7	36	--	1475	380-3743	16.6	0-195.0	434.8*	27.6-1242.5	55.78	1.6-621.7	30.61	0.01-169.0
Number of Sample Years	11		1		6		11		11		11		11	

*Average for 1974 was 91.5 and 38.8 for 1975.

Table 3. Summary of hydrologic characteristics, Wasatch Canyons (Hydroscience, Inc. 1976).

Stream	Drainage Area (sq. miles) (sq. kms.)	Mean Elevation (feet) (meters)	Stream Length (miles) (km.)	Stream Slope (ft/ft) (m/m)	Average Annual Precip. (in.) (cm.)	Average Annual Discharge 1930-1972 (cfs)	Average Annual Peak Discharge 1938-1971 (cfs)	Coeff. of Variation of Annual Discharge 1930-1972	Channel Losses 1964-1968 (cfs)	Gaging Station Elevation (feet) (meters)
City Creek	17.7 (45.8)	7070 (2155)	10 (16.1)	0.057	31.5 (80.0)	15.0	63	0.28	--	4800 (1463)
Red Butte Creek	7.3 (18.9)	6700 (2042)	3 (4.8)	0.13	30 (76.2)	--	--	--	--	5400 (1646)
Emigration Creek	18.2 (47.1)	6450 (1966)	10 (16.1)	0.044	28.6 (72.6)	5.60	36	0.54	1.4	4870 (1484)
Parleys Creek	50.7 (131.3)	6960 (2121)	12 (19.3)	0.041	30.8 (78.2)	22.6	113	0.41	2.9	4710 (1436)
Mill Creek	21.7 (56.2)	7950 (2423)	10 (16.1)	0.071	38.0 (96.5)	13.4	56	0.29	2.2	5050 (1539)
Big Cottonwood	50.0 (129.5)	8890 (2710)	13 (20.9)	0.054	44.2 (112.3)	64.5	360	0.22	6.5	4990 (1521)
Little Cottonwood	27.4 (71.0)	9170 (2795)	11.7 (18.8)	0.085	49.5 (125.7)	60.4	384	0.21	6.6	5080 (1548)

Table 4. Summary of use characteristics of Wasatch canyons and creeks (Hydroscience, Inc. 1976).

Canyon	Canyon Use	Water Use
City Creek Canyon	1) Picnicking, Hiking	1) Municipal
Red Butte Canyon	1) Natural Research Area	1) Municipal
Emigration Canyon	1) Year Around Residential	1) None
Parleys Canyon	1) Reservoir 2) Transportation 3) Hiking, etc.	1) Municipal
Mill Creek Canyon	1) Summer Residential 2) Picnicking	1) Irrigation
Big Cottonwood Canyon	1) Residential 2) Skiing 3) Picnicking 4) Hiking, etc.	1) Municipal 2) Irrigation
Little Cottonwood Canyon	1) Skiing 2) Hiking, etc.	1) Municipal 2) Irrigation

Red Butte Canyon

The Red Butte Canyon watershed has similar morphology and vegetation to City Creek. The canyon is closed to the public year round, and serves as a natural research area for environmental studies. Only a few landowners, military personnel, and hunters have access to the area. As a result, the canyon is extremely pristine and the water quality represents natural conditions. The Red Butte Reservoir near the base of the canyon supplies culinary water to the Fort Douglas military reservation. This water is chlorinated and settled in an open reservoir.

Parleys Canyon

Parleys Canyon contains sparse to moderate vegetation and some forestation. Sagebrush, grasses, and deciduous trees dominate Parleys and Mountain Dell Creeks, while conifers are more common in the Lambs Creek watershed. The Parleys Canyon hydrograph is moderately peaked. The canyon is developed in parts and heavily traveled. Mountain Dell Reservoir, located at the confluence of the streams in the canyon, has a storage capacity of 3.95 million m^3, is a primary water supply for SLCWD, and is the site of the Parleys water treatment plant. Below this point, the stream runs through a culvert underneath a freeway that runs the length of the canyon. There are seasonal eutrophication problems in the reservoir. Above the reservoir, are the Mountain Dell Golf Course, adjacent to Parleys Creek, picnic sites on Mountain Dell and Lambs Creek, and limited cabin development on Lambs Creek.

Big Cottonwood Canyon

Big Cottonwood Canyon is very mountainous with moderate to steep slopes and steep rocky walls consisting mainly of exposed rock outcrop with pockets of shallow to bedrock soils. As a result, the runoff hydrograph has a very sharp peak (short water detention time). Predominately coniferous forestation with significant amounts of undergrowth are found. This canyon has moderate to heavy year-round recreational and residential use. Peak use is during July and February. Activities include picnicking, hiking, fishing, camping, hunting, and skiing at Brighton and Solitude ski resorts. As in the other canyons used by SLCWD for domestic water supply, all sanitary waste is stored in vaults or holding tanks. Kitchen and shower waste is sent to a septic tank system although soils are mostly unsuitable for this purpose. The relatively high quality of water at the mouth of this canyon reflects the good wastewater management program, and the geology of firm granitic rock. This water is treated at the Big Cottonwood Creek water treatment plant.

Little Cottonwood Canyon

Little Cottonwood Canyon is extremely mountainous with very steep slopes and geology similar to Big Cottonwood Canyon. It has predominately coniferous forestation. Recreational use is the heaviest of all canyons and includes hiking, rock climbing, fishing, hunting, and skiing at the Alta and Snowbird ski resorts. Very few permanent residences live in the canyon. A pressure pipe sewer carries most of the wastewater out of the canyon. The microbiological water quality of Little Cottonwood Creek deteriorated during the construction of the Snowbird ski resort facility from 1970 to 1973 and has been in a state of transition since. But, even with very intensive winter use, in both Cottonwood canyons, total coliform concentrations have risen very little.

Deer Creek Reservoir

Although not included in the study area, the 18.55×10^7 m^3 Deer Creek Reservoir in the Provo River drainage south of Salt Lake County also provides water to the Metropolitan Water Department after treatment at the Little Cottonwood Metropolitan water treatment plant. This reservoir supports considerable recreational activity during summer months. The valley upstream of the reservoir is heavily developed for agriculture and dairying. Resultant nonpoint nutrient loadings have created eutrophic reservoir conditions (Garner 1982).

Water Treatment Plant Characteristics

Salt Lake City Water Department

Salt Lake City operates three major conventional drinking water treatment plants: City Creek, Parleys, and Big Cottonwood Creek (see Figure 1). Treatment consists of rapid mix, flocculation, sedimentation, rapid sand filtration, and clearwell unit processes. Prechlorination is normally practiced at rapid mix. Occasionally, the treated water is postchlorinated before filtration to maintain an adequate residual throughout the distribution system. A generalized schematic of the treatment processes at the plants is shown in Figure 2. The City Creek water treatment plant has a capacity of 15 mgd (5.7×10^4 m^3/d) and treats City Creek water. The Parleys plant has a capacity of 32 mgd (12×10^4 m^3/d) and treats Mountain Dell Reservoir water (directly above the plant) as its influent source. The Big Cottonwood treatment plant has a capacity of 42 mgd (15.9×10^4 m^3/d) and treats Big Cottonwood Creek water.

Metropolitan Water District of Salt Lake

The Little Cottonwood Metropolitan water treatment plant, located at the base of Little Cottonwood Canyon (Figure 1), serves both Salt Lake City and County. It has a capacity of 100 mgd

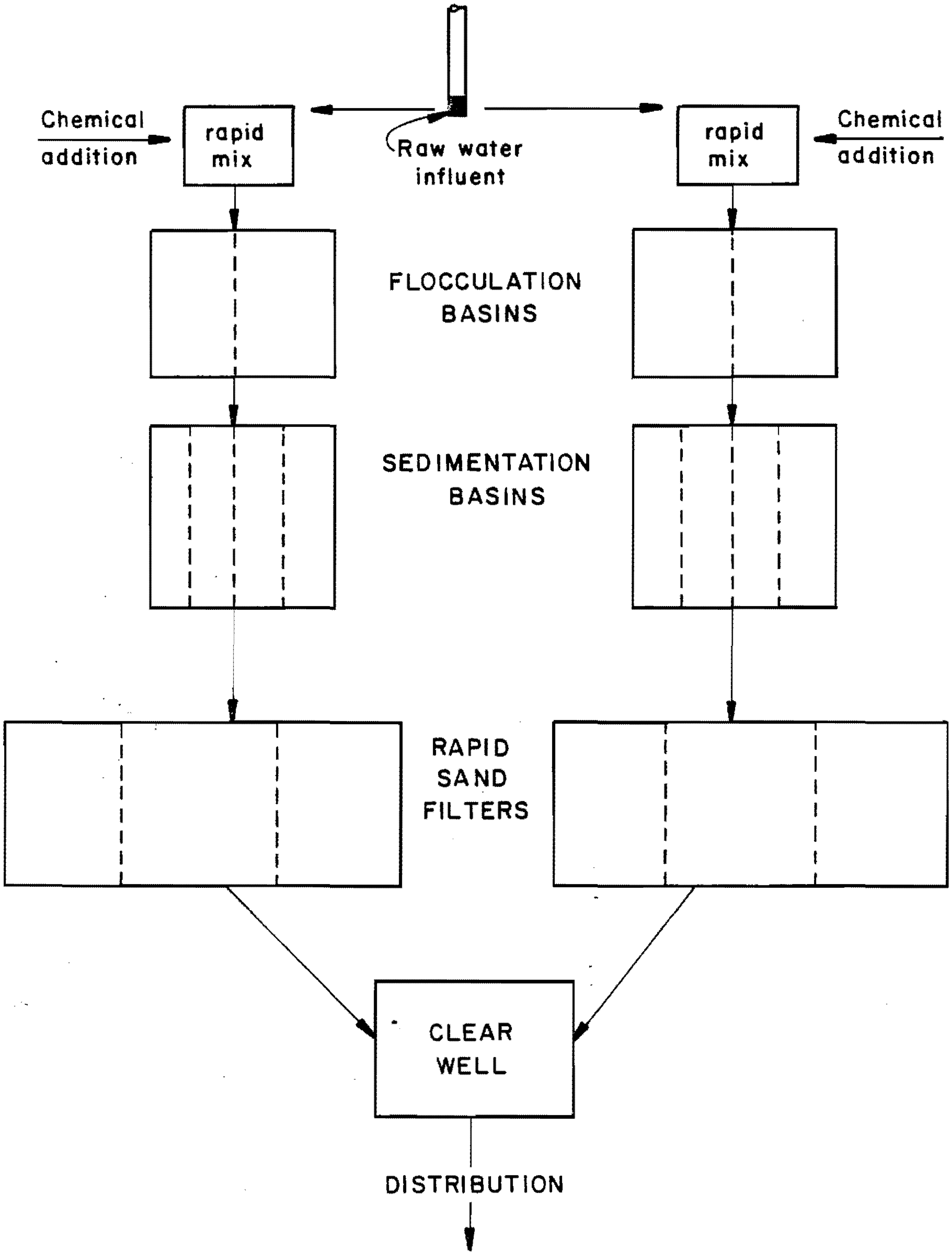

Figure 2. Schematic of generalized processes for the City Creek, Parleys, and Big Cottonwood conventional water treatment plants.

(38×10^4 m^3/d) and receives water from Little Cottonwood Creek and Deer Creek Reservoir. As shown in Table 5, Deer Creek Reservoir accounts for about 65 percent of the treated water annually with heaviest use occurring in the winter, summer, and fall seasons. This water is delivered via aqueduct to the treatment plant and is normally chlorinated at the reservoir outlet (0.5 mg/l chlorine) to control bacterial growth during transport. The water treatment processes are similar to those employed at the city treatment plants, but there are also aeration basins prior to the rapid mix and a potassium permanganate ($KMnO_4$) feed at the raw water influent (Figure 3). $KMnO_4$ is applied to reduce taste and odors during problem periods. Minor amounts of chlorine are added at the rapid mix to control algal and bacterial growth during treatment. Post-chlorination is used prior to filtration to maintain a residual.

Analytical Methods

The waters were analyzed for: trihalomethanes (THMs); total organic carbon (TOC); free and combined chlorine residuals; pH; temperature; and turbidity. In addition, water flow was measured.

THMs at the part per billion (µg/l) level were measured using a Tekmar LSC-1[1] liquid sample concentrator (purge and trap) followed by a Hewlett Packard[2] 5750 gas chromatograph with a Ni63 electron capture detector. TOC at the part per million (mg/l) level was measured with an Oceanographic International[3] oxidation infrared total carbon analyzer. Total and free chlorine residuals were measured with a Hach[4] DPD colorimetric comparator kit in the field, and a Wallace and Tiernan[5] amperometric titrator in the water treatment plants. A Corning Model 130[6] digital display meter with a

Table 5. Percentages of Little Cottonwood Creek and Deer Creek Reservoir influent waters treated during 1981 and 1982 at the Little Cottonwood Metropolitan Water Treatment Plant.

	Deer Creek Reservoir		Little Cottonwood Creek	
Seasonal	1981	1982	1981	1982
Dec.-Feb.	68%	64%	32%	36%
Mar.-May	50%	48%	50%	52%
Jun.-Aug.	68%	66%	32%	34%
Sep.-Nov.	69%	75%	31%	25%
Annual	66%	65%	34%	35%

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[1] Tekmar Company, Cincinnati, OH.

[2] Hewlett Packard, Avondale, PA.

[3] Oceanographic International, College Station, TX.

[4] Hach Company, Loveland, CO.

[5] Wallace and Tiernan, Belleville, NJ.

[6] Corning Glass Works, Corning, NY.

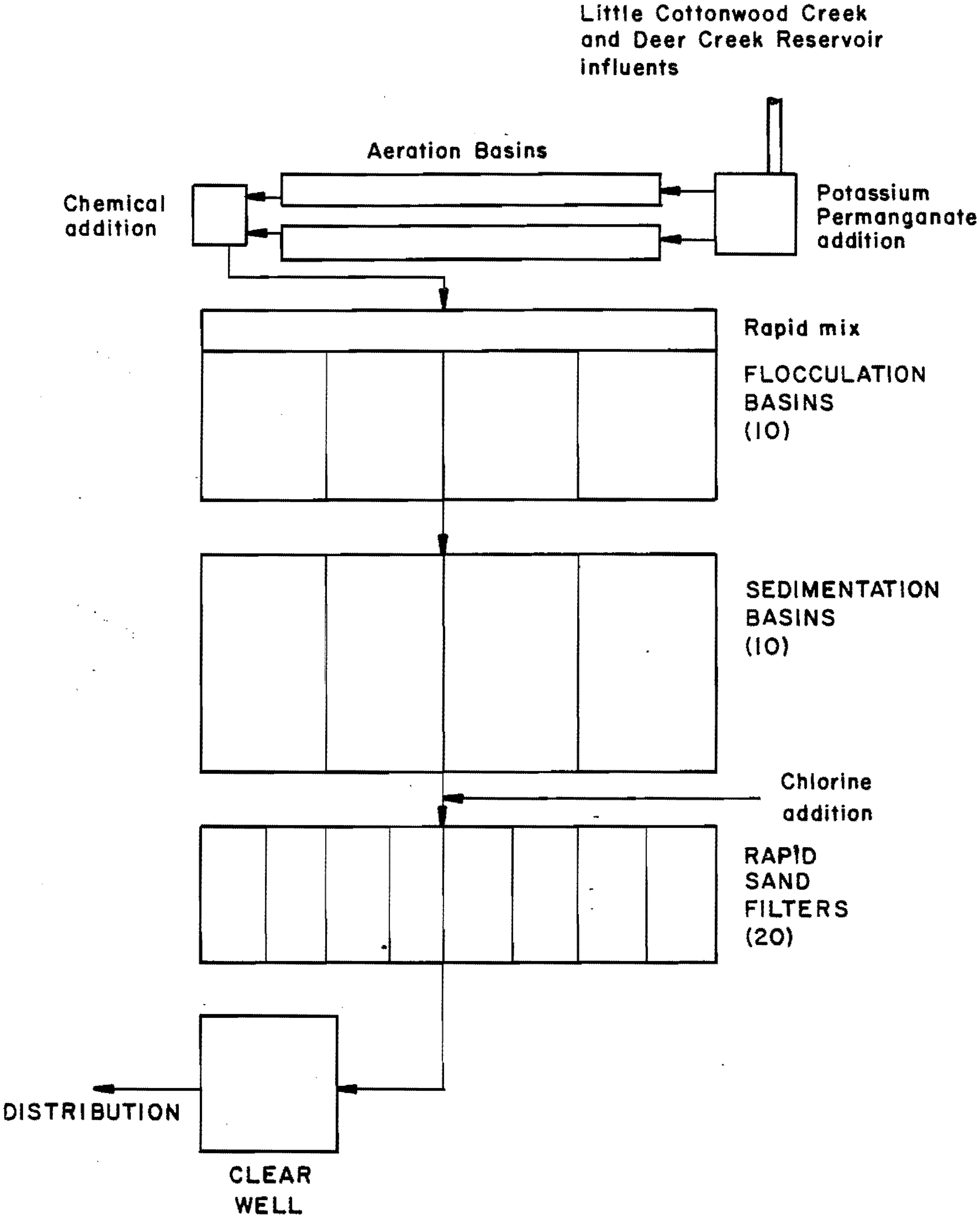

Figure 3. Schematic of processes for the Little Cottonwood Metropolitan water treatment plant.

calibrated standard glass electrode was used for pH measurements. Turbidity was measured as Nephelometric Turbidity Units (NTUs) in the laboratory with a HACH Model 2100A turbidimeter. Streamflow velocities were taken with a Marsh McBirney[7] pressure sensitive current meter.

The TOC measurement was used to estimate THM organic precursor concentrations. TOC has been used extensively as the best single parameter for prediction of trihalomethane levels (Trussell and Umphres 1978; Stevens et al. 1976; Schnoor et al. 1979). TOC samples were collected in acid washed glass bottles with aluminum foil seals, preserved at pH 2 with phosphoric acid and cooled at 4°C. Samples were sonicated to break up any particulate matter and three replicates of each sample were analyzed. All samples were analyzed within 7 days.

Trihalomethane samples were collected and analyzed according to USEPA regulations (Federal Register 1979), except for the addition of ascorbic acid to quench chlorine for instantaneous THM measurement (Kissinger and Fritz 1976). Further information on the trihalomethane analysis can be found in Peters et al. (1981).

Definitions

THM measurements include instantaneous, terminal, formation potential, and maximum potential. All THMs are measured as is the arithmetic sum of all four forms ($CHCl_3$, $CHBrCl_2$, $CHBr_2Cl$, $CHBr_3$). The measurements are defined as:

1. Instantaneous THM (inst-TTHM) is the THM concentration at the time of sampling.

2. Terminal THM (term-TTHM) is measured from a sample stored at 25°C for seven days before analyzing in order to allow complete THM formation.

3. THM formation potential is the difference between terminal and instantaneous THMs.

4. Maximum THM potential (MTP) is measured from a sample which is chlorinated with excess chlorine, usually 15 mg/l, and stored at 25°C for 7 days in order to allow maximum precursor reaction with the free chlorine.

Total THMs (TTHMs) is the arithmetic sum of all measured THM forms ($CHCl_3$, $CHBrCl_2$, $CHBr_2Cl$, $CHBr_3$).

Quality Assurance

The Utah Water Research Laboratory certified its trihalomethane analysis with the state and USEPA in March of 1980. USEPA and internal quality control audits were conducted at the laboratory during this study to maintain certification and substantiate the accuracy of the analysis. Quality assurance data may be found in Appendix D.

Sample Collection and Treatment

Watersheds

To determine the seasonal variation of THM precursor concentrations from the five Salt Lake County watersheds, sampling stations were established at locations upstream and downstream of known land uses, stream tributaries, and potential areas of water pollution. The stream sampling locations are presented in Figure 4. Water temperature, TOC, and streamflow were measured on three consecutive days quarterly (November, February, May, August) during 1980-81 at the primary watersheds (Parleys, Big and Little Cottonwood) and two consecutive days three times a year (November, May, August) for the secondary watersheds (City Creek and Red Butte) for a one year period. In addition, monthly data were collected from Parleys watershed and analyzed for the same parameters, for correlation to concurrent reservoir sampling in the

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[7] Marsh McBirney, Gaithersburg, MD.

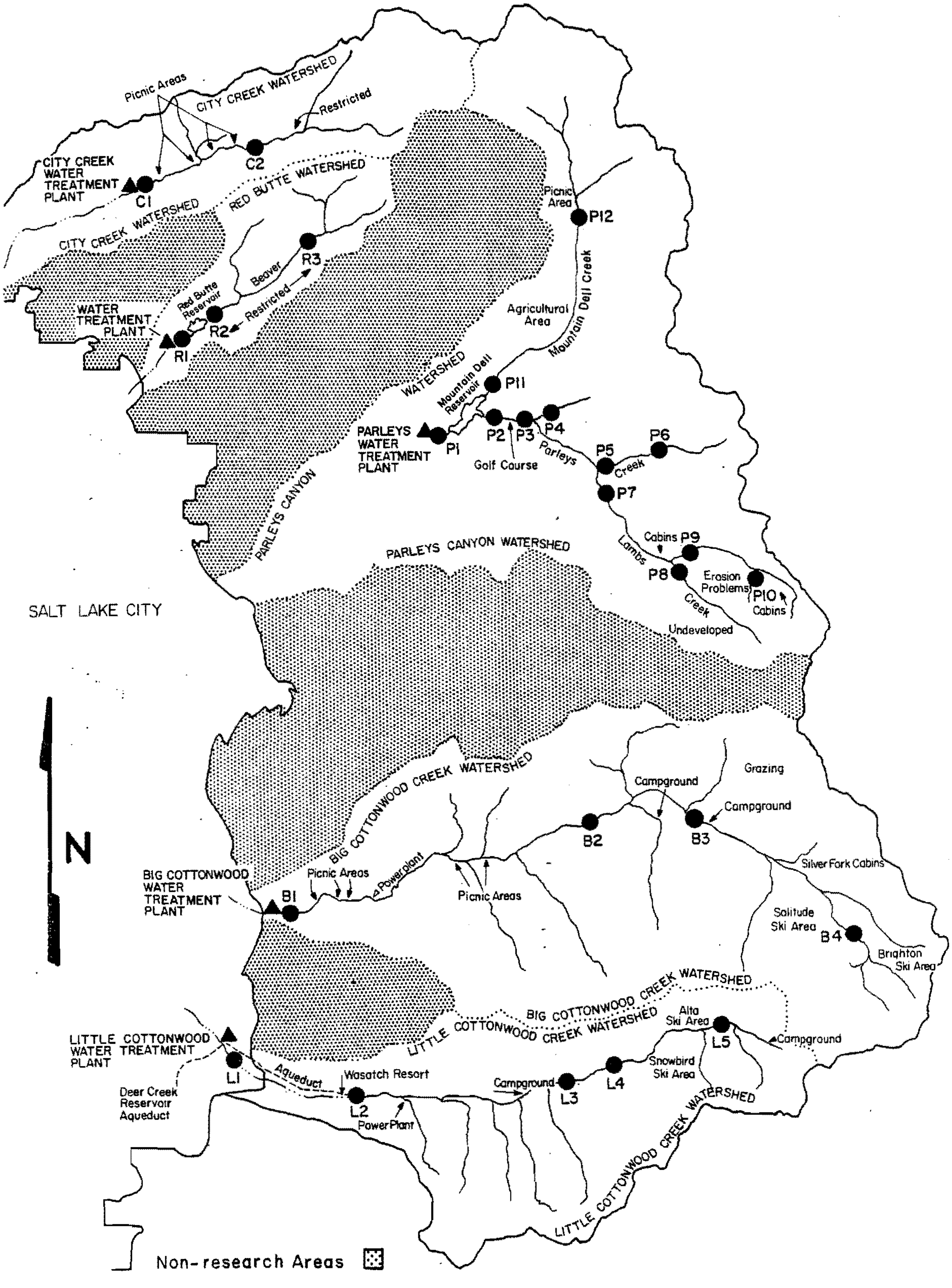

Figure 4. Stream sampling stations on the Salt Lake County watersheds.

area. Existing gaging stations were used where possible for streamflow measurements. When gaging stations were not available, man-made structures or natural stream channel cross sections were used. Grab samples were collected in the zone of complete mixing. Additional sampling stations were utilized as needed according to supplement the preliminary results.

Groundwater

Groundwater sources from selected deep and shallow wells in the Salt Lake County valley were also examined. Grab samples were collected in the spring and late summer to correspond to high and low water table elevations. These were analyzed for TOC and inst-TTHM, and maximum THM potential (MTP) to determine their contribution to the trihalomethane problem. Refer to the section on water treatment and distribution for the well locations.

Surface Runoff and Stormflow

Two approaches were used to estimate precursor loading during rain and snow events. First, surface runoff collection stations, utilizing specially designed collectors, (Figure 5) were located at potential runoff source areas such as agricultural, urban, sparsely vegetated, and recreational, on Parleys, Big Cottonwood, and Red Butte watersheds (Figure 6). These areas were considered to be indicative of the five watersheds being evaluated. The flow rate was estimated from the volume of runoff water collected over a measured period of time, and TOC was measured to approximate total precursor mass contributed to the receiving stream from each run-off area. Second, grab samples were obtained from the mouths of Big Cottonwood Creek at site B1 and the mouth of Little Cottonwood Creek at site L1 (Figure 4) during rainfall events and analyzed for TOC, MTP, and turbidity. Attempts were made to sample during surface runoff periods.

Mountain Dell Reservoir

Additional sampling was conducted at Mountain Dell Reservoir on August 1, 1981. The objective was to measure the distributions of precursor and TTHM concentrations at different depths and to compare the results with measurements from stream sampling. Water is released from the reservoir through a multi-level outlet works to the Parleys water treatment plant. The reservoir is dimictic and exhibits weak summer stratification in the main basin (Hanson et al. 1983). Morphological characteristics of the reservoir and contributing streams are given in Table 6.

Water temperatures in the reservoir at the time of sampling were between 11

Table 6. Morphological characteristics of Mt. Dell Reservoir and the major creeks in the watershed (Hanson et al. 1983).

Mt. Dell Reservoir	
Drainage basin	130.8 kilometers^2
Surface area (max.)	0.34 kilometers^2
Volume (max.)	3.95 x 195 meters^3
Depth (mean)	11.8 meters
Depth (max.)	30.5 meters
Mean retention time	0.16 years
Parleys Creek	
Drainage area	58.0 kilometers^2
Mean flow	0.314 meters^3/sec
Dell Creek	
Drainage area	48.2 kilometers^2
Mean flow	0.337 meters^3/sec
Lambs Creek	
Drainage area	24.6 kilometers^2
Mean flow	0.171 meters^3/sec

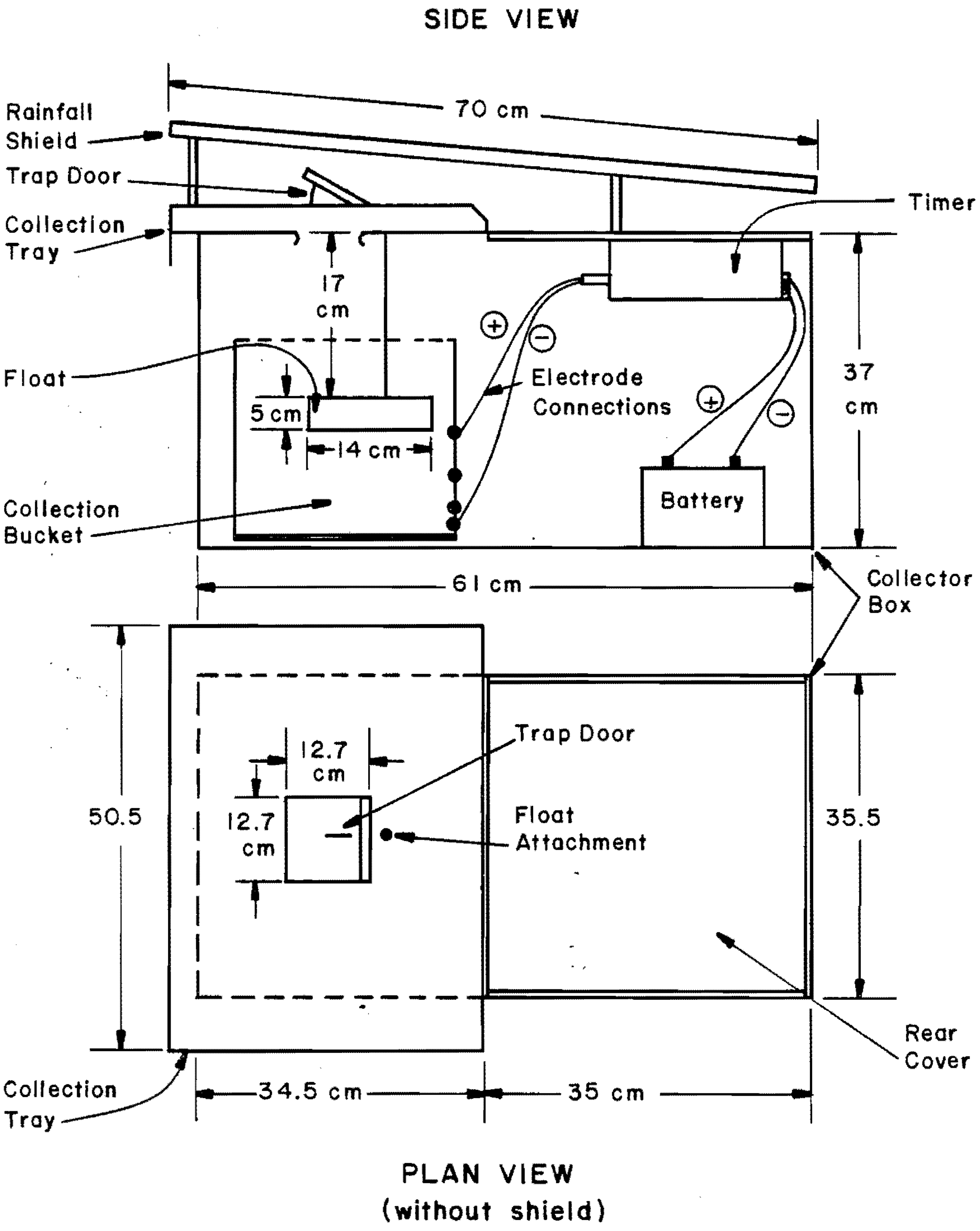

Figure 5. Schematic of surface runoff collector and apparatus (George and Cook 1981).

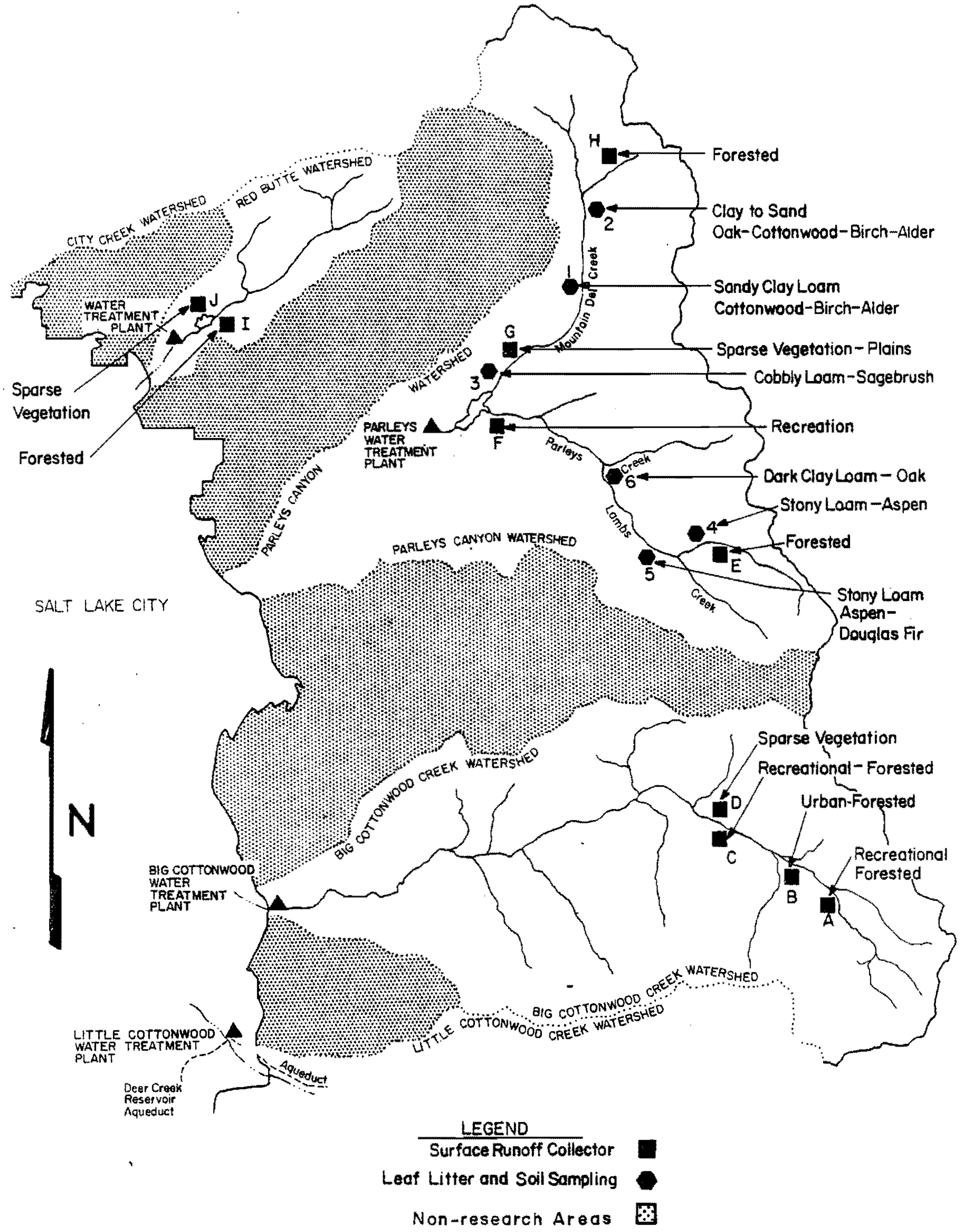

Figure 6. Surface runoff collection and leaf litter and soil sampling sites on the Salt Lake County watersheds.

and 20°C, close to the July maximums (see Table 7). The temperature data in Table 7 for site C indicate that the reservoir was approaching fall turnover (homogeneous temperature with depth) but temperature stratification still existed (Hanson et al. 1983). TTHM concentrations from reservoir treated water had been shown to increase during this time period (Peters et al. 1981), presumably due to increased temperatures and greater biological activity.

Grab samples were collected at 3 meter depth intervals from the water surface to the bottom with a Van Dorn depth sampler. Additional grab samples were collected at the gaged stations on Mountain Dell and Parleys Creeks (reservoir influent streams), stations P11 and P2 respectively, and at the Parleys water treatment plant influent and effluent. Reservoir and stream samples were measured for TOC, temperature, pH, and MTP. Treatment plant samples were measured for the same parameters and term-TTHM instead of MTP.

Leaching

Parleys Canyon watershed was sampled for selected leaf litter and soils in the riparian zone, and these sources were evaluated to determine their potential for contributing THM precursors. Sampling locations were selected to represent the observed major vegetation types of the watershed (Figure 6). The size and number of samples were selected to be representative of the sample area. Leaf litter was gathered by hand, and a 6 inch deep surface soil core sample was collected. All samples were cooled to (4°C) until processed.

Once in the laboratory, soil and leaf litter were oven dried at 105°C, crushed, and weighed into flasks. The leaf litter samples were buffered at approximately pH 8 with sodium bicarbonate because large amounts of leaves fall directly into the stream, which is a buffered system. Soil samples were not buffered. Millipore reagent grade water was used as the leaching solution. The leaching ratios were 2 gm leaf litter into 200 ml water (1:101) and 20 gm soil into 200 ml water (1:11). All samples were placed on a shaker at 100 rpm for 24 hours at room temperature. The leachate was then prepared for analysis by filtering it through washed and muffled GF/C glass fiber filters. An appropriate dilution was made for the TOC analysis, and a buffered (to standardize samples for later comparison) dilution was made for THM analysis. THM vials were chlorinated and stored following the MTP procedure.

Water Treatment and Distribution

To monitor the exposure of Salt Lake County residents to THM compounds, ten samples from the county distribution system, nine influent and effluent samples at the water treatment plants, and two samples from a storage reservoir were collected monthly for a 1-year period. Figure 7 shows the locations of the sampling stations listed in Table 8.

The City Creek, Parleys, Big and Little Cottonwood water treatment plants were sampled at approximately the same time of day each month. Distribution and reservoir samples were analyzed for inst-TTHM, free and total chlorine residuals, and temperature. Treatment plant measurements were inst-TTHM, term-TTHM, TOC, chlorine residuals, and temperature. Tap water samples collected at distribution stations other than treatment plants were allowed to run for approximately 2 minutes before sampling.

Unit Processes Analysis

To correlate any release of TTHMs in Salt Lake County treatment plant effluent waters with raw water sources and treatment plant practices, the Parleys, Big Cottonwood, and Little

Table 7. Water temperature (°C) for Mt. Dell Reservoir during 1980-1981 (Hanson et al. 1983).

Site and Depth (m)	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
CS	19.1	13.8	6.7	1.0	1.0	0.3	1.5[a]	4.1	12.7	16.2	21.2	19.7	17.8	14.7	7.8
C3	18.7	13.5	6.6	3.0	2.3	1.5		4.3	12.3	14.0	20.2	19.7	17.7	15.0	8.0
C6	18.2	13.5	6.6	3.3	3.3	3.6		4.4	10.1	11.6	15.9	18.3	17.7	15.0	8.1
C9	17.8	13.5	6.5	3.5	3.5	2.6		4.4	9.1	10.3	13.8	16.7	17.7	15.0	8.1
C12	17.6	13.4	6.5	3.6				4.2	8.0	9.6	11.9	15.4	17.2	14.7	8.0
C15	17.4	13.3						3.6	6.9	9.2	11.0	14.4	17.1	14.7	8.1
C18	17.1							3.4	6.2	9.1	10.5	13.4	17.0		
C21	16.0							3.5	6.1	8.9	9.8	11.6			
C24										8.8	9.5				
C27										8.7	9.3				
JS	19.5	13.9	7.5						13.0	16.4					
J2			7.2						12.9	15.4	21.0	20.1			
J3	19.2	13.6	7.2						12.3	14.8	20.2	20.0			
J4									12.0	13.7	18.7	19.8			
J6	18.9	13.1							10.4	11.8	16.0	18.7			
J8									9.7	10.7	14.3	17.3			
J9	18.3								10.3	10.4	13.7	16.7			
J10									9.7	10.1	13.1	16.4			
J12	17.7								8.7	9.8	12.4	15.8			
J15										9.5		14.8			
PS	19.4	14.6							13.3	16.4	20.7	20.0			
PB	19.4	13.8							10.1	11.8	15.4	19.5			
DS	19.5	14.1							13.2	15.8	20.8	19.9			
DB	19.4	14.0							12.2	11.5	15.1	17.8			

[a] Shoreline grab sample

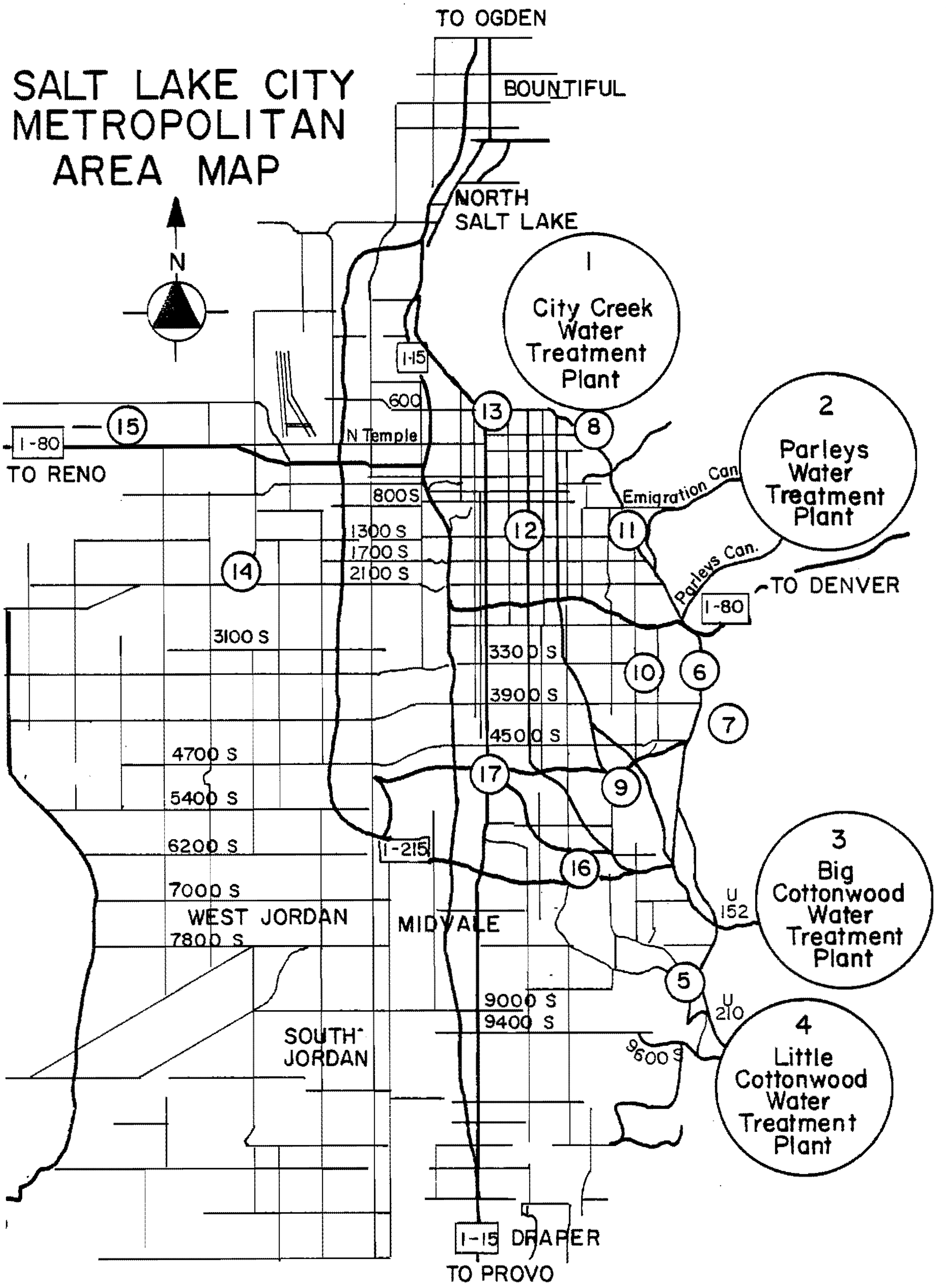

Figure 7. Salt Lake County water treatment plants and distribution system sampling stations.

Table 8. List of Salt Lake County locations sampled from September 1980 to December 1981.

Station Number	Station Location and Description
1	City Creek water treatment plant
2	Parleys water treatment plant
3	Big Cottonwood Creek water treatment plant
4	Little Cottonwood Creek water treatment plant
5	8644 South 3500 East, Residence
6	Salt Lake Metro Water District 33rd South terminal reservoir
7	3616 East Hermes 4135 South, Residence
8	851 East North Crest Drive, Residence
9	2727 East Kentucky, Residence
10	2475 East 3300 South, Residence
11	Bonneville Golf Course
12	Liberty Park, Greenhouse
13	Utah Capitol Building
14	1855 South Industrial Road 1800 West, Business
15	145 Wright Brothers Drive, Salt Lake International Center, Business
16	Groundwater Well 1656 (deep), 6475 South 2650 East
17	Groundwater Well 1657 (shallow), 4800 South 900 East

Cottonwood treatment plants were monitored before and after each unit process. The samples were taken during spring runoff and late summer to evaluate critical seasonal and watershed use periods. In addition, water samples were obtained at one product water storage reservoir affiliated with each plant. All samples were grab samples. An attempt was made to perform all sampling during periods of fair weather, and unit processes were sampled based on hydraulic flow time, calculated for the actual flow through the plants, to minimize any precursor loading fluctuations. Analyses included inst- and term-TTHM, TOC, chlorine residuals, pH, and temperature.

RESULTS AND DISCUSSION

Watersheds

The runoff from watersheds contributing to Salt Lake County's surface water supply was studied for the year of 1980-1981. The primary watersheds were Parleys, Big and Little Cottonwood. Secondary watersheds were Red Butte and City Creek. The Red Butte watershed is closed to the general public and was considered a "control" watershed. A map of the study area and a list of sampling stations are presented in Figure 8 and Table 9. The raw data are in Appendix A.

Stream Discharge

Water year 1980-1981 had below normal runoff from watersheds in the Wasatch Mountains. Approximate percentages of normal discharge (25 years of record, 1955-1980) for the watersheds studied were:

Little Cottonwood Creek	98%
Big Cottonwood Creek	79%
Parleys Canyon	65%
Red Butte Creek	56%
City Creek	82%

Plots of monthly flows from the contributing watersheds in Figures 9 to 13 (data from U.S. Geological Survey 1981 and Salt Lake City Water Department 1981) show a general trend of slightly greater than normal discharge in the fall of 1980 and considerably less than normal discharge during spring runoff.

Temperature

Table 10 summarizes the quarterly water temperature data at downstream stations on all streams. Sampling was performed at different times at different stations, but, as much as possible during the same period of the day for a given station on each of the three consecutive sampling days. It was not always possible to maintain the same time schedules from one quarter to the next. Stream temperatures can be affected by the time of day, stream channel characteristics, riparian (stream bank) vegetation, water source, and other factors (Hart 1978). Diurnal maximum and minimum stream temperatures occur during afternoon and early morning periods, respectively. Small, shallow stream channels experience greater water temperature fluctuations than large, deep channels.

In the quarterly samples, the maximum measured water temperature was 17.0°C in Mountain Dell Creek during August. The minimum was 0.5°C in Parleys Creek during February. Little Cottonwood Creek had consistently lower water temperatures than did the other streams, except in February, because of its source in melting snow from high elevations. February temperatures were lower for the Parleys Canyon streams than the Cottonwood streams because of earlier sampling times on smaller streams. Also the Parleys Creek temperature was measured below the gaging station, which was ponded and iced.

Table 11 shows monthly water temperatures for the Parleys Canyon watershed. Temperatures dropped to freezing during the winter months and rose to peak levels in July. Temperatures stayed high during summer months and began to decrease in the fall.

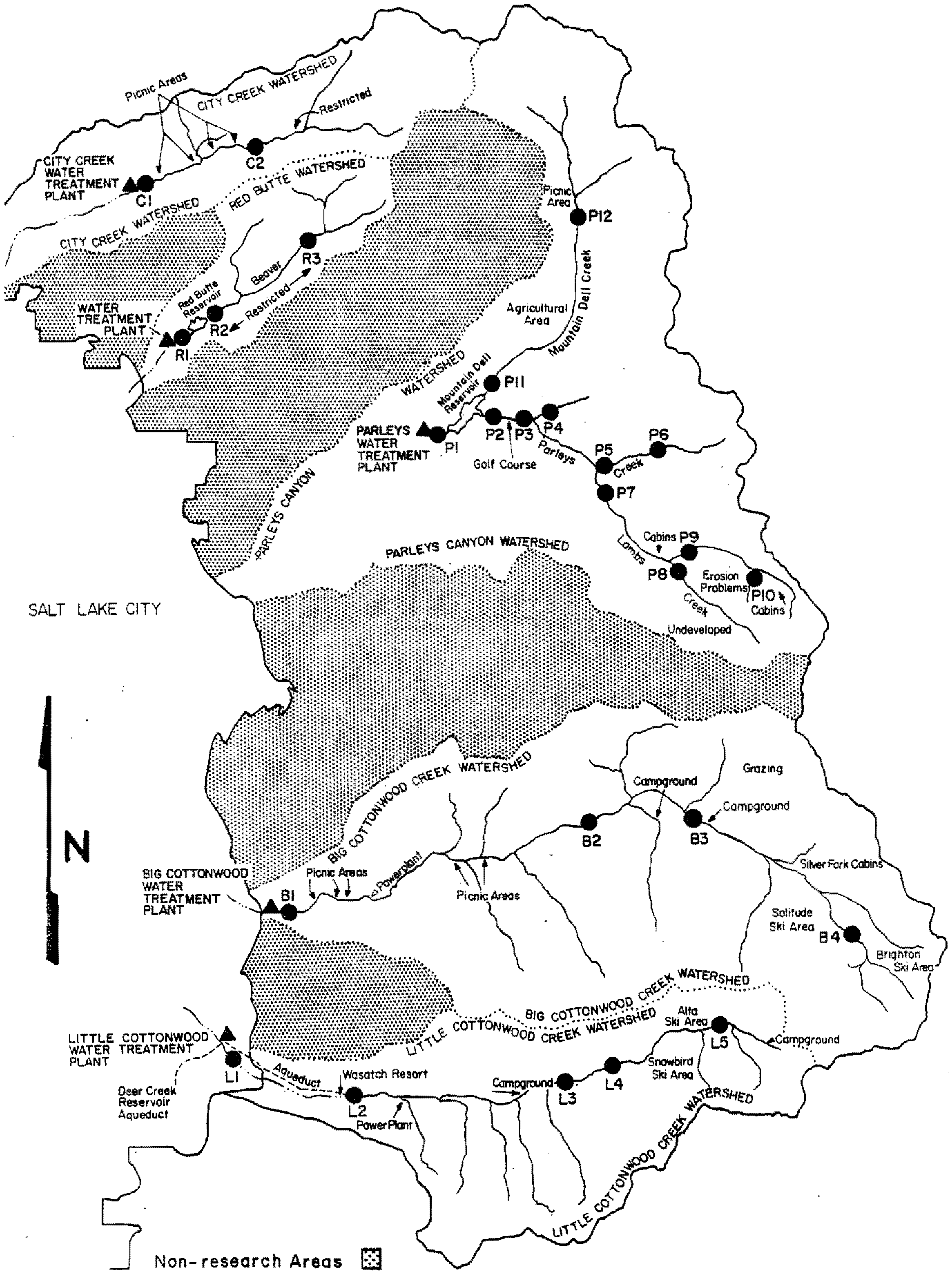

Figure 8. Stream sampling stations on the Salt Lake County watersheds.

Table 9. List of Salt Lake County watershed sampling stations for quarterly and monthly sampling, 1980-1981

Station Label	Station Location and Description
L1	Little Cottonwood Creek at the 15 ft (4.6 m) Parshall flume near Little Cottonwood treatment plant
L2[a]	Little Cottonwood Creek at Wasatch Resort aqueduct intake to Little Cottonwood treatment plant (aqueduct gaged)
L3	Little Cottonwood Creek at the Whitepine trailhead access (ungaged stream cross section)
L4[a]	Little Cottonwood Creek at the Snowbird Gad parking lot (ungaged culvert)
L5[a]	Little Cottonwood Creek at Alta near the ski jump, upstream from the main lift area (ungaged culvert)
B1[a]	Big Cottonwood Creek at the 20 ft (6.1 m) Parshall flume near Big Cottonwood treatment plant
B2[a]	Big Cottonwood Creek at the Argenta 12 ft (3.7 m) Parshall flume
B3[a]	Big Cottonwood Creek just downstream from the Spruces campground (ungaged stream cross section)
B4[a]	Big Cottonwood Creek at the Alpine forest camp (ungaged culvert)
P1	Parleys water treatment plant--influent
P2[a]	Parleys Creek at the stilling well gage upstream from Mountain Dell Reservoir
P3	Alexander Creek near its confluence with Parleys Creek (ungaged stream cross section)
P4	Parleys Creek at the upstream end of Mountain Dell Golf Course (ungaged stream cross section)
P5[a]	Parleys Creek just upstream from the Lambs Creek confluence (ungaged stream cross section)
P6[a]	Parleys Creek about 1 mile (1.6 km) upstream from site P5 (ungaged stream cross section)
P7[a]	Lambs Creek about 1/4 mile (0.4 km) upstream from the freeway undercrossing (ungaged stream cross section)

Table 9. Continued.

Station Label	Station Location and Description
P8[a]	Lambs Creek on the south fork near north fork confluence (ungaged culvert)
P9[a]	Lambs Creek on the north fork near south fork confluence (ungaged culvert)
P10	Lambs Creek on an upper north fork tributary (ungaged stream cross section)
P11[a]	Mountain Dell Creek at the stilling well gage upstream from Mountain Dell Reservoir
P12[a]	Mountain Dell Creek about 1 mile (1.6 km) upstream from the Mountain Dell agricultural area (ungaged stream cross section)
R1[a]	Red Butte Creek at the chlorination house below Red Butte Reservoir (gaged)
R2[a]	Red Butte Creek upstream from Red Butte Reservoir at the Parshall flume
R3[a]	Red Butte Creek in the upper section of the canyon at a small research Parshall flume (ungaged)
C1[a]	City Creek immediately upstream from the City Creek treatment plant (gaged)
C2[a]	City Creek about 1/4 mile (0.4 km) past the upper picnic area (ungaged stream cross section)

[a] Stations with complete data for the sampling period.

Table 10. Summary of downstream water temperatures for watersheds sampled quarterly during 1980-81.

	Temperature (°C)						
Date	Little Cottonwood Creek (L2)	Big Cottonwood Creek (B1)	Parleys Creek (P2)	Lambs Creek (P7)	Mountain Dell Creek (P11)	Red Butte Creek (R3)	City Creek (C1)
11/14/80	2.0	3.0	3.0	3.0	4.5	1.5	2.0
11/15/80	2.0	3.0	3.0	3.0	4.5	1.5	2.0
11/16/80	2.0	3.0	3.0	3.0	4.5		
2/21/81	4.0	4.0	0.5	2.5	4.0	-	-
2/22/81	4.5	4.0	0.5	2.0	2.5	-	-
2/23/81	5.0	4.0	0.5	2.5	2.5		
5/23/81	7.0	10.0	13.0	10.5	13.0	15.5	11.0
5/24/81	7.0	9.0	12.5	10.0	13.0	14.0	10.5
5/25/81	8.0	10.0	12.5	9.5	12.0		
8/12/81	12.5	14.0	14.0	13.0	17.0	13.0	12.0
8/13/81	12.5	13.0	15.0	10.0	16.0	14.5	13.5
8/14/81	11.5	12.5	16.0	12.5	22.5[a]		

[a] Questionable value--sampled earlier in the day.

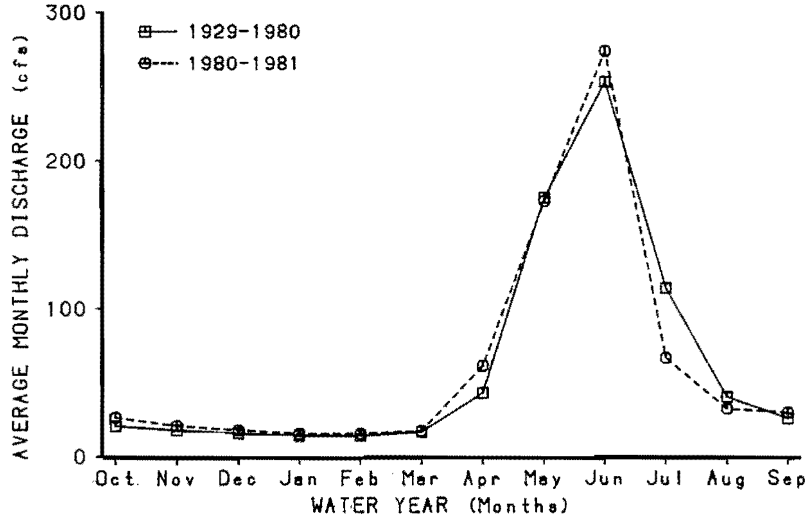

Figure 9. Hydrograph of normal and actual stream discharge for the Little Cottonwood watershed.

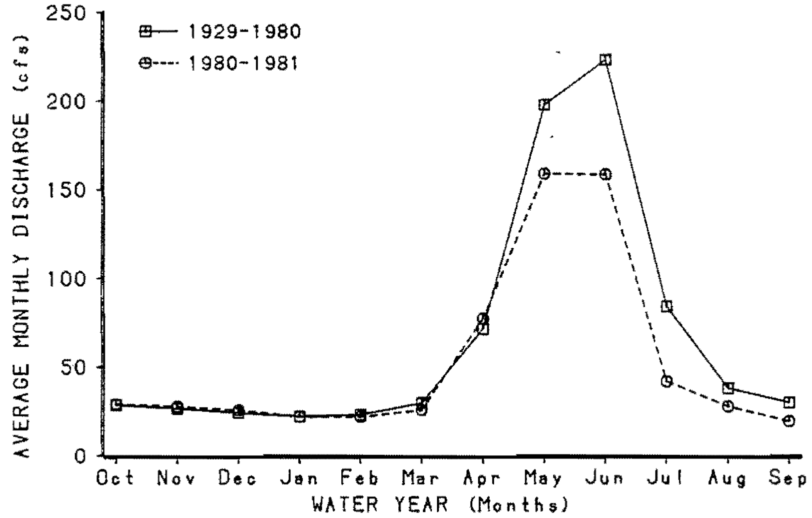

Figure 10. Hydrograph of normal and actual stream discharge for the Big Cottonwood watershed.

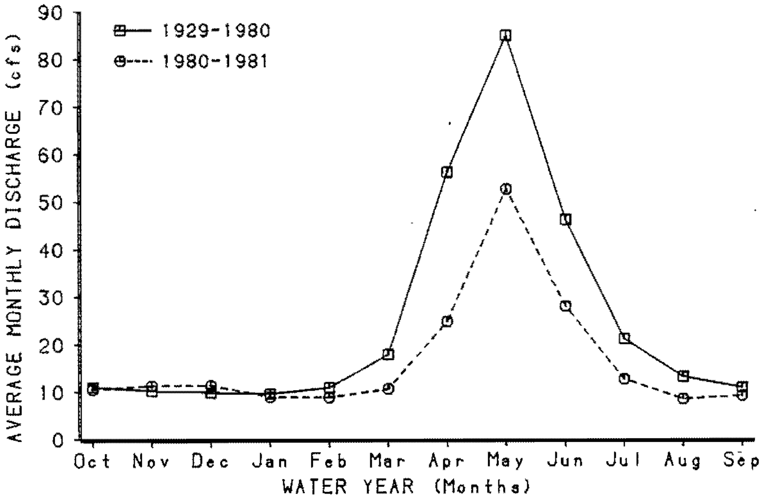

Figure 11. Hydrograph of normal and actual stream discharge for the Parleys Canyon watershed.

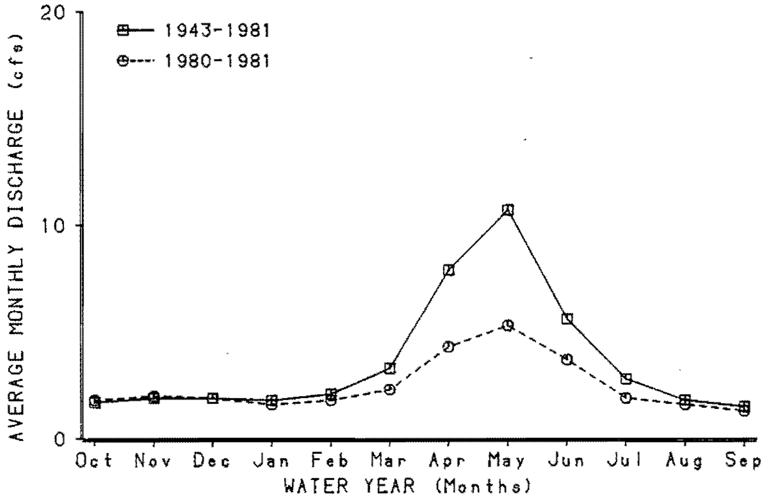

Figure 12. Hydrograph of normal and actual stream discharge for the Red Butte watershed.

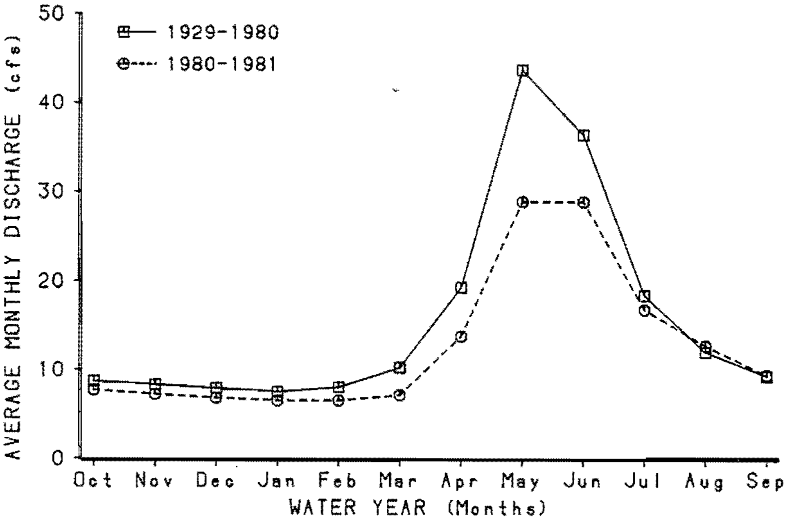

Figure 13. Hydrograph of normal and actual stream discharge for the City Creek watershed.

On February 22, 1981, during quarterly sampling, a 12-hour continuous sampling was performed at the Big Cottonwood Creek water treatment plant near station B1 to evaluate organic precursor concentration fluctuation with time and water temperature. During the 6 AM to 6 PM period, in which sampling was performed at hourly intervals, precursor concentrations expressed as total organic carbon, were within a small range of 0.7 to 1.2 mg/l and did not show a correlation to the time of day.

Organic Precursor Loading

In order to determine the amount of precursor material produced by a stream and to compare amounts among streams, the mass loading must be estimated from the concentration of the parameter and the rate of streamflow. Precursor mass loading per unit time was determined from the mass balance equation (WHO 1978):

$$LOAD = K \cdot C \cdot Q$$

where

LOAD = precursor load in kg total organic carbon/d,

K = a conversion constant (2.4465),

C = total organic carbon in mg/l, and

Q = streamflow in ft^3/s.

The average results and coefficients of variation are shown in Table 12. The time patterns over the year of mean seasonal organic precursor loading for the watersheds are presented graphically in Figures 14 through 20.

Little Cottonwood Creek. Station L2 on Little Cottonwood Creek (Figure 14) had low precursor loadings (Table 12) during November, February, and August (20 to 28 kg/d) but the amount increased to 989 kg/d, during spring runoff. The measured streamflow in May was 63 percent of the average for that month. The other three sampling stations also exhibited high loadings during May. Data for May and August show that loading increased from headwaters to stream mouth (according to station order). During November and February, however, downstream station L4 had greater precursor loadings than

Table 11. Summary of downstream water temperatures for Parleys Canyon watershed monthly sampling during 1980-81.

Date	Temperature (°C) Parleys Creek (P2)	Lambs Creek (P7)	Mountain Dell Creek (P11)
8/28/80	9.0	8.0	10.0
11/08/80	7.5	6.5	8.0
12/11/80	0.5	2.0	0.0
1/10/81	0	0.5	0.0
2/07/81	0	1.0	1.0
3/07/81	2.0	3.0	3.0
4/04/81	2.0	1.5	2.5
5/02/81	-	-	-
6/06/81	9.0	8.0	9.5
7/06/81	12.0	10.0	13.0
8/01/81	10.0	9.0	11.0

Table 12. Summary of mean precursor loading and coefficient of variation for quarterly sampling of contributing watersheds from November 1980 to August 1981 (n=3).

Station	Mean Precursor Load (kg/d) (Percent Variation) November	February	May	August
L1			850.4 (38.8%)	
L2	24.0 (30.8%)	20.5 (22.4%)	989.0 (37.7%)	28.1 (2.8%)
L3			398.0 (27.3%)	13.7 (10.2%)
L4	45.2 (87.6%)	25.7 (59.1%)	144.1 (41.9%)	11.6 -
L5	6.0 (60.0%)	ICED UP -	87.3 (51.5%)	2.2 (22.7%)
B1	33.3 (4.1%)	94.9 (48.4%)	887.1 (15.0%)	60.5 (41.2%)
B2	20.9 (11.0%)	29.6 (56.8%)	335.2 (4.7%)	44.1 (33.1%)
B3	13.4 (42.5%)	23.1 (44.2%)	319.7 (17.7%)	79.7 (45.2%)
B4	4.8 (10.4%)	2.7 (37.4%)	52.7 (9.3%)	39.8 (91.7%)

Table 12. Continued.

Station	Mean Precursor Load (kg/d) (Percent Variation)			
	November	February	May	August
P1	40.3 (41.7%)	20.0 -		68.0 (53.7%)
P2	6.8 (7.4%)	11.0 (30.0%)	200.4 (26.2%)	6.7 (11.9%)
P3			5.9 -	
P4			145.3 (8.6%)	6.3 (20.6%)
P5	1.9 (15.8%)	3.0 (23.3%)	28.5 (11.6%)	4.9 (12.2%)
P6		2.0 (30.0%)		
P7	3.1 (29.0%)	7.9 (32.9%)	122.2 (5.7%)	9.7 (42.3%)
P8	0.5 (20.0%)	1.1 (72.7%)	16.4 (43.9%)	2.7 (7.4%)
P9	1.3 (15.4%)	4.5 (46.7%)	47.7 (24.3%)	7.7 (3.9%)
P10			4.0 (40.0%)	
P11	4.2 (31.0%)	9.9 (4.0%)	257.9 (16.7%)	6.9 (18.8%)
P12	1.3 (30.8%)	3.0 (43.3%)	221.1 (17.3%)	4.0 (25.0%)
R1	1.6 (31.3%)		65.7 (5.8%)	9.4 (3.2%)
R2	2.9 (20.7%)		102.6 (13.9%)	6.8 (23.5%)
R3	1.5 (13.3%)		55.8 (1.6%)	1.3 (30.8%)
C1	8.3 (1.2%)		262.9 -	10.9 (9.2%)
C2	3.4 (2.9%)		141.2 (21.4%)	7.7 (51.9%)

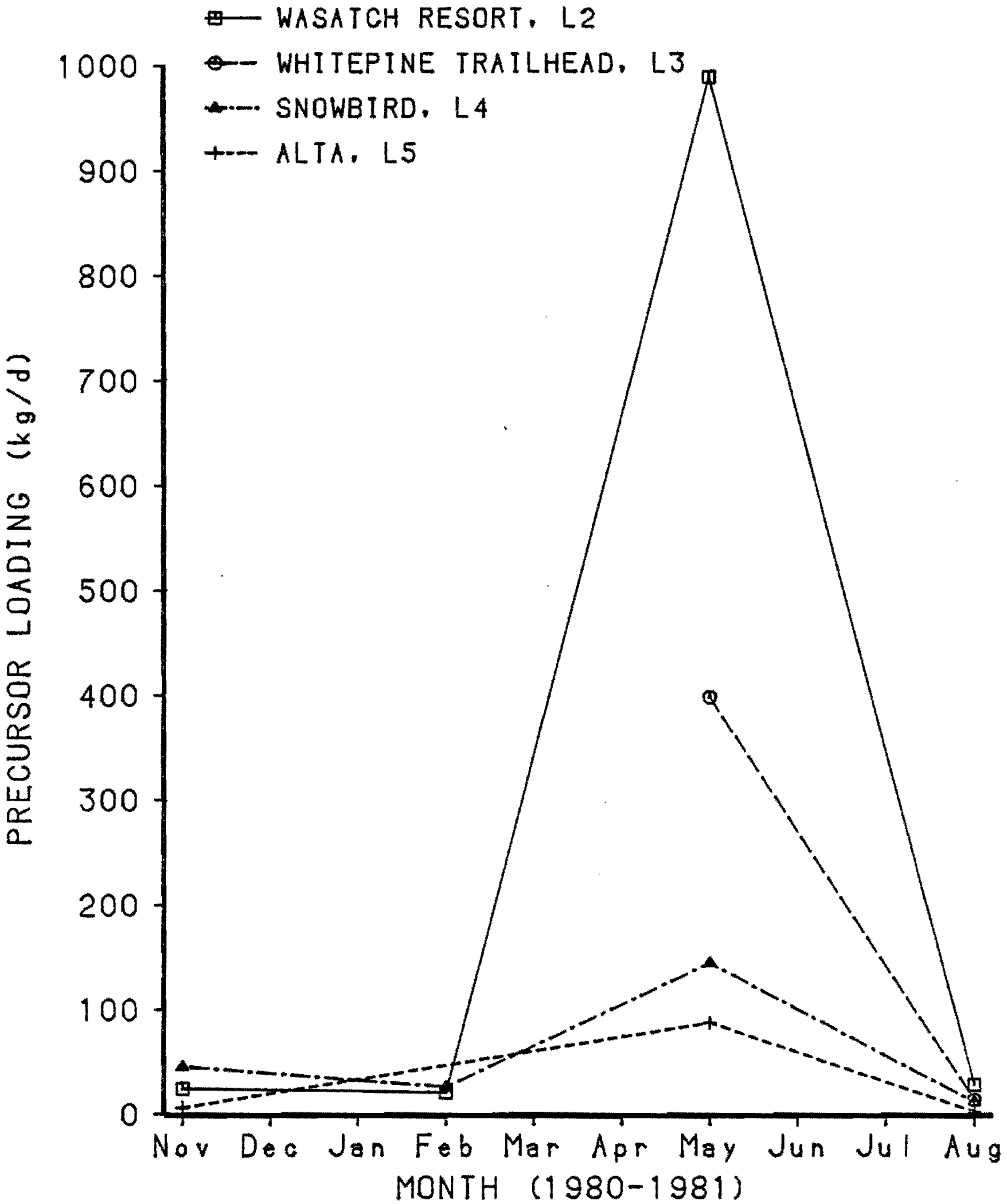

Figure 14. Mean seasonal precursor loading for the Little Cottonwood Creek watershed.

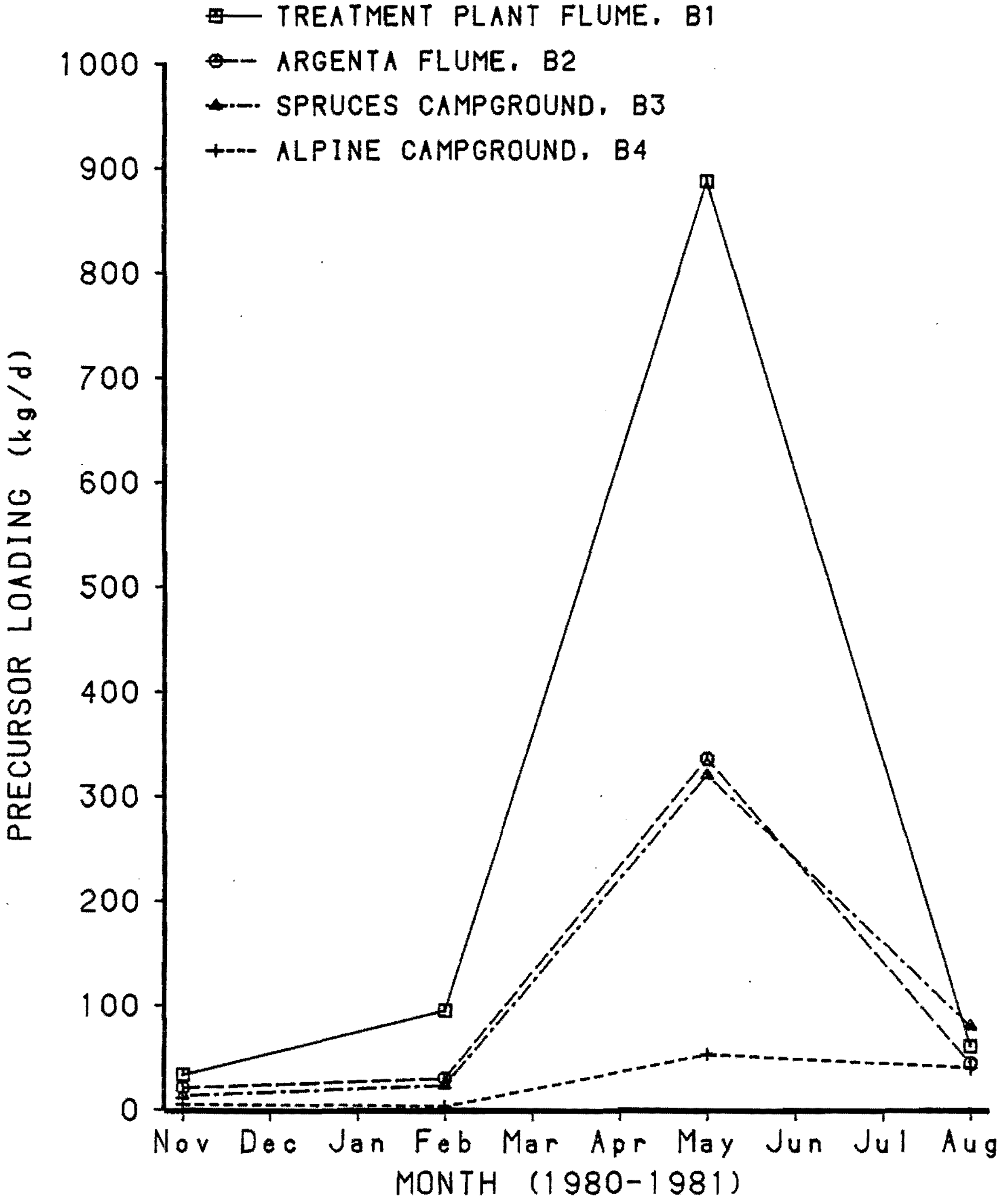

Figure 15. Mean seasonal precursor loading for the Big Cottonwood Creek watershed.

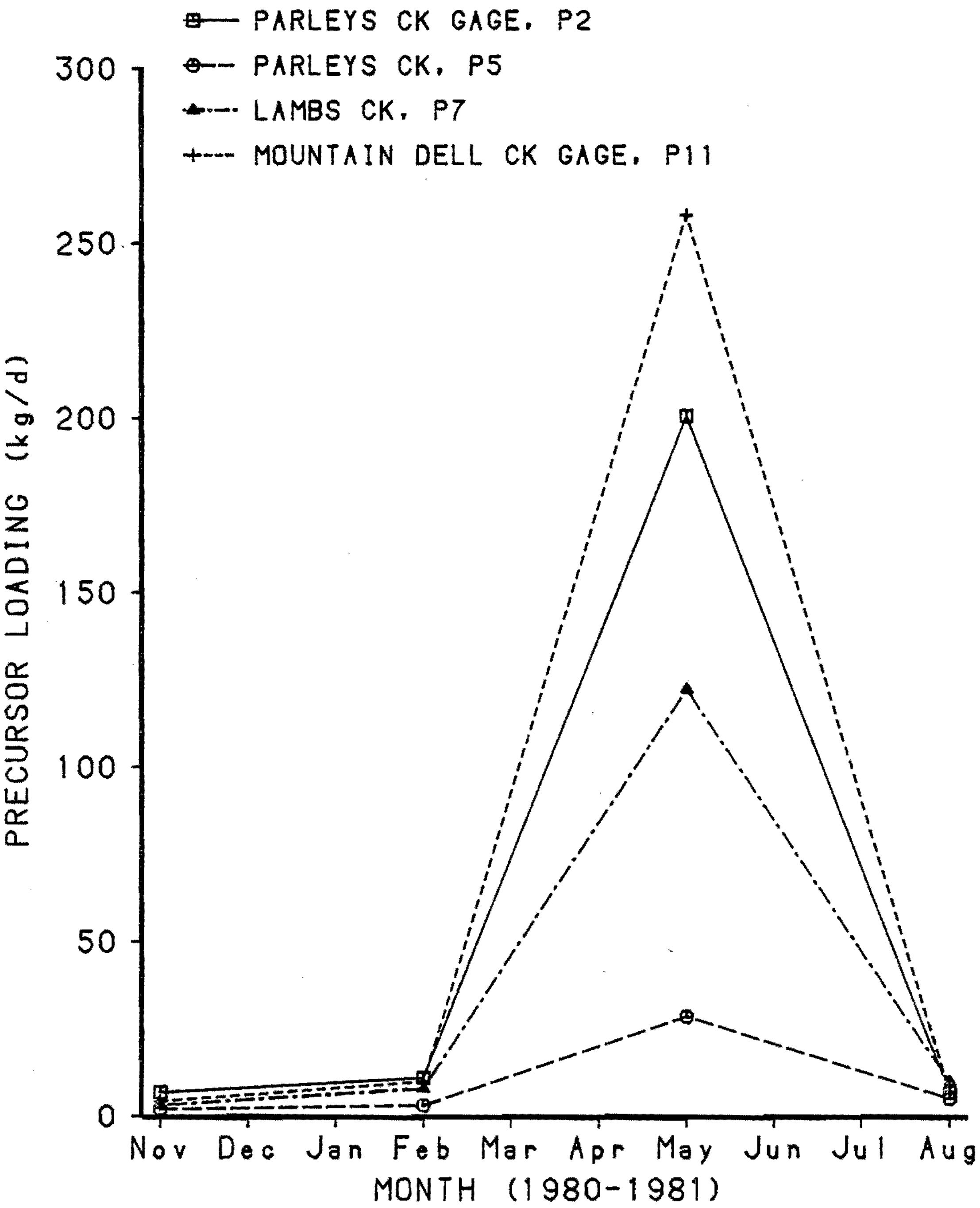

Figure 16. Mean seasonal precursor loading for Parleys Creek.

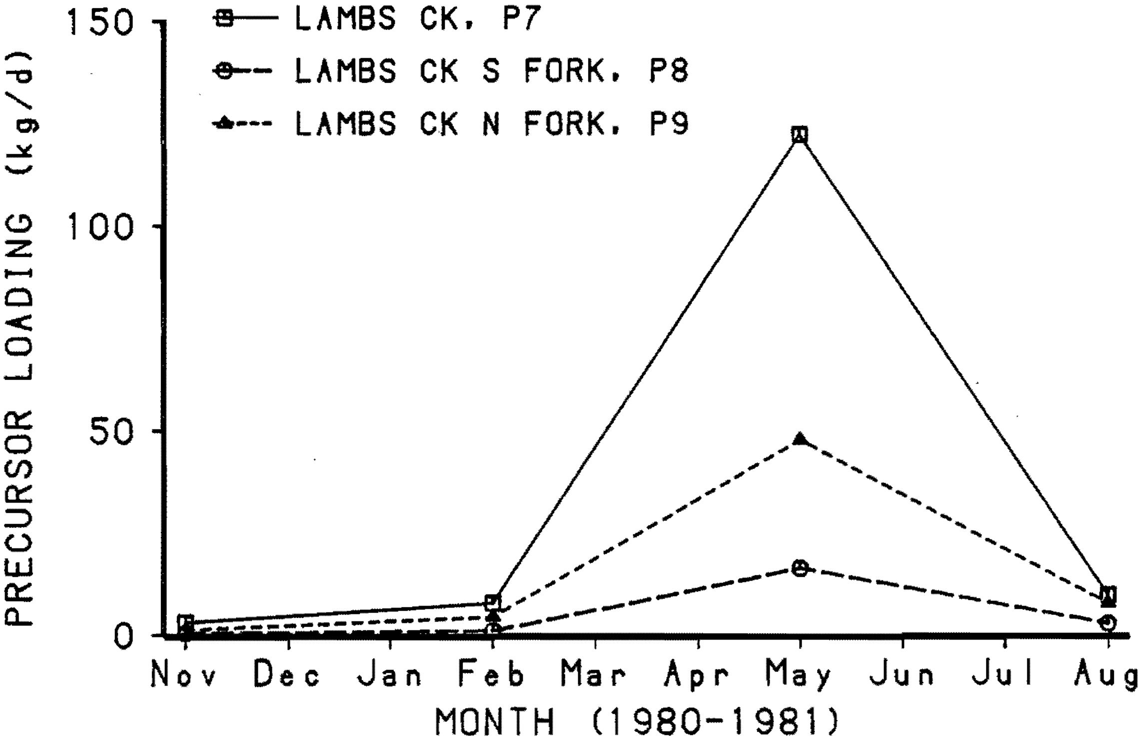

Figure 17. Mean seasonal precursor loading Lambs Creek.

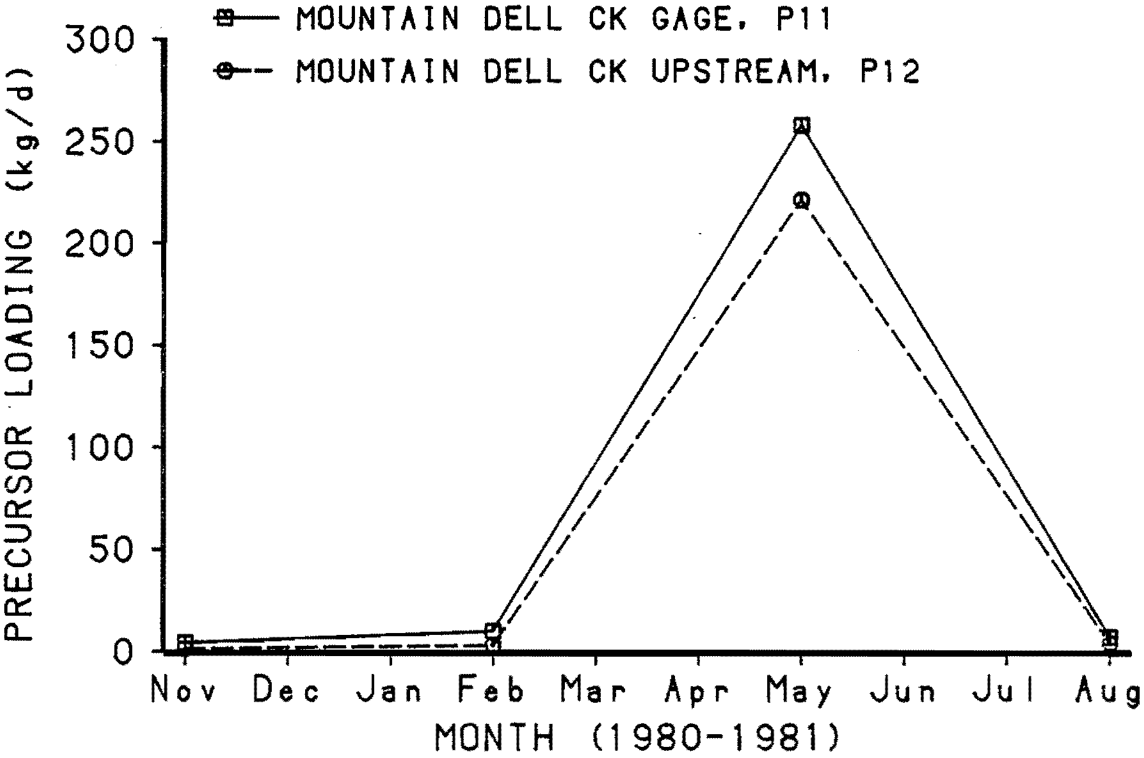

Figure 18. Mean seasonal precursor loading for Mountain Dell Creek.

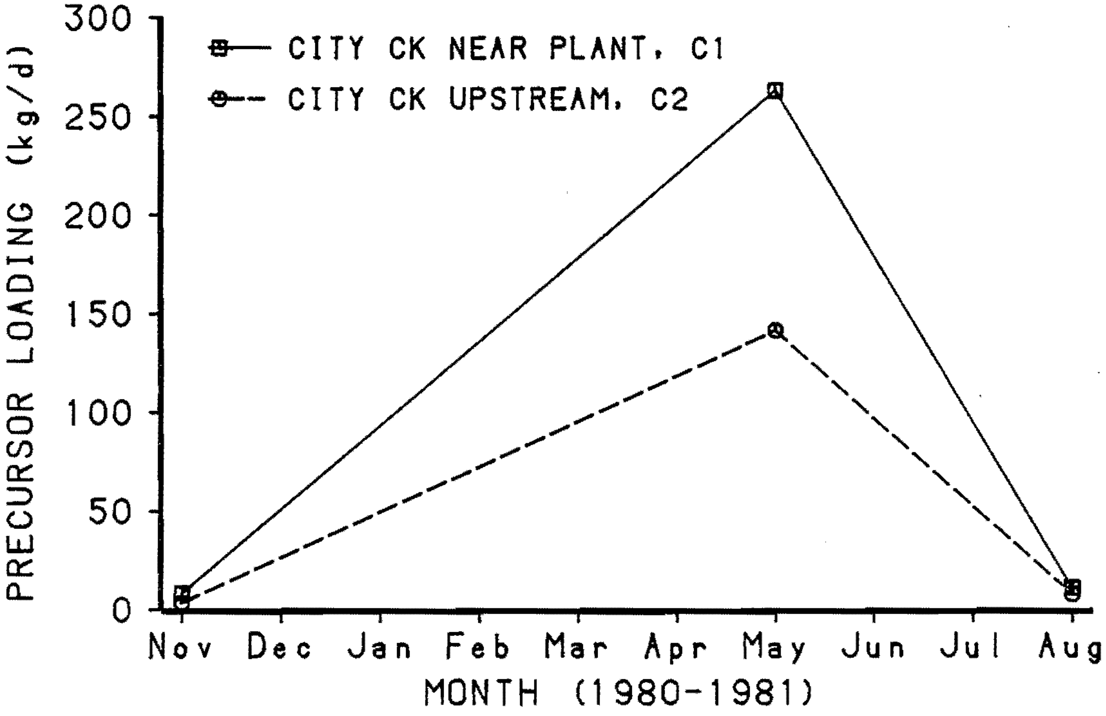

Figure 19. Mean seasonal precursor loading for the City Creek watershed.

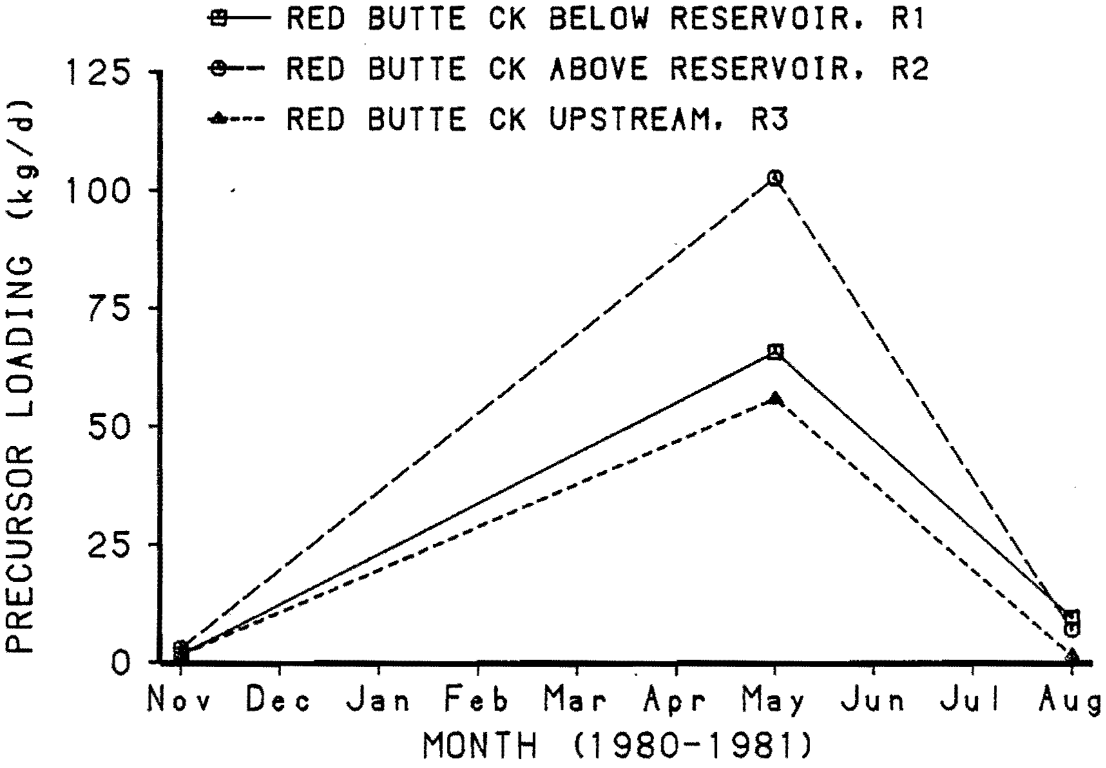

Figure 20. Mean seasonal precursor loading for the Butte Creek watershed.

upstream station L2 (station L3 was not sampled during these periods). It was not possible to sample station 5 during February because of icing. Mean precursor concentrations at station L4 were slightly greater than station L2, 1.0 and 0.6 mg TOC/l respectively, for both November and February. This was due to greater precursor concentrations (2.2 mg/l) on November 14 and February 23 as compared to the other dates. It is not known why the concentrations were larger on these dates. Station L5 also had a higher precursor concentration on the first sampling date in November (1.3 mg/l).

A statistical package for unbalanced analysis of variance (RUMMAGE) was used to evaluate season and location differences within watersheds for the various parameters measured. A significant statistical difference was not found between stations L2 and L4 during November and February for precursor concentration or precursor load. This means that the variability within each set of samples was too large for the differences among means to be considered significant. Therefore, it cannot be concluded that natural or other nonpoint sources were creating a significant increase in precursor loading upstream from station L4.

During May, mean precursor concentrations increased going downstream, as did streamflow (see Appendix A, Table A-1, for data). This resulted in the increased loadings going downstream. The maximum precursor concentration recorded was 3.4 mg/l at stations L1 and L3. In August, stations 2 through 5 produced precursor concentrations of 0.5 mg/l. Streamflow quantity was responsible for increased loadings, going downstream, at this time. Water temperatures were highest in August at all stations, but based on precursor concentration data this did not result in higher concentrations of organic precursor as compared to other seasons.

From station L4 to L3, the mean precursor concentration increased from 1.7 to 3.4 mg/l during May, but streamflow increased very little because these sites are so close together (within 1 km). In contrast precursor concentration levels were essentially constant between stations L3 and L2 while streamflow increased two-fold. The area between stations L3 and L4 is sparsely vegetated with conifers and shrubs, and has many granitic rock outcroppings. No tributaries flow into the main channel, and no obvious nonpoint sources are there to explain the increased precursor concentrations. The reason for the precursor concentration differences between stations L4 and L3 was not found.

Precursor loading is a function of precursor concentration and total streamflow. During periods of high streamflow, loading calculations are more sensitive to the magnitude of the flow than to precursor concentration. Accordingly, inaccurate flow measurements alter loading estimates. Table 13 compares the average daily flow measured at the time of sampling (mouth of watershed), average daily flow for the month during this study, and the average daily historical flow for that month of the year. From the magnitudes of these streamflow values, one can see that precursor loading was underestimated markedly during May for 1980-81 (37 percent) and historically (38 percent) and also during August by 66 percent and 29 percent respectively in Little Cottonwood Creek.

The statistical tests for significant season-location interaction differences for the Little Cottonwood Creek watershed (data in Appendix A, Table A-1) showed ($\alpha = 0.11$ to 0.22) the differences for organic precursor concentration (two analyses were performed for this watershed because of missing data) and the differences to be even stronger for precursor load. The greatest differences occurred during spring runoff.

Table 13. Quarterly sampling average stream discharge versus 1980-1981 water year mean daily stream discharge and historical (40 years record or greater) mean daily stream discharge.[a]

Watershed	Classification	Stream Discharge (cfs) November	February	May	August
Little	Measured	17.1	14.7	108.4	22.9
Cottonwood	1980-81 mean	20.5	15.4	172.5	32.1
Creek	Historical mean	17.6	13.9	174.9	40.1
Big	Measured	27.2	22.2	151.4	38.7
Cottonwood	1980-81 mean	27.5	21.7	158.9	27.6
Creek	Historical mean	26.4	23.0	197.8	37.9
Parleys	Measured	6.9	5.7	40.6	4.6
Canyon	1980-81 mean	11.3	8.8	52.6	8.4
	Historical mean	10.2	10.9	84.9	13.1
Red	Measured	6.8	-	30.3	9.4
Butte	1980-81 mean	7.2	6.5	28.8	12.6
Creek	Historical mean	8.3	8.0	43.6	11.9
City	Measured	2.0	-	9.0	1.9
Creek	1980-81 mean	2.0	1.8	5.3	1.6
	Historical mean	1.9	2.1	10.7	1.8

[a] Locations of stream discharge measurements were at stream stations L1, B1, P2 plus P11, R2, and C1.

Big Cottonwood Creek. The Big Cottonwood Creek watershed exhibited the greatest precursor loading during May at all sampling stations (Figure 15). The average precursor load was 398.7 kg/d over all stations, but a much larger mean peak load of 887.1 kg/d was observed at station 1. The smallest load was during the fall (November), averaging 18.1 kg/d over all stations. Precursor load increased going downstream during all the seasons except summer when the loadings at stations B3 and B4 were higher relative to stations B1 and B2 than in other seasons (Table 12). Precursor loading at station B3, 79.7 kg/d, was even greater than at station B1, 60.5 kg/d. The greater loads at the upstream stations in August was associated with higher precursor concentrations. Both stations B3 and B4 are downstream from heavily used summertime recreational and residential areas. While the analysis of variance did not indicate significant differences in the precursor load when comparing stations B3 and B4 with stations B1 and B2, during August, a significant difference in concentration was found when comparing station B4 to B1 and B2. Either the recreational activity and residences or the slower stream velocities and greater contact time, upstream of station B4, could have been responsible for the greater precursor concentrations during August.

The mean organic precursor concentration for the year at station B4 was 40 to 60 percent higher than at the other stations on Big Cottonwood Creek. However, the mean precursor load for the year was 75 percent smaller because of much lower flows at station B4. Significant statistical differences were determined at a 95 percent confidence interval (least squares difference) for organic precursor concentration between station B4 and B1, B2, B3. Further analysis of the season by location interaction produced differences during all seasons except spring (May) and summer (August) for stations B3 and B4. The area upstream from station B4 was therefore a significant production area for organic precursors. Because of lower streamflows at this station, however, precursor loading was not significantly different (greater) than for other stations.

The season by location interaction for precursor loading for the Big Cottonwood Creek watershed (data in Appendix A, Table A-1) was found to be significantly different at the 0.001 significance level or greater. Like Little Cottonwood Creek, seasonal loading differences were very dependent on the much greater loads measured during May.

Comparing the streamflow measured during sampling on Big Cottonwood Creek to 1980-81 and average historical values (Table 13) indicates minimal differences during November and February. During May, the flow at the time of sampling was about 38 percent below average for 1980-81 and historically. During August, the flow measured at the time of sampling was about 40 percent greater than the 1980-81 average but similar to the historical.

Parleys Canyon. Parleys Canyon watershed contains three streams which flow into Mountain Dell Reservoir (Figure 8). Figures 16, 17, and 18 graphically display the seasonal patterns in precursor loading for various sampling stations within the watershed. For the Parleys watershed, the mean precursor load was 127.8 kg/d during May, followed by August at 6.1 kg/d, February at 5.8 kg/d, and November at 2.7 kg/d (Table 12). In Figure 16, stations P2, P11, and P7, at the mouths of their respective streams, are plotted, and station P5 between stations P2 and P7 is included. Precursor load for all stations was greatest in May. At this time, stations P2 and P11, the two primary reservoir influent stations, had greatest loadings of 200.4 and 257.9 kg/d, respectively. Station P7, which has more streamflow year-round than station P5, had a greater loading also (122.2 versus 28.5 kg/d, respectively). Station P2 contributed an average precursor load of 56.2 kg/d while station P11 contributed 69.7 kg/d.

The data on Table 12 show that station P7 on Lambs Creek, which contributes to station P2, had a higher loading than station P2 did in August. Station P7 had more streamflow even though it is upstream from station P2. Diversions for golf course irrigation could account for the discrepancy, but there are no records of diversions. However, precursor loading from the North Fork of Lambs Creek (station P9) was also greater than from station P2 (7.7 kg/d), while streamflow was less. The mean precursor concentration at station P9 during this time was approximately twice that at stations P7 and P2. A significant difference ($\alpha = 0.05$) for precursor concentration between station P9 and P2, P7 was determined. This result, and the magnitude of the loading at station P9 during August, indicates the nonpoint precursor contribution upstream of this station to be greater than that downstream. Streamflow was steady during the sampling period. Some light rainfall occurred prior to and at the beginning of the sampling period. Therefore, overland flow was not considered to be a contributor to precursor production. The increased levels of organic precursor are suspected to have been caused by greater recreational activity (cabins, etc.), and most likely, by increased contact time of stream water with humic materials from the soils and riparian vegetation (Aspen, brush). Some beaver activity was also observed in the stream reach.

Station P5 on Parleys Creek produced a greater average yearly precursor concentration (2.7 mg/l) than did P2 (2.1 mg/l) and P7 (1.7 mg/l). Statistical tests confirmed a difference in concentrations between these sites (95 percent confidence interval). The higher concentrations at station P5 were the result of ponding that increased contact time with plant material and sediments along the stream channel.

Seasonal precursor loading at Lambs Creek stations P7, P8, and P9 are presented in Figure 17. The loading increased going downstream, except during August, as was found for Big Cottonwood Creek. Precursor loading was less at station P8 than station P9 for all seasons. Station P8 averaged one third the precursor loading over the four measurements at station P9, yet streamflow averages were nearly the same. The average yearly organic precursor concentration at station P9 was more than twice that at station P8 and statistically significant at the 95 percent confidence level. The watershed area surrounding station P8 is steeper than that surrounding and upstream of station P9, has predominantly coniferous vegetation, and is undeveloped. The area upstream of P9 is less steep, with more deciduous vegetation near the stream channel (lower portion of the stream), and contains an access road, streamside picnic areas, and cabins. Soil erosion problems were evident near the stream channel. The greater hydraulic contact times through the stream reach and inputs from deciduous vegetation and recreational related activities are likely causes for the increased precursor concentrations.

Figure 18 displays precursor loading for the Mountain Dell Creek stations. Station P12 is approximately 2.5 km upstream from station P11. A small agricultural area is located midway between the two stations. Precursor loading on Mountain Dell Creek was greatest during May, followed by February, August, and November, according to Figure 18 and Table 12. The familiar trend of increased precursor loading going downstream was observed, although during May the precursor load at station P12 was 14 percent less than that at station P11. Streamflow at the upstream station during May was measured to be about the same as that downstream, when it would be expected to be lower. The channel cross section (cement) used to gage flow at the upstream site produced a higher than actual flow measurement in May because of a steep channel gradient.

Organic precursor concentration did not contribute to greater loadings as seen in the fact that the differences in precursor concentration between stations P11 and P12 were not statistically significant. The increase in precursor load between the two stations was significant with a 95 percent confidence interval only during May. Therefore, it does not appear that the agricultural area significantly increases the organic precursor load to Mountain Dell Creek. A visual inspection of the agricultural area along the stream channel, during the summer months, did not show any signs of overland flow from the tilled land into the stream channel. Subsurface nutrient flows into the stream are, however, a possibility.

During November, measured precursor loading for the Parleys Canyon watershed, as related to streamflow quantity, was 61 percent of the 1980-81 monthly average and 68 percent of normal (Table 13). During February these values were 65 percent and 52 percent, respectively; 77 percent and 48 percent respectively for May; and 55 percent and 35 percent respectively for August. Consequently, the sampled loading was about half normal.

Red Butte and City Creek. Precursor loadings from the secondary watersheds (City Creek and Red Butte) are shown in Figures 19 and 20. Stream sampling stations are located as shown in Figure 8. Sampling was not performed on these streams during February. Red Butte Canyon was considered a control watershed because it is closed to the public. City Creek Canyon has regulated public access, a paved road, and picnic areas. The watersheds are similar in morphology and vegetation.

In City Creek, precursor loading at station C2 (upstream) was always less than at station C1, primarily due to the quantity of streamflow. The measured precursor load was much greater during May than in November or August. Precursor concentrations were greater in May (3.5 mg/l at station C1 and 2.2 mg/l at C2). Similar low values occurred in November and August at both stations (0.5 to 0.8 mg/l). Specific increases of organic precursor concentration from recreational, construction, or natural sources were not detectable.

Station R1 on Red Butte Creek was located downstream of the Red Butte Reservoir. Station R1 did not produce the highest precursor loadings (as might be expected because of its downstream location) probably because flow to this station was regulated by the reservoir outlet and spillway. Precursor loading was again greatest during May (102.6 mg/l at station R2). Loading at station R3 was always less than that downstream at station R2. Organic precursor concentrations were quite high at station R2 (4.7 mg/l) and station R3 (4.8 mg/l), during May, while 3.0 mg/l was measured at station R1. During August, however, station R1 had a greater concentration of 2.3 mg/l as compared to 1.5 mg/l at station R2, and 0.7 mg/l at R3. Water temperature at station R1 was 1°C higher in August. Reservoir impoundment apparently increased the precursor concentration in August.

Organic precursor concentrations in Red Butte Creek were higher than City Creek on a seasonal basis. The maximum concentration for Red Butte was 4.8 mg/l, and for City Creek 3.5 mg/l. Red Butte Creek has a lower annual flow rate than does City Creek, and lots of organic debris and ponding occur in the stream channel as a result of beaver activity, a small stream gradient, and a lack of stream clearing activities. These factors combined to create greater organic precursor concentrations in Red Butte Creek during periods of higher water temperatures, but City Creek produced the greater loadings because of its higher streamflow.

Precursor loading as related to streamflow (Table 13) for City Creek was very close to the 1980-81 average in November and May, but underestimated as compared to normal by 19 percent and 31 percent, respectively. During August, measured streamflow, and thus loading, was 25 percent less than the 1980-81 average, and 21 percent less than normal.

For Red Butte Creek, precursor loading as related to streamflow did not vary much compared to average (1980-81) and normal values during November and August.

Season and watershed interaction. The unbalanced analysis of variance program (RUMMAGE) was used to test the watershed data (Appendix A, Table A-1) for variation of measured and calculated parameters by season for grouped watersheds, variation by watershed for grouped seasons, and interaction. The tests were performed only on sampling stations with complete data for the combinations analyzed. Two analyses were run: 1) all watersheds (primary and secondary) for November, May, and August data, and 2) the primary watersheds only, for all seasons. The statistical model used was:

$$Y = S + W + SW + L + SL + E$$

where Y is the dependent parameter measured, S is the season, W is the watershed, SW is the season-watershed interaction, L is the location or station, SL is the season-location interaction, and E is an error term. Seasons and watersheds were treated as fixed variables and locations were treated as random. The statistical package performed an F-test to determine the general significance of treatments and interaction. Second, a least squares difference (LSD) test was applied to the estimated means of specific comparisons in order to determine a confidence interval.

Temperature and streamflow had significant season by watershed interactions ($\alpha = 0.001$) for both the primary and all watersheds. This was expected because of normal seasonal fluctuations.

For the three season by five watershed test, the season-watershed interaction for precursor concentration was significant at the $\alpha = 0.001$ level. Precursor load was found to be significant at a low level ($\alpha = 0.16$). Analysis of the main treatments separately showed differences in precursor load by watershed to be not significant ($\alpha = 0.38$) and by season to be highly significant ($\alpha =$ less than 0.001). An LSD test by season for precursor load concluded that there was no real difference between the summer and fall seasons. The same test by watershed indicated similarities between Little and Big Cottonwood watersheds, Parleys Canyon, Red Butte, and City Creek watersheds, and Red Butte to City Creek. Winter data were not included because February measurements were not taken for Red Butte and City Creeks.

For the four season by three watershed (Little Cottonwood, Big Cottonwood, and Parleys) test, the season-watershed interaction for precursor concentration was found significant at $\alpha = 0.011$. However, a lower 0.077 significance level was calculated for precursor loading. Once again the watershed treatment did not show differences in precursor load to be highly significant ($\alpha = 0.358$). The LSD test showed no significant differences for precursor load between fall and winter, fall and summer, and winter and summer seasons. In contrast, the three watersheds all had significantly different precursor loading for the year.

Summary of statistical analysis. Water temperature and streamflow quantity were found to vary significantly among all combinations of season and watershed. The fall, winter, and summer seasons did not produce significant differences in precursor loading among (within) watersheds. Little and Big Cottonwood Creek watersheds, and Parleys Canyon, Red Butte, and City Creek watersheds had similar patterns and magnitudes of precursor loading for the fall, spring, and winter seasons combined. For all seasons, Little Cottonwood, Big Cottonwood, and Parleys watersheds all had significantly different precursor loading.

Streamflow and Precursor Concentration Relationships

Precursor-streamflow ratios. Ratios of precursor concentration to streamflow, expressed as percentages, were developed for all watershed locations and sampling periods and are presented in Table 14. The quarterly (seasonal) data for the Big and Little Cottonwood Creek watersheds shows a definite trend of increasing percentages going upstream as streamflow decreases. This trend was less consistent on Parleys watershed, but it did occur between stations P2 and P5 on Parleys Creek, stations P7 to P9 on Lambs Creek, and stations P11 and P12 on Mountain Dell Creek during fall and winter (streamflow measurements at station P12 were questionable during spring and summer because they were higher than those downstream at station P11). Stations R2 to R3 (R1 is below the

Table 14. Ratios of organic precursor concentration as streamflow expressed as percentages for both quarterly and monthly watershed data.

	Mean Quarterly Percentage			
Station	Fall (November)	Winter (February)	Spring (May)	Summer (August)
L2	3.5	4.1	2.4	2.2
L3	-	-	6.8	4.5
L4	9.7	14.3	4.9	5.3
L5	25.0	-	12.3	38.3
(Mean of L2-L4)	6.6	9.2	3.7	3.8
B1	1.8	7.6	1.6	1.5
B2	3.8	10.0	6.9	2.7
B3	7.0	17.5	15.2	7.8
B4	414.3	700.0	118.6	37.3
(Mean of B1-B4)	106.7	183.8	35.6	12.3
P2	13.7	50.0	34.6	34.5
P5	475.0	700.0	130.0	200.0
P7	19.7	80.0	30.5	17.0
P8	1.5	433.3	70.2	22.7
P9	66.7	242.3	151.4	116.3
P11	28.0	55.6	16.6	100.0
P12	45.5	187.5	15.1	61.2
(Mean of P2-P12)	92.9	249.8	64.1	78.8
R1	60.0	-	33.0	135.3
R2	30.8	-	51.7	76.3
R3	45.5	-	100.0	81.3
(Mean of R2,R3)	38.2		75.9	78.8
C1	7.4	-	11.6	5.3
C2	18.2	-	8.2	20.3
(Mean of C1,C2)	12.8		9.9	12.9

	Mean Monthly Percentage								
Station	Aug.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.
P2	19.2	23.3	28.6	21.9	17.1	36.7	28.9	26.4	27.7	40.3
P5	-	866.7	525.0	266.7	-	1200.0	221.4	154.5	57.9	487.5[a]
P7	43.5	25.0	20.0	15.6	17.9	40.0	17.2[a]	18.8	20.3[a]	31.7[a]
P11	44.0	53.8	28.1	34.6	33.3	27.8	21.7	23.8	20.6	70.0
P12	130.0	60.0	175.0	83.3	200.0	112.5	72.2	17.9[a]	41.3	53.5[a]
(Mean of P2,P11)	31.6	38.6	28.4	28.3	25.2	32.3	25.3	25.1	24.2	55.2

[a] Questionable values because of inconsistent measured streamflow values.

reservoir) and C1 to C2 also generally exhibited this trend. Stations B4 and P5 had the highest percentages (up to 700 percent). Both of these stations had very low flows and some ponding.

The winter (February) data for the primary watersheds produced the greatest percent organic precursor concentration per unit streamflow, calculated as a mean value using stations with complete data. During the spring (May), mean percentages were much lower and comparable to fall and summer. This was because precursor concentrations increased noticeably during the spring, but substantial streamflow increases diluted this effect. It should be noted that during the winter sampling, weather conditions were steady and measured streamflows were generally the lowest of all seasons (slightly less than fall--see Appendix A, Table A-1). Again, low flows indicate higher precursor concentrations per unit streamflow. This could be a consequence of greater contact time between water and sources of organics. However, more data would be necessary to accurately determine the spatial relationship of season to organic precursor production versus streamflow quantity. Little Cottonwood Creek and City Creek watersheds produced the lowest percentages of precursor per unit streamflow of all watersheds, with yearly means of 5.8 percent and 11.9 percent respectively.

The monthly data for Parleys watershed did not show February to have the consistently highest percentages of precursor to streamflow. Mean monthly values for stations P2 and P11 (both gaged and downstream stations), by sampling date, ranged from 24.2 percent in June to 55.2 percent in July. Except for the higher July mean, no obvious trends were apparent. Water temperatures were normally at a peak in July for the monthly dates sampled. At station P5, percentages were greatest, again corresponding to lower streamflows.

This analysis indicates that the greatest concentrations of organic precursor per unit of streamflow occurs during low flow periods and that this trend is intensified by warmer water temperatures. A greater concentration of organic precursors generally occurred upstream. The quarterly data show the winter period (February) produced the greatest mean percent precursor concentration to streamflow, while the monthly data for Parleys watershed (stations P2 and P11) indicate greatest mean percentages in July. Variability with sampling time is indicated. Streamflow (velocity), water temperature, and the availability of organic materials appeared to be important factors in the production of organic precursor concentrations.

Regression analysis. The analysis for significant relationships explaining precursor loadings suggests that greater precursor concentrations may be directly correlated with larger streamflows. To test this theory, simple linear regression analyses were performed on sampling station data with streamflow (cfs) as the independent variable and precursor concentration (mg TOC/l) as the dependent variable. The results are presented in Table 15. Other forms (logarithmic, exponential) were tried with poor results. Quarterly and monthly sample sites with the most complete data were included in the analysis. For the quarterly data, stations R2, R3, C1, and C2 produced good correlations at an acceptable level of significance (α less than or equal to 0.10) but had a small data base of six samples. Parleys watershed had better overall correlations for quarterly data than Little and Big Cottonwood Creek watersheds. Stations P2 and P11 (both gaged) show r^2 values of 0.835 and 0.874 respectively at a 0.005 significance level. On the other hand, station B1, also gaged, had an r^2 of 0.431 at a 0.025 significance level. For the monthly data, all taken on Parleys watershed, the results were also variable. The strength of the correlation

Table 15. Summary of linear regression analysis for precursor concentration (dependent variable as mg TOC/l) and streamflow (independent variable, ft^3/s).

Sampling Station	Slope	Intercept	Correlation Coefficient (r^2)	Significance Level	No. of Observations	Data Base (1980-81)
L2	0.021	0.277	0.630	0.005	12	Quarterly
L4	0.031	0.618	0.239	0.25	11	
L5	0.0904	0.475	0.598	0.025	9	
B1	0.0110	0.640	0.431	0.025	12	
B2	0.0629	-0.185	0.615	0.005	12	
B3	0.138	-0.293	0.646	0.005	12	
B4	0.0147	3.28	0.001	>0.25	12	
P2	0.349	-0.125	0.835	0.005	12	
P5	0.631	1.92	0.614	0.005	12	
P7	0.274	0.197	0.773	0.005	12	
P8	0.194	0.894	0.111	>0.25	11	
P9	1.22	0.387	0.600	0.005	12	
P11	0.125	1.00	0.874	0.005	12	
P12	0.114	0.867	0.857	0.005	12	
R1	0.206	1.14	0.604	0.10	6	Nov., May, Aug.
R2	0.509	0.054	0.947	0.005	6	
R3	1.06	-0.398	0.990	0.005	6	
C1	0.130	-0.543	0.983	0.005	6	
C2	0.063	0.465	0.738	0.05	6	
P2	0.263	0.050	0.919	0.005	10	Monthly
P5	0.219	2.463	0.277	>0.25	8	
P7	0.184	0.261	0.896	0.005	10	
P11	0.166	0.710	0.603	0.01	10	
P12	0.143	0.993	0.578	0.025	10	

at stations P2 and P7 increased over the quarterly data to 91.9 and 89.6 percent, respectively. Other stations did not improve.

Regressions of precursor concentration on streamflow were also run. These correlations did show a strong correlation, up to 92 percent at a 0.005 significance level, indicating a probable relationship. More samples throughout the year are needed to further test the correlation hypothesis.

The greater precursor concentration with higher streamflow could have been the result of sediment transport due to channel scour, the flushing of organic debris, and possibly surface erosion during storms. Precursors move with suspended solids.

Stream Parameter Correlation

On August 14, 1981, samples were collected on Big Cottonwood, Lambs, Parleys, and Mountain Dell Creeks, and at the Parleys water treatment plant intake. These were in addition to the regular quarterly sampling. The purpose of this sampling was to determine if organic precursor concentration as total organic carbon (TOC) adequately predicted TTHM formation potential. The maximum trihalomethane potential test was used.

Simple linear regression was performed on the data to test for relationships. When all the data were lumped together a poor correlation resulted (r^2 = 38.4 percent but significant at the 95 percent confidence level). When data were grouped by watershed, and by stream within watersheds, improved relationships resulted, but the number of observations was reduced. Linear regression of the data for stations P4 through P9 (Parleys and Lambs Creeks) produced a good fit (r^2 = 88.2 percent, Figure 21) at the 95 percent confidence level ($\alpha = 0.05$). For Big Cottonwood Creek stations B1 through B4 (Figure 22) a good linear correlation was also found (r^2 = 92.9 percent, $\alpha = 0.05$). Therefore, TOC was concluded to provided an estimate of TTHM formation potential.

An interesting by-product of this analysis was that organic precursors measured as TOC, from different sources, caused variable TTHM formation. That is, similar concentrations of TOC from different sources produced different levels of TTHMs--the organic precursors appeared to be site specific.

Summary of Precursor Loading and Parameter Relationships

The watershed areas studied had low runoff during water year 1980-1981, averaging about 76 percent of normal. Individual creeks varied with Little Cottonwood Creek almost 100 percent of normal discharge and Red Butte Creek lowest with 56 percent of normal discharge.

The mean concentration of organic precursor during May (spring runoff) for the three primary watersheds (Little and Big Cottonwood, Parleys) was 3.4 mg/l. For the other seasons, mean precursor concentration ranged from 0.9 to 1.4 mg/l. The mean precursor load during May for the three primary watersheds was 364.4 kg/d, approximately 18 times greater than during other seasons which ranged from 16.4 to 26.8 kg/d. Increased precursor loading during May was a function of both precursor concentration and streamflow quantity. Instream precursor concentrations ranged from less than 0.5 mg/l to 7.0 mg/l at stations sampled on a regular basis.

The Little and Big Cottonwood Creeks produce the greatest runoff and had the largest precursor loadings. Little Cottonwood and City Creeks had lower average organic precursor concentrations (1.1 mg/l and 1.3 mg/l, respectively) than Big Cottonwood, Parleys Canyon, and Red Butte Creeks (2.0 mg/l, 2.0 mg/l, and 2.1 mg/l, respectively).

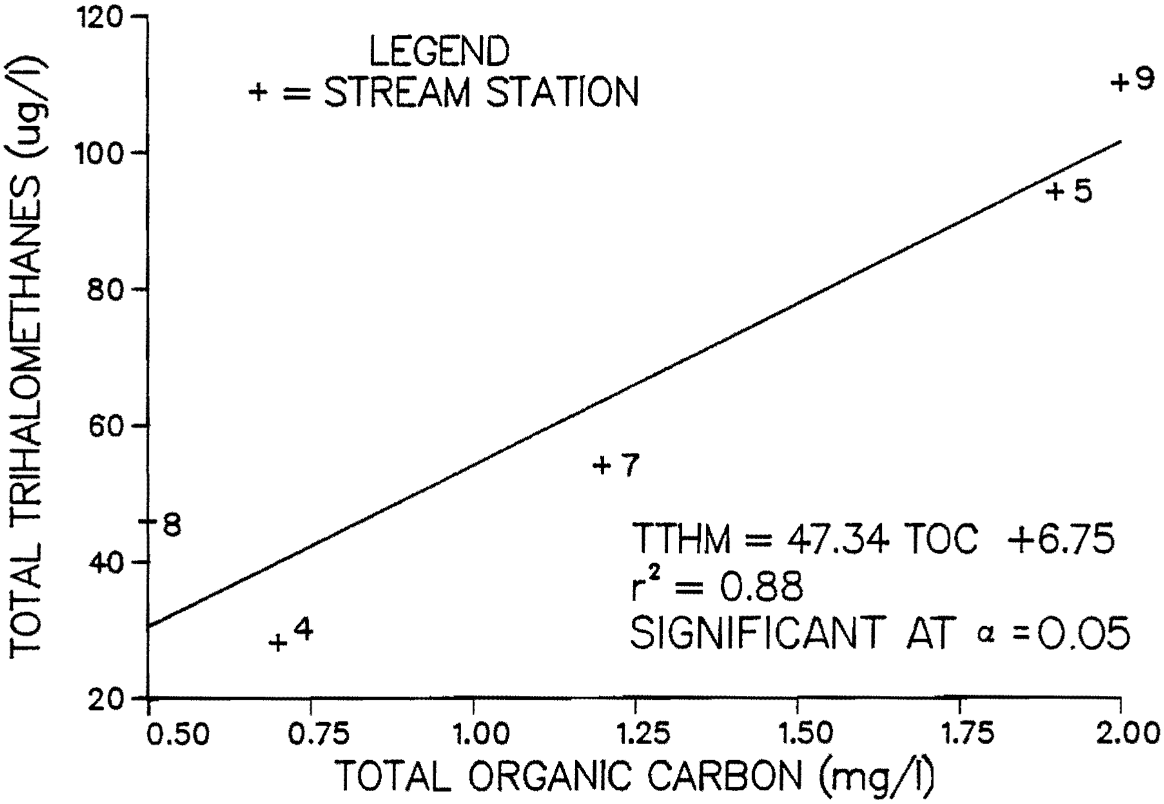

Figure 21. Linear relationship of maximum potential trihalomethanes and organic carbon for Parleys Canyon stream waters.

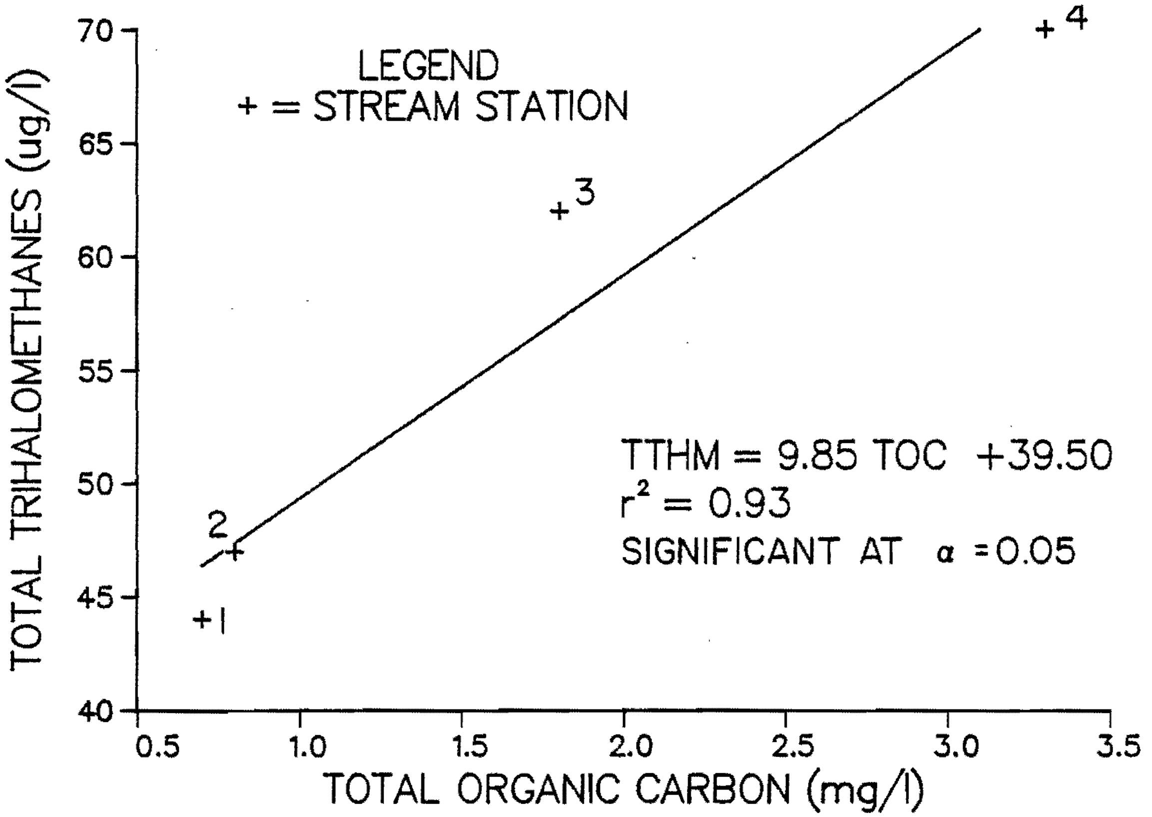

Figure 22. Linear relationship of maximum potential trihalomethanes and organic carbon for Big Cottonwood Creek stream waters.

As a rule, organic precursor load increased from headwaters to mouth on a given stream. Noticeable deviations from this pattern were observed and suspected to be associated with sources of precursor production. A statistical program (RUMMAGE) was used to assess this situation. Precursor concentration was determined to be significantly greater during August (95 percent confidence interval) at stream station B4 (Big Cottonwood Creek, Figure 8) than at stations B1 and B2, which were much farther downstream. Summertime activities, increased contact time of stream water with sources of natural organics, and higher summer water temperatures upstream of station B4 were thought to be the cause. Precursor loading at this station, however, was about the same as downstream because of lower streamflows.

In Parleys watershed, the north fork of Lambs Creek (upstream from station P9) was a significant contributor (relatively) to precursor concentration and loading during August for reasons similar to those observed for B4. In addition, the north fork of Lambs Creek was determined to produce twice the mean annual precursor concentration of the south fork while stream discharges were similar. The south fork is essentially undeveloped. The Mountain Dell Golf Course and agricultural area near Parleys and Mountain Dell Creeks were not determined to be nonpoint source contributors to increased precursor concentration and load.

A greater concentration of organic precursor to measured streamflow was generally found going upstream. The greatest concentration of organic precursor per unit streamflow occurred during low discharges and/or low discharges with higher water temperatures. Stream discharge versus organic precursor concentration correlations produced a strong linear relationship (maximum $r^2 = 92$ percent at $\alpha = 0.005$). This relationship could have been the result of increased suspended solids with increasing streamflow.

Finally, satisfactory correlations between organic precursor concentration as total organic carbon (the measured parameter) and maximum total trihalomethanes (MTP test) were determined for Big Cottonwood Creek waters ($r^2 = 92.9$ percent, $\alpha = 0.05$) and Parleys Canyon waters ($r^2 = 88.2$ percent, $\alpha = 0.05$). Other streams were not tested.

Additional Watershed Studies

Surface Runoff

Precipitation for water year 1980-81 was below average, and the day conditions hindered attempts to collect snowmelt and rainfall surface runoff (overland flow). Specially designed collectors (Figure 5) were used to collect surface runoff samples. Additionally, grab samples of both rain and snowmelt runoff were obtained at alternate sites on Big Cottonwood and Lambs Creeks. Figure 23 shows the collector locations. Sampling results are presented in Table 16.

Some snowmelt runoff was collected in the surface runoff collectors, but very little rainfall runoff was collected. Snowmelt runoff obtained near the Solitude ski resort (collector A) in Big Cottonwood Canyon originated mostly from disturbed areas (frontage road) and snowpack melt. On April 18, 1981, the snowmelt organic precursor concentration averaged 9 mg/l, and loading was 0.045 kg/d, which is relatively low compared to stream values. On April 25, the average snowmelt organic precursor concentration was 7.6 mg/l, and the loading was 0.11 kg/d. In May, snowmelt organic precursor concentration and loading increased to averages of 27 mg/l and 1.50 kg/d. This runoff was delivered directly into the stream system. The May runoff originated entirely from the access road. A snowmelt grab sample was obtained from parking lot runoff (see Table 16) on May 2 and a loading of 0.02 kg/d was calculated for this sample by estimating flow by using a bucket and watch.

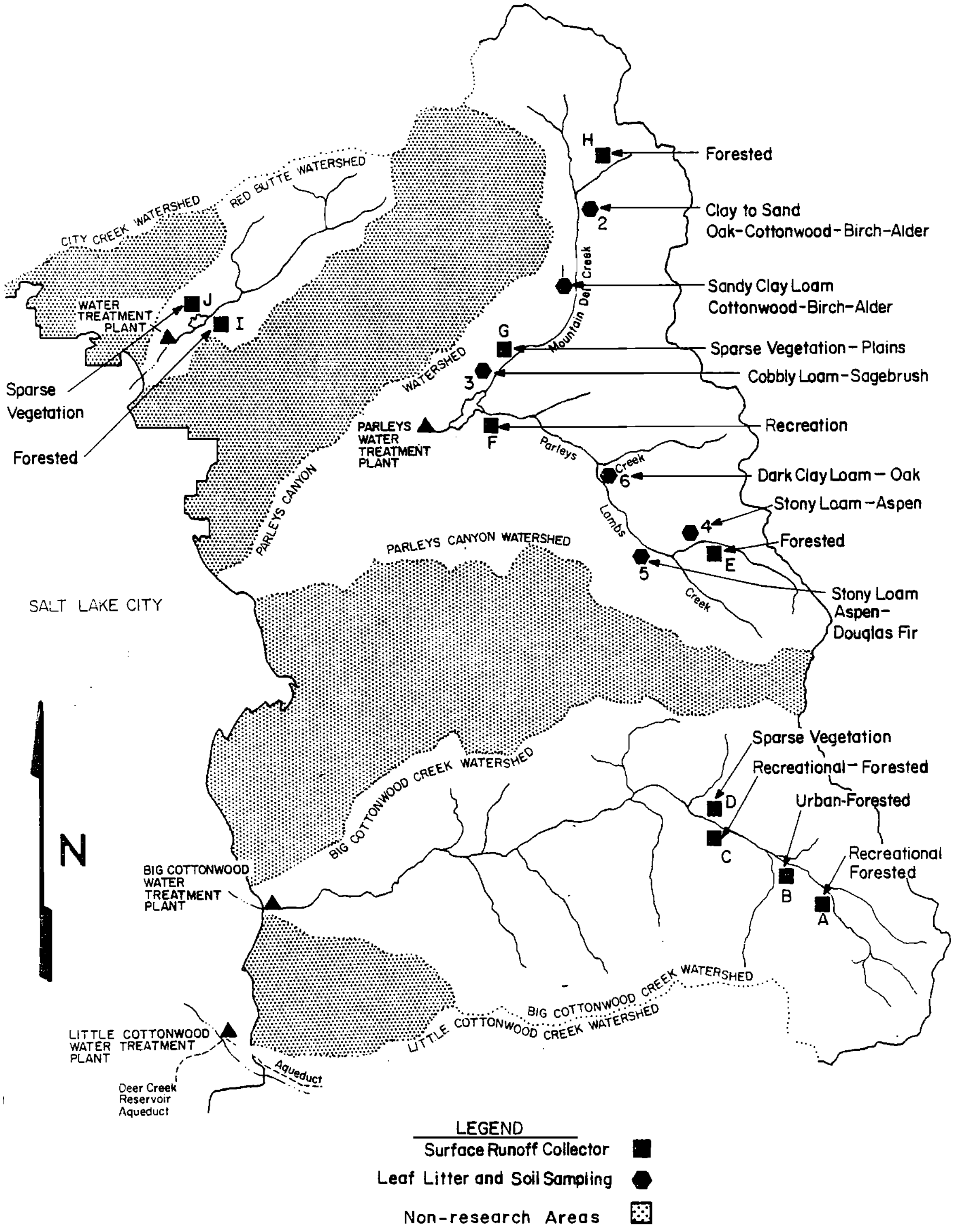

Figure 23. Surface runoff collection and leaf litter and soil sampling sites on the Salt Lake County watersheds.

Table 16. Total organic carbon concentrations and estimated flows for snowmelt and rainfall surface runoff samples.

Sample Site, Type and Location	Collection Date	TOC (mg/l)	Flow (cfs)	Mass Loading (kg/d)
Big Cottonwood Canyon near Solitude ski resort; snowmelt; surface runoff collector	4/18/81	11.6	0.002	0.06
	4/18/81	6.8	0.002	0.03
	4/25/81	7.6	0.006	0.11
	5/2/81	27.2	0.023	1.53
Big Cottonwood Canyon at Solitude ski resort lower parking lot; snowmelt; grab sample	5/2/81	9.5	0.02	0.5
Big Cottonwood Canyon near Reynolds Flat area; rainfall; grab sample	5/2/81	23.6	0.025	2.5
Big Cottonwood Canyon near Spruces campground; rainfall; grab sample	5/2/81	128.2	0.05	15.7
North fork of Lambs Creek; rainfall; grab sample	5/2/81	638.0	0.05	78

Rainfall runoff samples from collectors had no flow measurements so precursor loading could not be calculated. Rainfall runoff grab samples had the highest loading values, but flow measurements were rough. These samples were obtained in Big Cottonwood Canyon and Lambs Canyon on the north fork. At both sites runoff originated as road runoff and eventually entered the stream system. The Big Cottonwood sample produced an organic precursor concentration of 128 mg/l, and gave estimated loading of 16 kg/d. The Lambs Creek sample gave a precursor concentration of 638 mg/l and estimated loading of 78 kg/d.

Organic precursor concentrations in both rain and snowmelt direct runoff were greater than in the instream concentrations measured in Big Cottonwood Creek during regular sampling. Concentrations in the snowmelt runoff were as much as five times greater, and concentrations in rainfall runoff were from 5 to 128 times greater. The rainfall runoff samples showed visible discoloration and high turbidity. The estimated runoff flows were less than streamflows by a magnitude of six or greater. Loading derived from snowmelt runoff, a seasonal (spring) occurrence, was calculated to be at most 3 percent of instream loading for the time period. However, loading from rainfall runoff in Big Cottonwood Canyon was calculated to be up to 30 percent of the instream transport, and this percentage could be even higher when rain showers occur during a period of lower streamflows as was observed for Lambs Creek rainfall runoff where direct runoff loading temporarily exceeded 100 percent of the instream transport rate estimated for the time period. These high loading rates from rainfall runoff only last during short periods of intense rainfall.

The high concentrations of organic precursors in rainfall runoff suggest that road runoff could be making a significant contribution to the overall stream TTHM precursor loading. Snowmelt runoff appears to make considerably less contribution to stream TTHM precursor loading.

Surface runoff data were sparse because most snowmelt and rainfall infiltrate during dry years. Consequently, the measurements from the surface runoff collectors were insufficient to establish any correlations with the characteristics of their small tributary catchments. However, basin-wide comparisons show that the concentration of organic precursor from Lambs Canyon is much higher (Table 16) than in the rainfall and snowmelt runoff samples from Big Cottonwood Canyon. The probable explanation is that the soils in the upper Lambs Canyon are predominantly clays while those in the Big Cottonwood Canyon are sandy. Clay-sized particles are easily detached by rainfall, settle very slowly, and are transported further. Also, the sorption of pollutants by clay-sized particles generally results in clay soils having more associated pollutants (Chesters et al. 1980).

Stormflow

A number of Big and Little Cottonwood stream samples were collected from December 1981 to May 1982 during rainfall events. The goal was to sample during direct runoff periods to evaluate changes in precursor concentration and TTHM formation. Table 17 presents the results. Instantaneous TTHM was measured prior to sample chlorination and maximum TTHM potential afterwards. Samples collected on December 3, 1981, were not collected during a rain event and can be considered baseline conditions for that period.

All samples produced less than 1 μg/l inst-TTHMs. Stream samples from December 21, 1981, were collected at a time with similar streamflow rates and thus also represented baseline conditions. Higher precursor concentrations for Little and Big Cottonwood Creeks (2.0 and 1.3 mg/l, respectively) and fewer MTP-TTHMs (119 and 124 μg/l, respectively) were measured. The April and May samplings showed an increase in precursor concentration (up to 7 mg/l) for the larger flows. MTP-TTHM levels showed a less consistent relationship. At Little Cottonwood Creek, April-May MTP-TTHMs increased with precursor concentration although on April 12 and 29 the TTHMs were similar to December 3 (190 μg/l) when the precursor concentration (0.7 mg/l) was much less. Big Cottonwood Creek produced more MTP-TTHMs during April and May (268 to 305 μg/l) than were measured in December (119 to 190 μg/l). MTP-TTHM levels did not increase with precursor concentration. The levels of precursor concentration were larger during this period (April-May) in samples from Little Cottonwood Creek. Streamflow on May 3 was increased by precipitation (determined from storm hydrograph) that also contributed loading of organic precursor and turbidity. Little Cottonwood Creek MTP-TTHMs were the greatest at this time. On February 19, streamflow in Little Cottonwood Creek was 16.2 cfs (0.46 m^3/s), less than during December. The MTP-TTHMs (12 μg/l) were also very low. TTHMs from Big Cottonwood Creek (70 μg/l) were also low, and streamflow (33.4 cfs (0.94 m^3/s)) was a little greater or equal to the levels of December. Organic precursor concentrations were not available for February but streamflow was decreasing from a peak on February 17 of 39 cfs (1.10 m^3/s), so concentrations were probably less than or equal to December 21 values.

The stormflow data, although limited, suggest that organic precursor concentrations increased, over baseline conditions, during precipitation events

Table 17. Results of stormflow sampling during December 1981 to May 1982 rainfall events on Big and Little Cottonwood Creeks.

Sampling Station	Date	Streamflow (cfs)	TOC (mg/l)	INST-TTHM (μg/l)	MTP-TTHM (μg/l)	Turbidity (ntu)	Precursor Load (kg/d)
Little Cottonwood Creek	12/03/81	22.0	0.7	<1	190	-	33.7
	12/21/81	21.1	1.3	<1	119	-	67.1
	2/19/82	16.2	-	<1	12	-	-
	4/12/82	57.7	2.8	<1	173	1.8	395.3
	4/29/82	122.9	3.8	<1	196	2.8	1142.6
	5/03/82	253.1	7.1	<1	357	26.0	4396.4
Big Cottonwood Creek	12/03/81	24.1	0.7	<1	164	-	41.3
	12/21/81	33.3	2.0	<1	124	-	162.9
	2/19/82	33.4	-	<1	70	-	-
	4/12/82	122.3	5.0	<1	305	14.0	1496.0
	4/29/82	199.2	6.2	<1	304	27.0	3021.5
	5/03/82	273.2	7.0	<1	268	28.0	4678.7

by amounts that depended on streamflow. MTP-TTHMs, on the other hand, were more variable but trended toward greater concentrations with higher streamflow and more precipitation.

Reservoirs

The effects of reservoir storage of raw water supplies on precursor and TTHM concentrations were studied at Mountain Dell Reservoir on August 1, 1981. The deepest part of the reservoir was grab sampled at 3-meter depth intervals. Samples were analyzed for organic precursor concentration (TOC), pH, and temperature and were chlorinated and tested for maximum trihalomethane potential (MTP). Grab samples were also obtained from the two influent streams (Parleys and Mountain Dell Creeks) and Parleys water treatment plant influent and effluent and analyzed for the same parameters. Results are presented in Table 18.

The reservoir and treatment plant precursor concentrations ranged from 2.2 to 2.5 mg/l. As indicated by the temperature data and from known periods of reservoir turnover (spring and fall), the reservoir was weakly stratified at the time of sampling. This had no apparent effect on precursor concentrations--they remained almost constant with depth. However, stream and plant effluent precursor concentrations were 38 percent less than those in the reservoir and plant influent samples. These data suggest that the storage of stream source water in the Mountain Dell Reservoir during July/August resulted in an increase in organic precursor concentrations that were subsequently reduced by treatment to the original stream concentrations. Watershed sampling data at stream stations P2 and P11 during August 12 to 14 showed precursor concentrations ranging from 0.7 to 1.9 mg/l (the mean was 1.55 mg/l), all less than the measured reservoir concentrations on August 1.

A linear regression analysis of MTP-TTHM with organic precursor (TOC)

Table 18. Results of August 1, 1981, sampling of Mountain Dell Reservoir, influent streams, and Parleys water treatment plant.

Site	Total Organic Carbon (mg/l)	Maximum Trihalomethane Formation (μg/l)	Temperature (°C)	pH
Reservoir Surface	2.4	116	20	8.3
3 m Depth	2.5	92	20	8.3
6 m	2.3	136	18	8.3
9 m	2.4	126	17	8.3
12 m	2.3	110	15	8.1
15 m	2.4	122	14	8.0
18 m	2.4	102	13	7.7
21 m	2.2	110	12	7.6
Plant Influent	2.4	94	14	8.0
Plant Effluent	1.5	33*	--	7.7
Station P2 (Parleys Creek)	1.5	67	10	-
Station P11 (Mountain Dell Creek)	1.5	66	11	-

*Terminal TTHM

for the reservoir samples was not significant (r^2 = 12.3 percent), but there was not enough variation of precursor concentrations. TTHM concentrations fluctuated more but were not dependent on reservoir temperature because of the nature of the test. Also, precursor concentration did not appear to depend on reservoir temperature or pH. Stream and treatment plant effluent TTHM levels were noticeably less than reservoir levels. The plant effluent sample was a terminal TTHM (free chlorine residual of 0.65 mg/l at the time of sampling), probably accounting for the lower TTHM concentration. The mean reservoir TTHM concentration was 112 μg/l versus a mean stream TTHM concentration of 66.5 μg/l. On July 28 the water treatment plant influent precursor concentration was 2.6 mg/l, and the effluent term-TTHM was 40 μg/l. On August 28 influent precursor concentration was 2.2 mg/l and effluent term-TTHM was 53 μg/l. These levels were similar to those measured during reservoir sampling.

These findings support the hypothesis that the impoundment of surface water supplies increases the organic precursor concentration and TTHM formation potential. The Mountain Dell Reservoir is in a mesotrophic/eutrophic state (Hanson et al. 1983). Total nitrogen to total phosphorus ratios obtained from algal bioassays suggested high summer algal productivity, which could account for increased organic precursor concentrations. These ratios also indicate phosphorus limitation during summer and fall. Phosphorus loadings into the reservoir were found to be greatest during the spring. Data from lakes and reservoirs in the United States indicate a positive correlation between total phosphorus and TOC measurements (Walker 1983). In addition, many studies have identified phosphorus as the nutrient most often limiting the productivity of aquatic systems. Since considerable phosphorus loading occurs as a result of surface runoff within a drainage basin (Watson et al. 1979), the control of streamside erosion might reduce organic precursor concentrations within the reservoir and ultimately TTHM formation.

Leaf Litter and Soils Leaching

Leachate was collected from leaf litter and soils taken from the sampling sites presented in Figure 24 and Table 19. The results are presented in Tables 20 and 21. The calculated concentrations (g/l) for organic precursor (TOC) and trihalomethanes (MTP-TTHM) were adjusted for the dilutions necessary for concentration measurement but not the ratios of sample mass to volume (mass) of leaching solution. Therefore, the mass-to-mass ratios are the most meaningful.

Both leaf litter and soil leachates produced much higher concentrations (g/l) of potential organic precursor and TTHMs than were found in the stormflow analysis. The maximum precursor and TTHM concentrations measured for leaf leachate were 105.6 g/l and 15.2 g/l, respectively. For soil leachate the maximums were 7.44 g/l and 0.7385 g/l, respectively. While these values were lower, they still showed litter and soils to be potential sources of THM formation.

The average mass of organic precursor generated from leaf litter leachate was 6.68 g per 100 g sample. The average mass of TTHM was 589 mg per 100 g sample. For the soil leachate, the average mass of organic precursor generated was 0.361 g per 100 g sample. The average mass of TTHM was 0.0306 g per 100 g sample. Accordingly, potential organic precursor and TTHM mass concentrations for the leaf leachate were measured at approximately 19 times greater than for the soil leachate. However, interpretation of this difference must take into consideration the laboratory procedures. First, leaf litter leachate pH was stabilized at about pH 8 during leaching, while soil leachate was not. Soil leachate generally ranged from about pH 6 to 7. This may have had in a minor effect on the quantity of organic precursor (TOC) going into solution and hence TTHM concentrations. All TTHM samples were buffered with dilution water for standardization. Second, it was necessary to use different sample to leachate ratios (2 g into 200 ml for leaf litter and 20 g into 200 ml for soils), meaning that potentially more soil organic precursor could have gone into solution. Third, all TTHM samples had a free chlorine residual when analyzed so that THM formation was not inhibited. It therefore appears that these results are representative of the potential differences between the leaf litter and soil samples collected.

Chloroform ($CHCl_3$) was the dominant THM specie. The leaf litter was relatively free of bromide ions, but dichlorobromomethane ($CHBr_2Cl$) occurred in minor amounts in some soil samples.

Replicates run on the same leachate extract (designated as (r), Tables 20 and 21) were consistently good. Duplicates taken from the same source material (designated as (d)) but leached,

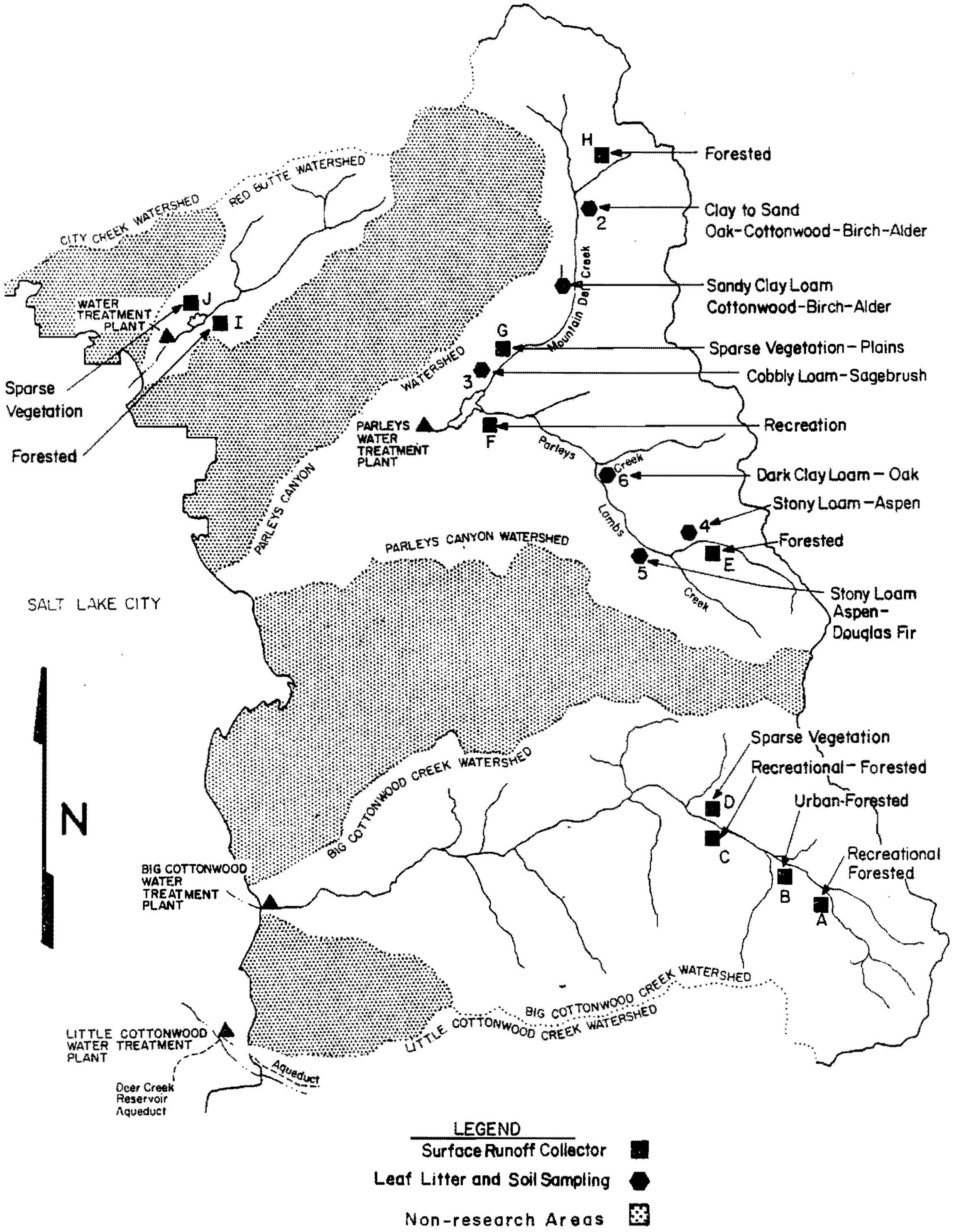

Figure 24. Surface runoff collection and leaf litter and soil sampling sites on the Salt Lake County watersheds.

Table 19. Leaf litter and soil leaching study sample site location, designation, and description.

Site Location	Sample Designation	Sample Description
Mountain Dell Creek agricultural area, 2 mi upstream from reservoir	Soil: 1A 1B	Loamy Borrow Pits (sandy to clay loam), Mixed Aluvial (clay to sand, medium organic-matter), Harkers Soil (dark loam and clay loam, high organic-matter) Types
	Leaf Litter: 1C	Narrowleaf Cottonwood and Shrubs
	1D	Narrowleaf Cottonwood
	1E	Birch-Alder
Mountain Dell Creek upper campground, 3.5 mi upstream from reservoir	Leaf Litter: 2A 2B	Gambel Oak, Narrowleaf Cottonwood, and Birch-Alder
	Soil: 2C 2D	Mixed Alluvial (clay to sand, medium organic-matter) Type
Mountain Dell Creek near watershed station P11, just upstream from reservoir	Soil: 3A 3B	Harkers-Wallsburg (loam and cobbly loam), and Mixed Alluvial Types. Sagebrush area.
Left fork of Lambs Creek near watershed station P9	Soil: 4A 4B	Lucky Star (stony loam, high organic-matter) Type
	Leaf Litter: 4C 4D	Aspen
Lambs Creek, 0.5 mi downstream from confluence of left and right forks	Soil: 5A 5B	Lucky Star (stony loam, high organic-matter) Type
	Leaf Litter: 5C	Douglas Fir and Aspen ground debris
	5D	Douglas Fir
Parleys Creek near watershed station P5, just upstream from Lambs Creek confluence	Soil: 6A 6B	Harkers Soil (dark loam and clay loam, high organic-matter), Harkers-Wallsburg (loam and cobbly-loam) Types
	Leaf Litter: 6C	Gambel Oak

Table 20. Total organic carbons and maximum total trihalomethane potentials for leaf litter leachate samples.

Sample Site		TOC (g/l)	TOC (g/100 gm sample)	MTP-TTHM (g/l)	MTP-TTHM (g/100 g sample)
$1C_1$	(d)	86.7	8.67	8.96	0.896
$1C_2$	(d)	105.6	10.56	7.64	0.764
1D		98.4	9.84	15.21	1.521
1E		80.6	8.06	9.46	0.946
$2A_1$	(d)	62.7	6.27	4.71	0.471
$2A_2$	(d)	53.0	5.30	3.36	0.336
2B		47.7	4.77	2.46	0.246
4C		45.1	4.51	4.21	0.421
4D		57.1	5.71	5.36	0.536
5C		36.2	3.62	3.93	0.393
$5D_1$	(r)	42.0	4.20	1.46	0.146
$5D_2$	(r)	42.0	4.20	1.09	0.109
$6C_1$	(r)	88.7	8.87	7.30	0.730
$6C_2$	(r)	88.7	8.87	7.30	0.730

(d) duplicate sample : separate leaching

(r) replicate sample : same leachate

Table 21. Total organic carbons and maximum total trihalomethane potentials for soil leachate sample.

Sample Site	TOC (g/l)	TOC (g/100 gm sample)	MTP-TTHM (g/l)	MTP-TTHM (g/100 g sample)
$1A_1$ (d)	4.670	0.425	0.6198	0.0564
$1A_2$ (d)	1.450	0.132	0.3011	0.0274
1B	3.429	0.312	0.3286	0.0299
$2C_1$ (d)	2.297	0.209	0.2879	0.0262
$2C_2$ (d)	2.011	0.183	0.2879	0.0262
$2D_1$ (r)	5.517	0.502	0.3835	0.0349
$2D_2$ (r)	5.517	0.502	0.4198	0.0382
$3A_1$ (r)	2.593	0.236	0.2242	0.0204
$3A_2$ (r)	2.593	0.236	0.1967	0.0179
3B	2.066	0.188	0.1527	0.0139
$4A_1$ (r)	4.759	0.434	0.2846	0.0259
$4A_2$ (r)	4.769	0.434	0.3066	0.0279
4B	4.110	0.374	0.2626	0.0239
5A	7.440	0.677	0.7385	0.0672
5B	6.220	0.566	0.5187	0.0472
6A	4.549	0.414	0.2231	0.0203
6B	3.440	0.313	0.1747	0.0159

(d) duplicate sample : separate leaching

(r) replicate sample : same leachate

filtered, and treated separately produced less consistent results. These variations may have been due to the sample or laboratory techniques.

The leaf litters from the Narrowleaf Cottonwood, Birch, and Alder samples from the Mountain Dell agricultural area, and Gambel Oak from Parleys Canyon were higher in mass of organic precursor and TTHM per 100 g than were the other samples (86.7 to 105.6 g TOC per 100 g sample and 0.730 to 1.521 g TTHM per 100 g sample). The lowest organic precursor and TTHM measurements came from the Lambs Creek forest floor Aspen and Fir litter, and Douglas Fir samples (3.62 to 4.20 g TOC per 100 g and 0.109 to 0.146 g TTHM per 100 g). But the Oak, Cottonwood, Birch, and Alder samples from upper Mountain Dell Creek also produced low TTHMs (0.246 g per 100 g sample). Deciduous forest litters produced overall greater mass concentrations of organic precursors and TTHMs than did the conifers. A linear correlation with an r^2 of 69.1 percent and a significance level of $\alpha = 0.005$ was found when the leaf litter organic precursor mass concentration was regressed TTHM.

Among the soils, the Lambs Creek samples, classified as high mountain stony loam (very high in organic matter), produced the greatest mass of precursor and TTHM per mass of sample (566 to 677 mg TOC per 100 g and 47.2 to 67.2 mg TTHM per 100 g). This site had the minimum mass concentrations of precursor and TTHM per mass of sample for leaf litter (conifers). Harkers soil (Mountain Dell agricultural area, Mountain Dell near the reservoir, and Parleys Canyon sites), classified as having high organic-matter content but mixed with other soil types, had less mass concentrations of precursor and TTHM than did the Lambs Creek soils. The Harkers soil sites were associated with Cottonwood-Birch-Alder, Sagebrush, and Gambel Oak, respectively. The soil samples from the upstream section of Mountain Dell Creek, obtained from undulating bottomland sampling terrain, had considerably lower precursor mass concentrations (236 versus 502 mg per 100 g sample). TTHM samples were less variable. The linear regression of soil organic precursor (TOC) on TTHM produced an r^2 of 47.7 percent at $\alpha = 0.005$, less than the leaf litter leachate samples. Differences among sample types were less, and the relative magnitudes of precursor and TTHM mass concentrations varied from those for leaf litter. There was, however, a rough correlation for greater soil organic matter content with increasing TTHM levels.

From the leaching results, the ratio of organic precursor to MTP-TTHM was calculated to be about 11:1 for both soil and leaf litter leachates. In other words, the TTHM formation potential for both sample types was similar.

Summary of Leaf Litter and Soils Leaching

Both leaf litter and soil leachates were shown to be potentially significant sources of TTHM production. Organic precursor and TTHM mass concentrations (g per 100 g sample) for leaf litter were found to be approximately 19 times those for soils. The deciduous vegetation produced greater mass concentrations of organic precursor and TTHM than did the coniferous vegetation, but only a small number of coniferous samples was analyzed. Chloroform was the dominant THM.

The concentrations produced from laboratory leaching are not indicative of potential precursor and TTHM levels during natural leaching processes. The transport of these organic precursor materials in a dissolved or particulate form to the surface water system and subsequent dilution would result in much lower finished water TTHM concentrations, even with maximum chlorination practices.

It has been estimated (Fisher and Likens 1973) that 99 percent of the organic matter in an undisturbed stream system comes from the surrounding forested watershed or from upstream areas. Of the total input, about 44 percent came directly from the surrounding forest, mostly in a particulate form, 29 percent of this was due to leaf litter alone. The remaining organic input entered the stream in surface and subsurface inflows, about equally divided between the two. About 83 percent of the geologic input occurred as dissolved organic matter. Therefore, leaf litter and soil leachates would appear to be important contributors to TTHM precursor production in a relatively undisturbed watershed. The division between these two sources would depend on watershed characteristics. Deciduous vegetation would probably contribute more precursor to a stream system than conifers, especially during the fall, because the trees lose their leaves and are usually more abundant along a stream course (except at high altitudes). The relative soil contribution would depend on interflow and baseflow amounts and paths.

Water Treatment and Distribution

City Creek, Parleys, and Big and Little Cottonwood water treatment plants and distribution systems were monitored once a month from September 26, 1980, to December 30, 1981 (16 months). All sampling stations and their locations are shown in Figure 25 and described in Table 22. Water treatment plant process schematics are presented in Figures 2 and 3. The raw data can be found in Appendix B.

Water Treatment

The results of the inst-TTHM, term-TTHM, and organic precursor (TOC) measurements at the four treatment plants are presented graphically in Figures 26 through 29. Inst-TTHMs and term-TTHMs followed the same general trend at all treatment plants: peak periods were approximately from March to June, during spring runoff, and September to October, late summer, early fall. Precursor concentration fluctuations did not always correlate with increased levels of TTHM production.

Inst-TTHMs at the City Creek water treatment plant (Figure 26) were greatest during March and April (21 and 18 μg/l, respectively). Term-TTHMs showed an increase at these times also. Another inst-TTHM peak occurred during October, 1981. The associated term-TTHM (54 μg/l) was the maximum recorded at the plant. Term-TTHMs were also greater in October, 1980 (42 μg/l). Organic precursor levels showed some relationship to increased TTHMs during the spring, but were less than 1.0 mg/l in both Octobers. The March 1981 precursor concentration of 3.8 mg/l was almost twice that of other months and was associated with increased TTHM concentrations, but term-TTHMs were lower than might be expected. This may be an indication that the free chlorine residual was consumed. Depths of 1.0 cm and 2.3 cm of precipitation recorded during the October 1980 and 1981 sampling dates, respectively, may have been partially responsible for the increased TTHM levels.

Samples from the Big Cottonwood water treatment plant displayed TTHM data trends similar to those at City Creek (Figure 27). Inst-TTHMs and term-TTHMs were highest in April (35 μg/l inst-TTHM and 69 μg/l term-TTHM). The chlorine demand (dose less free residual) in May (1.3 mg/l) was greater than in April (0.75 mg/l) but did not produce more TTHMs. Measured influent organic precursor was also greater in May by 1.9 mg/l (and in June). Inst-TTHMs and term-TTHMs were greater in September 1980 than October 1980 even though no precipitation occurred on the September sampling date (1.0 cm was recorded in October).

The Parleys water treatment plant (Figure 28 was off-line from December

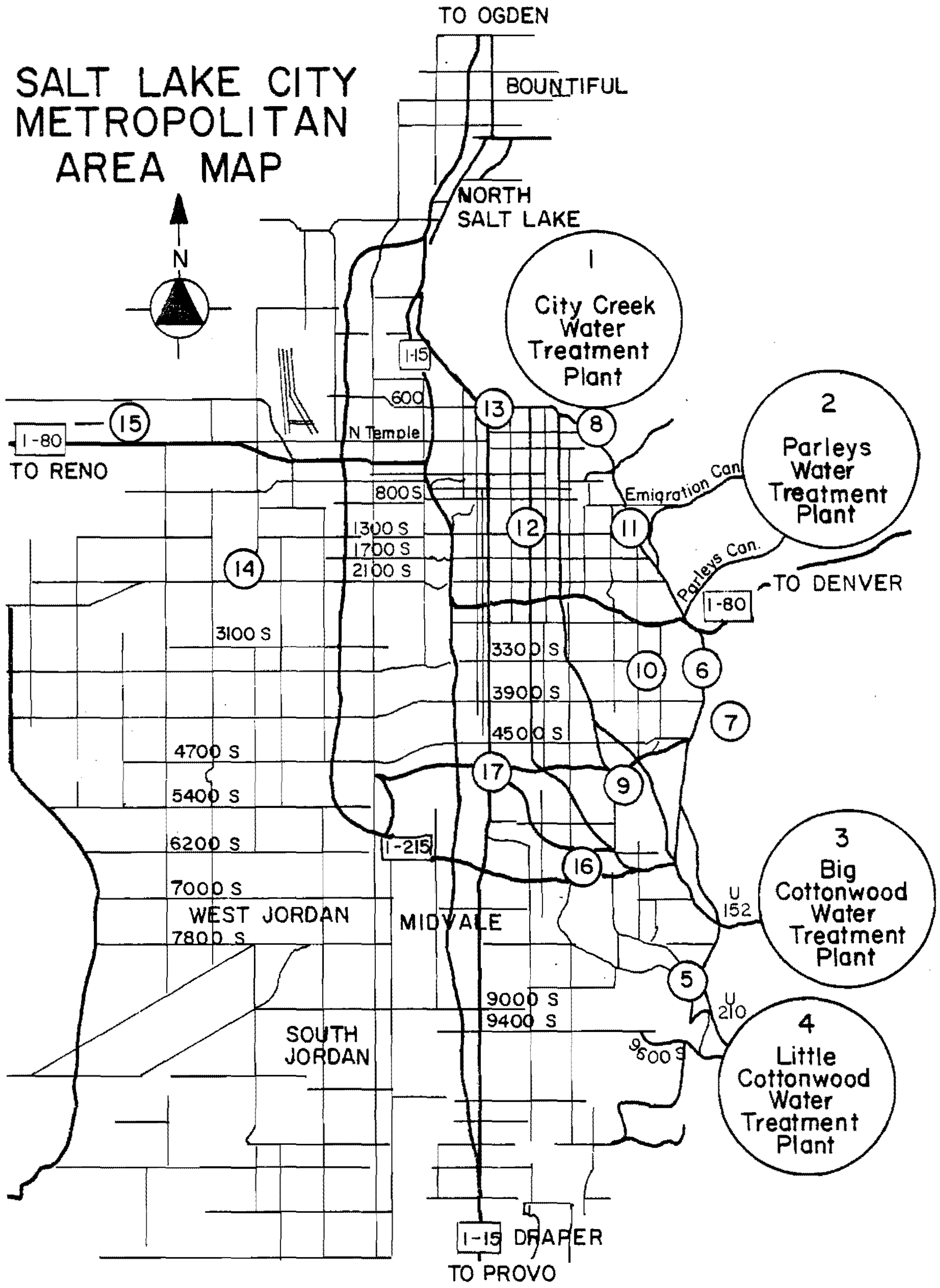

Figure 25. Salt Lake County water treatment plants and distribution system sampling stations.

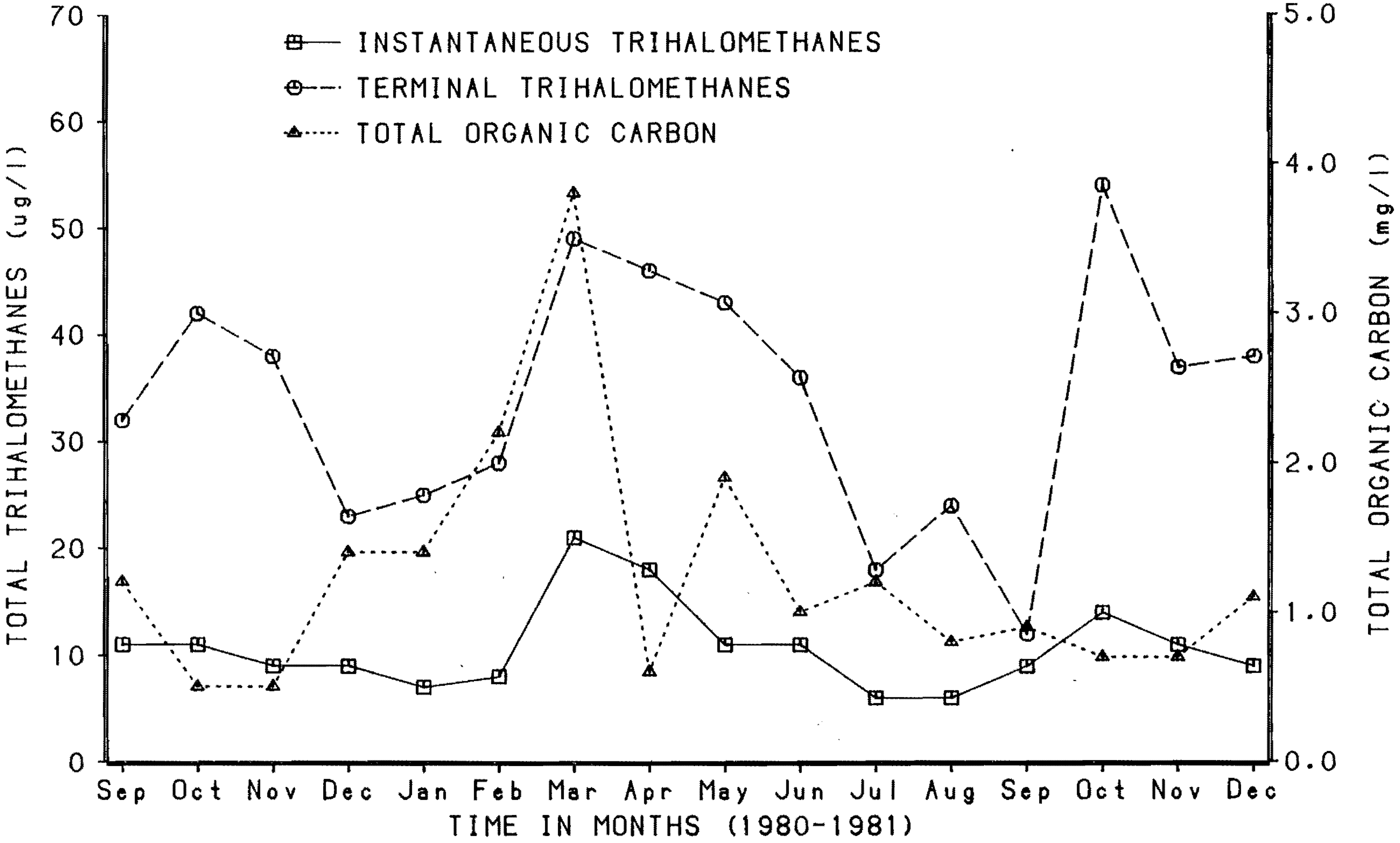

Figure 26. Effluent trihalomethanes and influent total organic carbon at the City Creek water treatment plant.

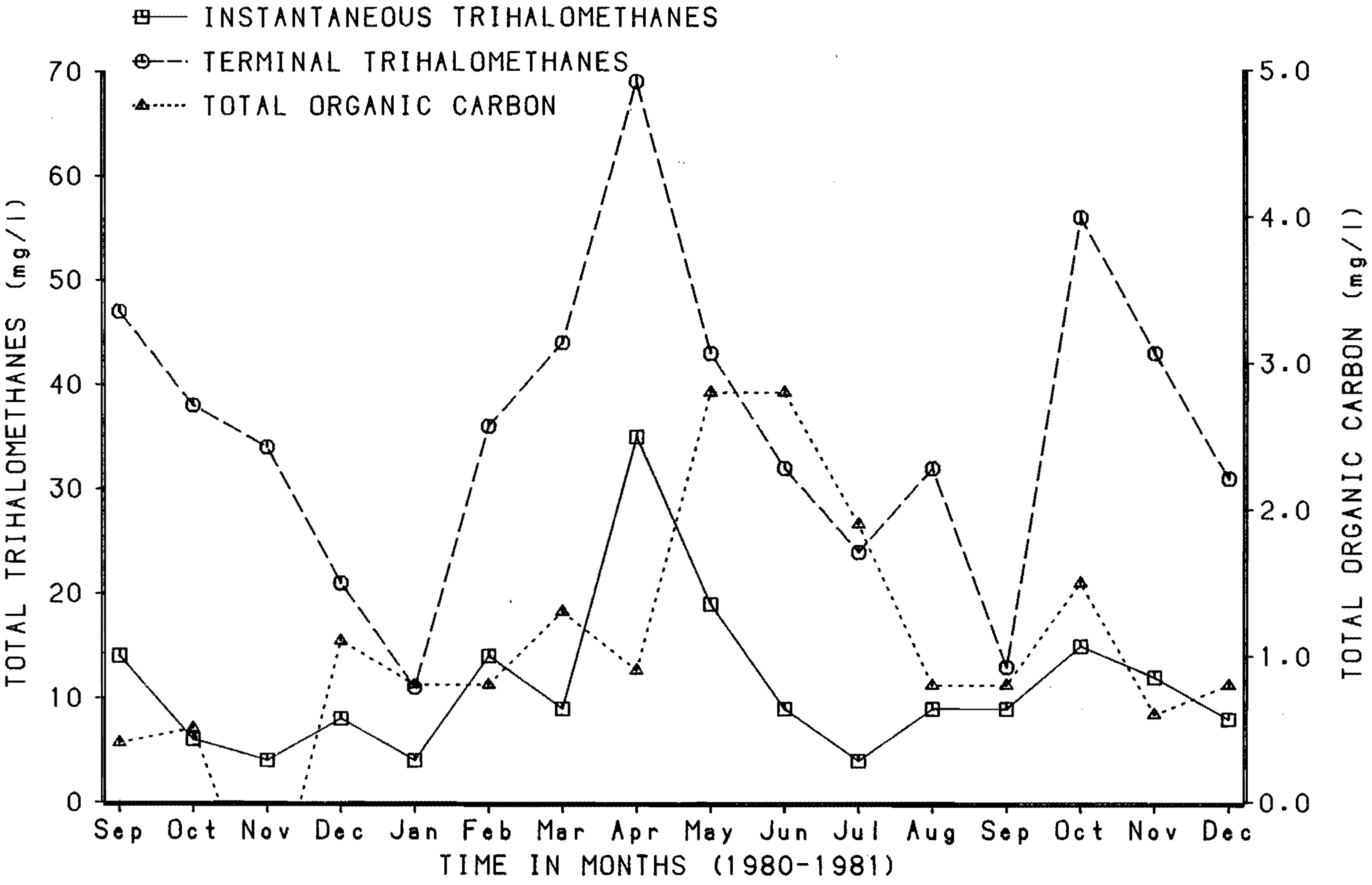

Figure 27. Effluent trihalomethanes and influent total organic carbon at the Big Cottonwood water treatment plant.

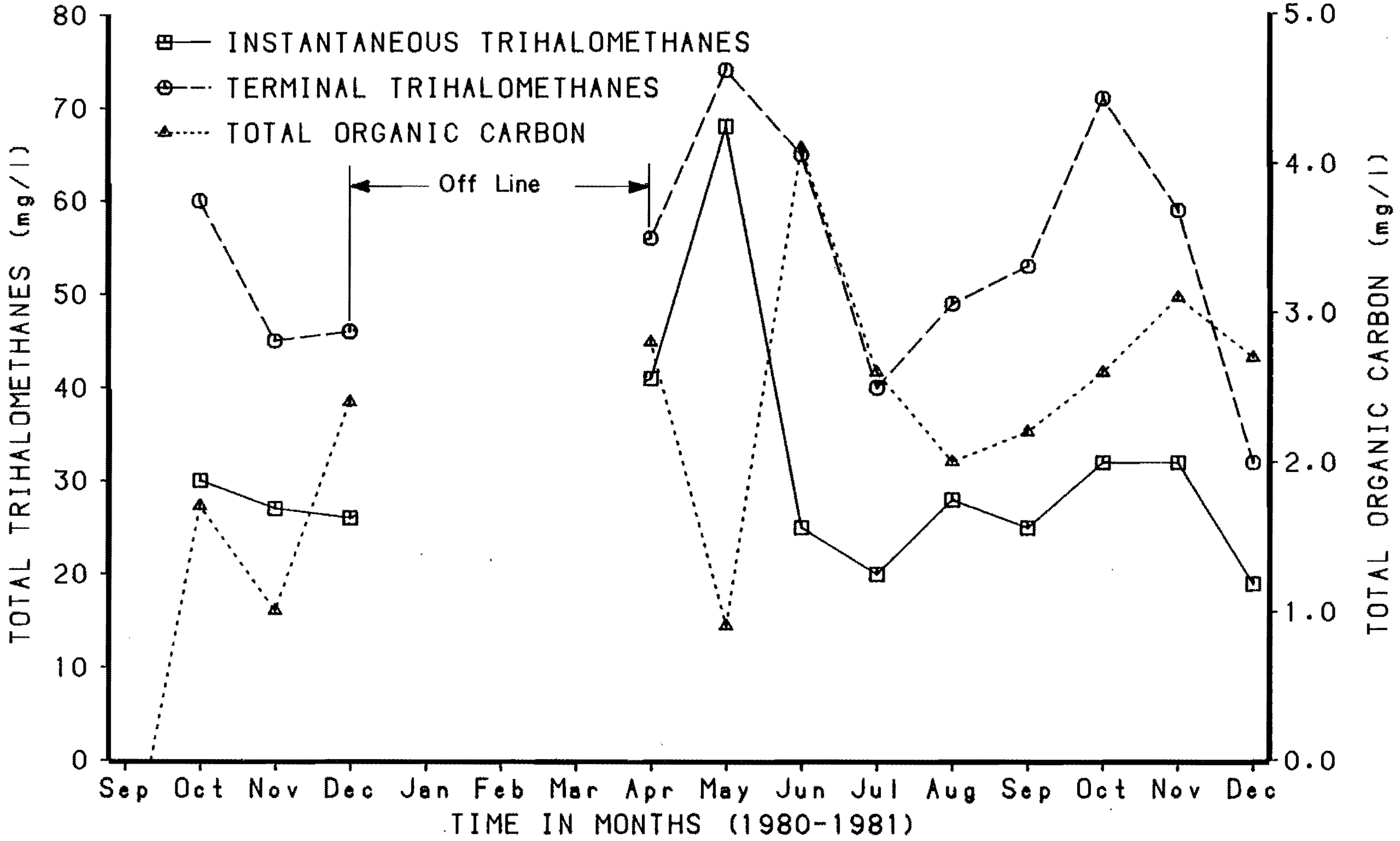

Figure 28. Effluent trihalomethanes and influent total organic carbon at the Parleys water treatment plant.

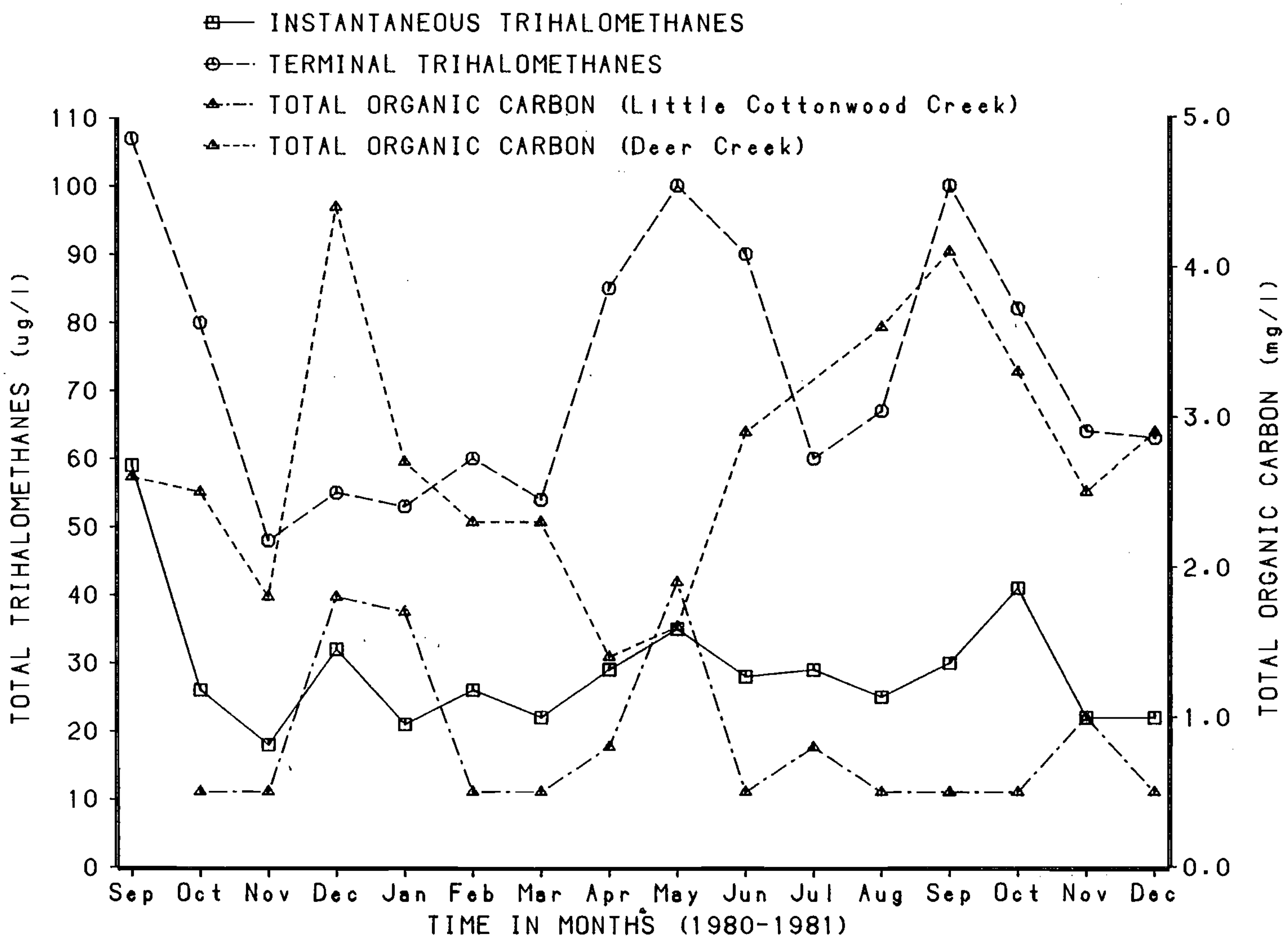

Figure 29. Effluent trihalomethanes and influent total organic carbon at the Little Cottonwood water treatment plant.

Table 22. List of Salt Lake County distributions sampling stations for monthly sampling, September 1980 to December 1981.

Station Number	Station Location and Description
1	City Creek water treatment plant
2	Parleys water treatment plant
3	Big Cottonwood Creek water treatment plant
4	Little Cottonwood Creek water treatment plant
5	8644 South 3500 East, Residence
6	Salt Lake Metro Water District 33rd South terminal reservoir
7	3616 East Hermes 4135 South, Residence
8	851 East North Crest Drive, Residence
9	2727 East Kentucky, Residence
10	2475 East 3300 South, Residence
11	Bonneville Golf Course
12	Liberty Park, Greenhouse
13	Utah Capitol Building
14	1855 South Industrial Road 1800 West, Business
15	145 Wright Brothers Drive, Salt Lake International Center, Business
16	Groundwater Well 1656 (deep), 6475 South 2650 East
17	Groundwater Well 1657 (shallow), 4800 South 900 East

to April. TTHM peaks were observed in October 1980 and 1981, and May. The May peak coincided with a low organic precursor concentration of 0.9 mg/l. The inst-TTHM concentration (68 μg/l) was nearly as high as the term-TTHM concentration (74 μg/l). The treatment plant was actually off-line at this time and the chlorinated effluent had been in storage, resulting in a high inst-TTHM concentration from prolonged contact time. Concentrations of all parameters were higher than at the City Creek and Big Cottonwood Creek treatment plants which treated only raw stream water.

The Little Cottonwood water treatment plant receives raw water from both Little Cottonwood Creek and Deer Creek Reservoir. In 1981 the Little Cottonwood Creek equaled or exceeded the Deer Creek Reservoir contribution during April, May, and June. TTHM peaks corresponded to those for the Parleys water treatment plant; during September/October and spring runoff (April, May, June) (Figure 29). Inst-TTHMs did not show the pronounced peak during spring found at the other treatment plants, although term-TTHMs were high at this time (100 μg/l in May). The TTHM formation potential during both fall periods was primarily a function of Deer Creek Reservoir precursors and slightly greater chlorine doses, while during May both precursor sources appeared responsible. Based on precursor concentrations, term-TTHM concentrations should have been greater during December 1980. Term-TTHM levels were always lower at this time at all treatment plants. Term-TTHM formation in December at the Little Cottonwood plant may have been limited by the 0.70 mg/l free chlorine residual (it was normally 1.0 mg/l or greater during spring and summer months).

The Deer Creek Reservoir influent was regularly chlorinated at the reservoir (0.5 mg Cl/l) and contributed from 10 to 50 μg/l inst-TTHMs upon entering the treatment plant. This influent to the Little Cottonwood water treatment plant had a greater mean inst-TTHM concentration (34 μg/l) over the 16 month sampling period than did the mean inst-TTHM concentration for the plant effluent (29 μg/l). The effluent concentration was apparently the result of dilution with Little Cottonwood Creek water, the lack of contact time (post chlorination was practiced) for additional inst-TTHM formation, and removal of precursors and TTHMs in treatment. The TTHM formation potential (Deer Creek Reservoir water) based on terminal TTHMs (term-TTHM less inst-TTHM) averaged only 5 μg/l. The available free chlorine of the Deer Creek Reservoir influent was usually exhausted. In contrast, the mean TTHM formation potential for the plant effluent was 44 μg/l, where a free chlorine residual was maintained. It was not possible to determine accurately from these data the influence of Deer Creek Reservoir influent water on effluent TTHM formation at the Little Cottonwood water treatment plant. However, the Deer Creek Reservoir influent probably contributed to the majority of TTHM formation (except during spring runoff) because of its greater precursor concentrations (average precursor concentrations for Deer Creek Reservoir and Little Cottonwood Creek influents, respectively were 2.7 and 0.8 mg/l) and its providing nearly twice as much influent water annually.

The watershed precursor loading data discussed previously revealed highest organic precursor concentrations during spring runoff. Precursor loadings (and concentrations) were low for all stream systems during fall, winter, and summer. From the monthly treatment plant data for all water treatment plants, TTHM levels increased during spring runoff when watershed precursor concentrations were highest, dropped during July and August as runoff decreased and water temperatures rose, and then rose during September and October while water temperatures were still relatively high. Treatment plants using only stream water had greater influent organic precursor concentrations during the spring, and lower concentrations through summer and fall. Treatment plants using reservoir water had higher influent concentrations of organic precursor during September and October, as compared to spring concentrations, than plants treating only stream water. Reservoir turnover was occurring from March to May and September to November (established from Mountain Dell Reservoir data, Hanson et al. 1983, and Little Cottonwood plant personnel 1983). This phenomenon, combined with precipitation events, could have been partly responsible for the increased TTHM concentrations during September and October. Precipitation would increase the streamflows and thus the amount of precursor available for TTHM formation. Reservoir turnover may produce the same effect by mixing suspended and reservoir bottom organics, algae and algal by-products. Algal data obtained from Deer Creek Reservoir during 1980-1981 at the sampling station nearest to the aqueduct intake resulted in highest counts on August 13 and September 13, 1980, and September 23, 1981 (weekly samples). The algicide copper sulfate ($CuSO_4$) was used minimally during these years. The Little Cottonwood water treatment plant was sampled on September 26, 1980, and September 28, 1981. Thus, algal biomass may have contributed to organic precursor concentrations and greater TTHM formation during the September periods. Increased levels of TTHMs during September and October at treatment plants using only stream water (City Creek and Big Cottonwood Creek) were not associated with greater precursor loading. Leaf-fall and precipitation, with resultant influxes of organics, may have been responsible for the increased TTHM levels. Surprisingly, all treatment plants produced fewer TTHMs during July and August (67 μg/l maximum) than in the spring and fall, even though stream water temperatures were high at this time (up to 13°C). Water temperatures at treatment plants serviced by reservoirs were a little higher in September (16°C). The findings of lower July and August TTHM concentrations contrasted with those of Peters et al. (1981) in which the highest average TTHM exposure levels to Salt Lake residents were observed in July of 1980. It is possible that TTHM peaks may vary from year to year as to when they occur in the summer or fall months, depending on environmental conditions such as runoff peaks, algal blooms, and water temperatures. Lower concentrations of organic precursors were apparently responsible for lower TTHM levels during July and August of 1981.

Statistical analyses were performed on monthly water treatment plant data to search for correlations among measured parameters. Data from the City Creek, Parleys, and Big Cottonwood water treatment plants were grouped because the treatment schemes were similar and prechlorination was practiced. The Little Cottonwood water treatment plant was considered separately because post chlorination was practiced. The Deer Creek Reservoir aqueduct water which is influent to that plant contains trihalomethanes, and permanganate was added at the influent to control periodic taste and odor problems (see plant schematics, Figures 2 and 3).

The data for the combined plants showed poor correlations for instantaneous and terminal TTHMs with influent or effluent TOC (maximum $r^2 = 23.2$ percent for effluent inst-TTHM versus effluent TOC). When these plants were examined individually the correlations did not improve. The Little Cottonwood treatment plant also produced poor correlations for instantaneous and terminal TTHMs with effluent TOC ($r^2 = 3.8$ percent for effluent inst-TTHM versus effluent TOC). The best linear fit of measured parameters was for term-TTHMs regressed against the effluent free chlorine residual at the Little Cottonwood plant ($r^2 = 0.639$, $\alpha = 0.005$) with the March data point excluded because the chlorine residuals were abnormally high. The resultant equation was [term-TTHM] = 16.6 + 52.9 [free chlorine].

The free chlorine residual can be considered an estimate of the magnitude of the chlorine dose in the treatment plant. If a free chlorine residual is maintained throughout the TTHM reaction, the level of term-TTHM formation is dependent on the availability of precursor material, all other factors being equal. It has been shown (Trussell et al. 1979), as well, that higher chlorine doses accelerate TTHM formation. Therefore, one would expect higher chlorine doses to produce greater TTHM levels in the distribution system. However, if the travel time to the consumers' tap is too short to complete free chlorine consumption, TTHM levels will be reduced. Parameters that affect the reaction rate, such as temperature, pH, and the type of organic precursor, need to be included in the formation equation.

Although the TTHM content of the treated water did not correlate well with organic precursor concentrations, plots of watershed and treatment plant data (Figures 14 through 20 and 26 through 29) show a trend toward greater TTHM concentrations with increasing precursor levels. Influent organic precursor as TOC at water treatment plants did not provide a reliable predictive tool for effluent TTHM formation. Two problems may be associated with this. First, more than one grab sample would probably be necessary to adequately characterize influent precursor concentration at any one time. Second, treatment processes may affect TTHM formation, and in the case of term-TTHMs, the chlorine dose will influence ultimate TTHM formation. The specific type of organic precursor coming from the environment may also cause differential TTHM formation.

Table 23 shows the distributions among the individual THMs at the various water treatment plants and groundwater and storage reservoir sampling sites. The detected THM species all contained chlorine, and the THMs dominated by chlorine ($CHCl_3$ and $CHBrCl_2$) were detected most frequently. The groundwater and reservoir water (Mountain Dell and Deer Creek) sources contained greater percentages of the brominated THMs than did stream water sources. The groundwater samples contained the greatest percentage of the brominated species (51 percent). In other research, increasing the bromide concentration increased the percentage of brominated THMs (Luong et al. 1982). Bromine acted principally as a substituting agent in haloform (THM) reactions when bromine and chlorine reacted in combination. In addition, organic bromine probably originates principally from the inorganic bromide in raw water by rapid oxidation by chlorine. TOC, chlorine, and ammonia were important parameters in determining the overall balance of THMs produced. Under low TOC concentrations (2.5 mg/l) and very high bromide levels (2000 μg/l) bromoform was the major species present (Luong et al. 1982). The greater percentages of brominated THMs suggest that the groundwater, Parleys effluent, and Deer Creek influent sources may contain greater concentrations of bromide ion.

Bromide was apparently not present in sufficient quantities to form strictly brominated THMs. An average concentration of bromide reported in the literature for natural fresh waters is approximately 0.006 mg/l (Livingstone 1963). In this study the halogen chlorine was utilized in the formation of both chlorinated and brominated THM species. $CHCl_3$ was the dominant specie. Lowering the chlorine dose or the organic precursor concentration (TOC) could result in decreased concentrations of the $CHCl_3$ species.

Summary

TTHM formation at the City Creek, Parleys, Big and Little Cottonwood water treatment plants was greatest during March to June and September to October (September 1980 through December 1981). The greater TTHM concentrations in the spring correlated with greater organic precursor concentrations in the spring snowmelt runoff. During the fall, organic precursor production from precipitation events, reservoir turnover, algal blooms, and possibly leaf-fall appear to be responsible. Slightly greater chlorine doses at the Little Cottonwood water treatment plant may have contributed to increased TTHM levels during fall of 1981. TTHM levels in the treated water were conspicuously low during July and August. Water temperatures were high at this time, but low concentrations of the organic precursors were mostly responsible for low TTHM levels. Inst-TTHM formation was greatest at the Little Cottonwood water treatment plant but did not exceed the MCL (100 μg/l). The primary difference seemed to be that the Deer Creek Reservoir water treated by that plant had more available organic precursor.

Influent organic precursor concentrations were not highly correlated with effluent TTHM levels at the water treatment plants, but there was a trend toward greater TTHM concentrations during periods of higher precursor levels. Influent organic precursor concentration as TOC may not be a good surrogate parameter for estimating TTHM levels in finished water.

The groundwater and reservoir water sources sampled and chlorinated contained a greater percentage of the brominated THM species than did the stream sources. The groundwater samples after chlorination contained the greatest amount of the brominated species (51 percent). The halogen chlorine was utilized in the formation of both chlorinated and brominated THM species.

Table 23. Mean percent of individual trihalomethane species in Salt County surface waters and groundwaters.[a]

Source	Chloroform, ($CHCl_3$) (%)	Dichlorobromomethane, ($CHBrCl_2$) (%)	Dibromochloromethane, ($CHBr_2Cl$) (%)	Bromoform, ($CHBr_3$) (%)
Little Cottonwood Water Treatment Plant: Deer Creek Influent	69	25	6	–
Little Cottonwood Water Treatment Plant: Effluent	80	16	4	–
33rd South Terminal Storage Reservoir: Effluent[b]	73	21	6	–
Parleys Water Treatment Plant: Effluent	62	28	10	–
Big Cottonwood Creek Water Treatment Plant: Effluent	88	11	1	–
City Creek Water Treatment Plant: Effluent	85	14	1	–
Groundwater Wells 1651 and 1657 (combined)[c]	49	32	19	–

[a] Terminal (7-day) trihalomethanes, except where specified.
[b] Instantaneous trihalomethanes.
[c] Maximum potential trihalomethanes (excess chlorine).

$CHCl_3$ (chloroform) was the dominant THM specie overall.

Distribution System

The mean and standard deviations of inst-TTHMs measured during 1981 at the water treatment plants and the distribution sampling sites are shown in Figure 30. Table 22 lists the sampling stations. The first four stations are the treatment plants. The two treatment plants using stream water as a source, City Creek (station 1) and Big Cottonwood Creek (station 3), produced the lowest inst-TTHM concentrations (11 and 12 µg/l, respectively) of the treatment plants. Product water from Parleys (station 2) and Little Cottonwood (station 4) treatment plants contained higher levels of inst-TTHMs (32 and 28 µg/l, respectively). These two plants treat reservoir water although the Little Cottonwood plant mixes about one part of stream to two parts of reservoir water. The mean and standard deviation were both greater for the Parleys plant, but it must be noted that Parleys plant data were missing during the winter months when TTHM levels would normally be lower.

Figure 31 shows the Little Cottonwood plant effluent mean free chlorine residual during 1981 (1.22 mg/l) to be greater than the other plants, but with a greater standard deviation. The greater free chlorine residual at the Little Cottonwood Plant results from post chlorination (less time for chlorine to be used up in oxidation reactions). The Parleys plant had the lowest average free chlorine residual (0.69 mg/l), although it was only slightly less than the values for the City Creek (0.86 mg/l) and Big Cottonwood Creek (0.80 mg/l) residuals. All three plants prechlorinate.

Although the Little Cottonwood plant post chlorinates, inst-TTHMs were nearly as great as at the Parleys plant. Evidently, influent TTHMs from Deer Creek Reservoir and the chlorine added at premix (up to 1.0 mg/l) increase inst-TTHM concentrations in the product water. The high mean free chlorine residual at the Little Cottonwood treatment plant was associated with term-TTHMs that were greater than at any other facility (up to 107 µg/l). Peak term-TTHMs from the Parleys plant (71 µg/l in May and 74 µg/l in October 1981) were slightly more than at Big Cottonwood (69 µg/l in April) and greater than at City Creek (54 µg/l in October) under finished water chlorination conditions.

The data from the distribution system (stations 5 through 17) should be representative of TTHM concentrations in municipal water throughout the Salt Lake City area (complete data can be found in Appendix B). The maximum inst-TTHM concentration found during 1981 was 64 µg/l at station 5 (October). This was less than the 100 µg/l MCL. Inst-TTHMs at all distribution stations averaged less than 40 µg/l for the year, and a free chlorine residual was almost always present at the time of sampling. A 0.2 mg/l free chlorine residual in distribution systems is required by the State of Utah.

The 33rd South finished water storage reservoir (station 6) receives its water supply from the Little Cottonwood water treatment plant. Mean inst-TTHMs (Figure 30) were higher than the treatment plant effluent samples (38 versus 28 µg/l, respectively). The mean free chlorine residual (0.75 mg/l) was about 40 percent less. These differences were the result of longer contact time for TTHM formation in the presence of a free chlorine residual. The storage reservoir mean TTHM concentration was the highest observed at any of the distribution sites.

Station 5 was a residence in very close proximity to the Little Cottonwood water treatment plant. It had an average yearly inst-TTHM concentration (38 µg/l) as high as the storage reservoir, and its mean free chlorine residual concentration (1.06 mg/l) was

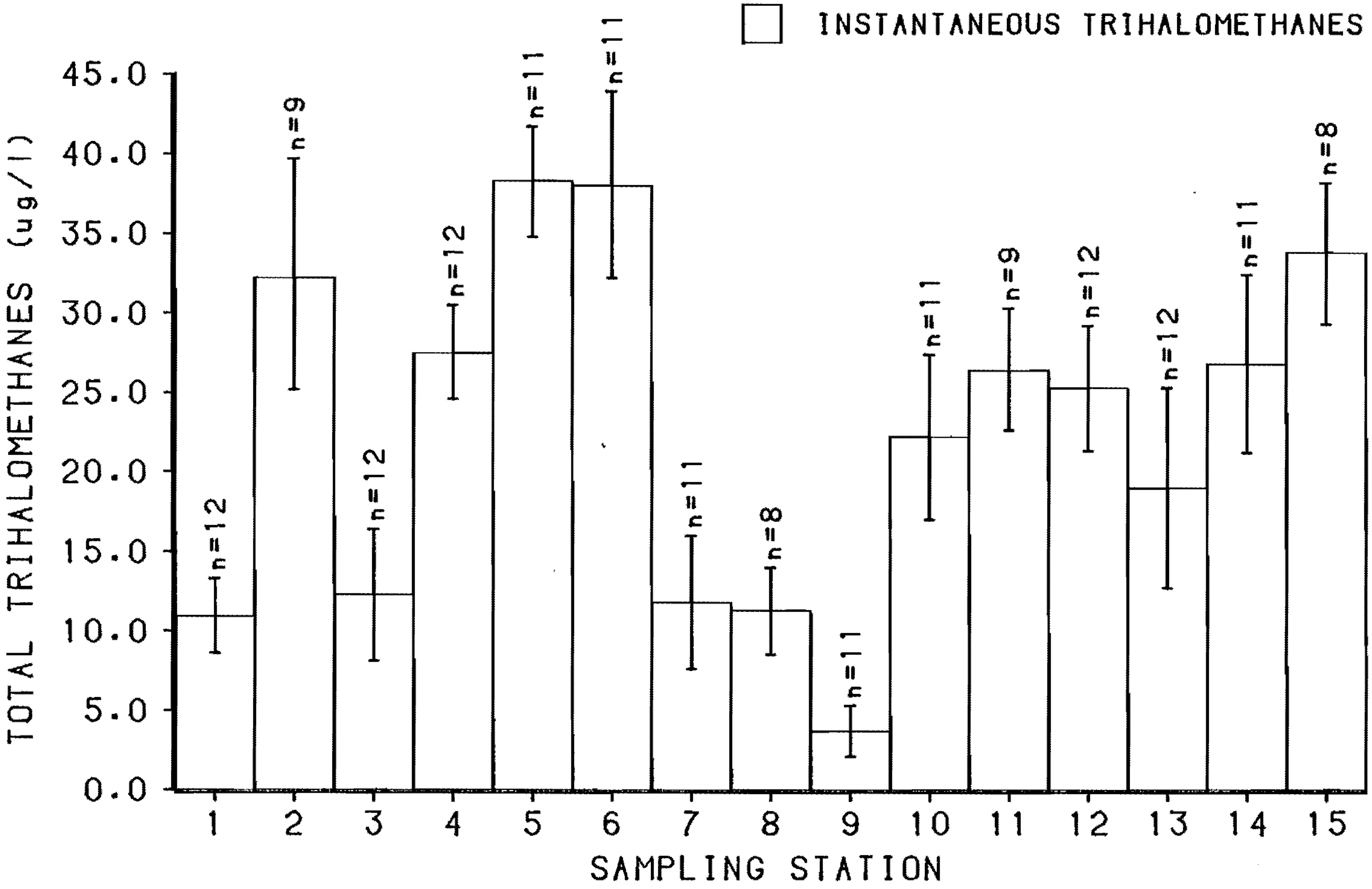

Figure 30. Finished water mean monthly instantaneous trihalomethanes with standard deviations for water treatment plants and distribution stations during 1981.

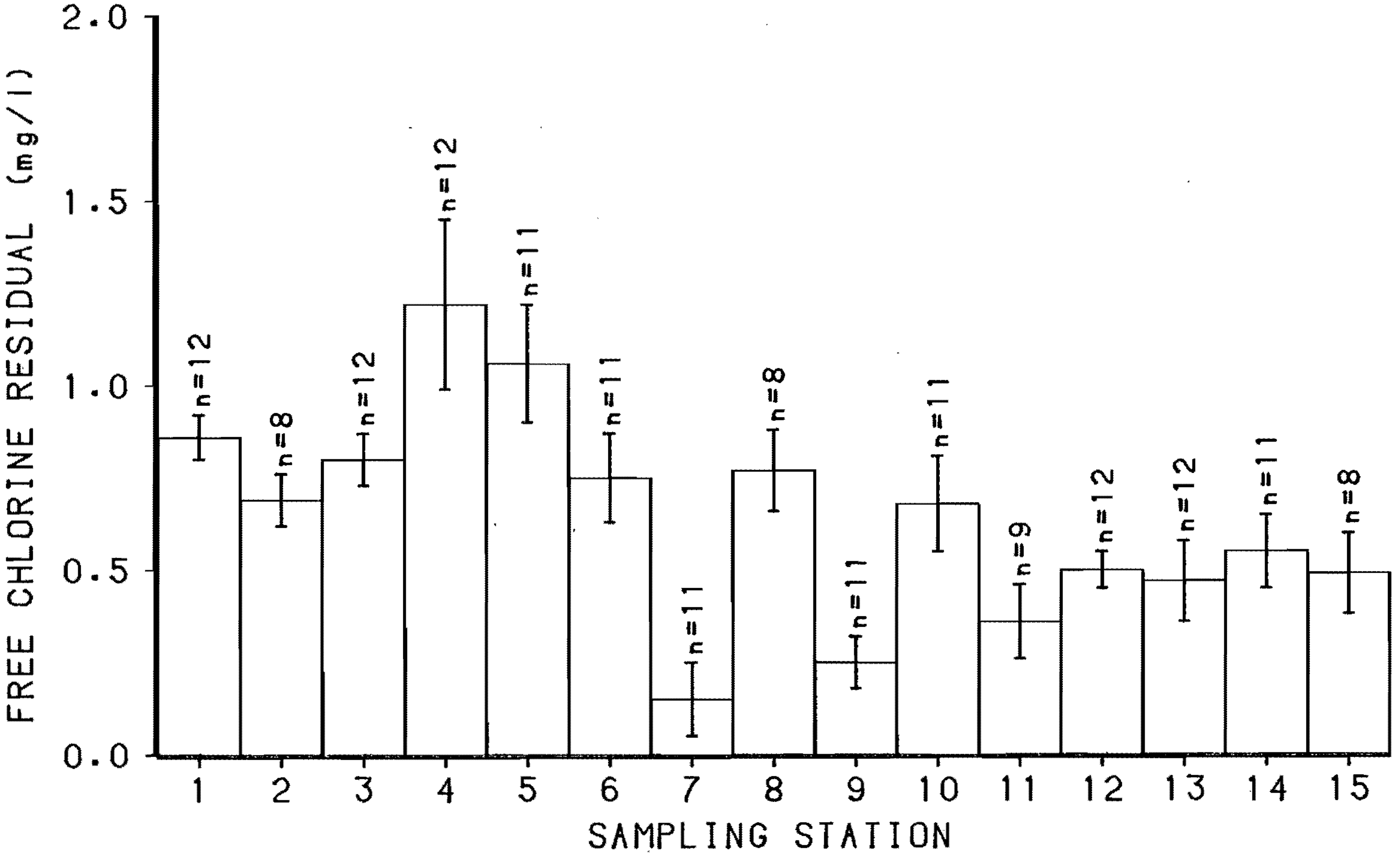

Figure 31. Finished water mean monthly free chlorine residuals with standard deviations for water treatment plants and distribution stations during 1981.

greater. This station can receive water from either Little or Big Cottonwood water treatment plants, depending on the season and pumping requirements (Schenck 1983). The high mean free chlorine residual concentration indicates that a large percentage of the water at station 5 was coming from the Little Cottonwood plant.

The distribution station furthest from the water treatment plants, station 15, had a comparatively high mean inst-TTHM level (34 μg/l), while maintaining a mean free chlorine residual of 0.49 mg/l. Mean inst-TTHMs, however, were not as high as at stations 5 and 6 even though water delivered to station 15 has a potentially longer residence time in the distribution system, and hence greater potential TTHM formation potential. Station 15 uses predominantly City Creek water, except in the summer when Little Cottonwood Creek and possibly Parleys water may be substituted. There is probably no well water dilution at this station. The mean inst-TTHMs at station 15 were equal to or greater than those at all water treatment plant effluents and indicate increased TTHM formation with time, especially if City Creek water was extensively used. The sample size at station 15 was, however, smaller (missing data were January through March).

Since TTHM formation uses the free chlorine residual over time, distribution stations with lower free chlorine residuals might be expected to have greater TTHM concentrations if the original doses were similar. Stations 7 and 9 had the lowest mean free chlorine residuals (0.15 and 0.25 mg/l, respectively) but also had comparatively low average inst-TTHMs (12 and 4 μg/l, respectively). The mean inst-TTHM concentration at station 9 was very low because that location is primarily supplied with spring water (from Neff Canyon). Spring water will normally contain lower concentrations of organic precursors than does surface waters. The chlorine dose averaged less than the relatively low value of 1.0 mg/l at station 9, and a small chlorine demand was exerted. The small standard deviations (see Figures 30 and 31) for inst-TTHMs and free chlorine residual indicate consistently low inst-TTHM formation at this site. Station 7 uses either Big or Little Cottonwood Creek water (usually Big Cottonwood). No well water is used but possibly some spring water. The low mean free chlorine residual of 0.15 mg/l reflects the long residence time of the water in the distribution system before reaching this site. Water is stored in holding tanks for gravity feed. The mean inst-TTHM concentration did not indicate increased TTHM formation with time.

Station 10, receiving water from the 33rd South storage reservoir (station 6), also did not produce increased inst-TTHMs with time. Although the mean free chlorine residual was nearly the same as station 6, inst-TTHMs dropped from an average of 38 μg/l to 22 μg/l. There may have been some loss of TTHMs due to volatilization. Well water dilution is minimal.

Station 11 uses Emmigration tunnel spring water. Mean inst-TTHMs there were 26 μg/l, greater than might be expected from this source. Station 13 uses water predominantly from the City Creek treatment plant. Very little well water is used. The mean inst-TTHM (19 μg/l) at station 13 was 8 μg/l greater than the mean for the City Creek plant, and the mean free chlorine residual (0.47 mg/l) was 0.29 mg/l less than at the plant. The free chlorine demand resulted in slightly greater TTHM formation with time. Likewise, another station using almost exclusively City Creek water (station 8) had mean inst-TTHMs almost identical to the treatment plant but practically no chlorine demand. In other words, organic precursors from this source water were of low concentration or did not readily react to form TTHMs. The residence time in the distribution system may have been very short.

The time variable patterns in which the waters from various sources mix in a large interconnected distribution network make it difficult to identify the water sources associated with the distribution system stations. Stations 12 and 14, specifically, use a variety of water sources. Concentrations of mean inst-TTHMs and free chlorine were similar at these stations and at about average values for the distribution network as a whole.

Two statistical tests were performed on the monthly distribution system data for the last 6 months of sampling (no missing data points). First, analysis of variance of the inst-TTHM means for the 10 sampling stations, excluding water treatment plants and the storage reservoir, identified a significant station by station variation, at the 99 percent confidence level. In other words, there were significant differences in inst-TTHM concentrations among the stations during that time period (May through October 1981) as influenced by water source, treatment, and distribution.

Second, simple linear regression of inst-TTHM against the free chlorine residual for the distribution stations did not produce a significant correlation. This was probably because the measured free chlorine residuals (and inst-TTHMs) were not associated with a specific source water but were affected by mixing and dilution.

Deep and shallow groundwater wells (stations 16 and 17) sampled in the spring and late summer (June and September) had maximum TTHM potentials (MTP) of 12 and 19 µg/l, respectively. The shallow well produced greater TTHM concentrations in both seasons, 19 µg/l in June and 17 µg/l in September. Organic precursor (TOC) concentrations for both wells were less than 0.5 mg/l in June. In September, the precursor concentration was 0.5 mg/l at the shallow well, and 3.0 mg/l at the deep well. The latter concentration seems high because of the low production of TTHMs. However, groundwater organic precursor as TOC has not been characterized and may not adequately predict TTHM formation.

MTP-TTHM concentrations measured from groundwater samples were less than those for stream and reservoir waters. The maximum TTHM concentration for groundwater was 19 µg/l. The minimum TTHM concentration for reservoir waters (Mountain Dell Reservoir) was 92 µg/l, and for stream waters (Parleys Creek) was 28 µg/l (the mean was 54 µg/l). Therefore it appears that uncontaminated groundwater sources have less potential for TTHM formation than surface water sources. In Salt Lake County, well water is pumped directly into distribution system lines, without prechlorination, hence groundwater TTHM levels would be dependent on the available free chlorine residual of concentration less than or equal to the water treatment facility effluent. Based on TTHM results, it appears that the deep well had slightly less available organic precursors. TTHM levels at both wells showed no appreciable difference between seasons. The brominated THM species represented a larger percentage of the TTHMs as also reported by Houghton (1946).

Summary

During 1981, water treatment plants which treated reservoir water, or a combination of stream and reservoir waters (the Parleys and Little Cottonwood plants, respectively), produced greater effluent mean inst-TTHM formation than plants treating strictly stream waters (City Creek and Big Cottonwood Creek). Water treatment schemes were similar at the City Creek, Parleys, and Big Cottonwood treatment plants (all plants routinely prechlorinate) but inst-TTHMs from Parleys water treatment plant effluent averaged 64 percent greater. The Little Cottonwood water treatment plant, which receives chlorinated Deer Creek Reservoir influent water and practices post chlorination, produced mean inst-TTHMs almost as great as the Parleys plant, and term-TTHMs were the highest of all plants (up to 107 μg/l). Influent organic precursor concentrations (as TOC) were consistently greater at the Parleys and Little Cottonwood water treatment plants.

Inst-TTHMs at all distribution stations (not including water treatment plants) averaged less than 40 μg/l for the year. Greatest concentrations were found at stations supplied specifically by the Little Cottonwood Creek water treatment plant, but mixing and dilution of municipal waters within the distribution system hindered comparisons of water source and distribution station data. The lowest mean inst-TTHM concentration (4 μg/l) occurred at a station (9) receiving exclusively spring water. TTHM formation was not inhibited by the absence of free chlorine at this station.

Groundwater samples which were chlorinated and measured for maximum TTHM potential (MTP) produced TTHM concentrations well below mean MTP TTHM concentrations for stream and reservoir waters. The maximum TTHM concentration from the groundwater samples was 19 μg/l. Spring and well waters had less TTHM formation potential than surface waters.

Unit Processes Analysis

The effect of water treatment plant unit processes on TTHM formation was examined at the Big and Little Cottonwood and Parleys treatment plants during June/July and September 1981. The raw data are in Appendix A. Schematic diagrams of the unit processes (Figures 2 and 3) and theoretical hydraulic detention times were used to schedule the taking of grab samples on selected dates as water passed through the plants. The concentrations of TTHMs and TOC in the samples are plotted on Figures 32 through 37. Hourly monitoring of the influent water was conducted to evaluate precursor concentration fluctuations.

Big Cottonwood Creek

The Big Cottonwood Creek water treatment plant has a design capacity of 42 mgd (15.9 x 10^4 m^3/d). The plant was monitored twice. On July 1, 1981, the plant was operating near capacity (40 mgd; 15.1 x 10^4 m^3/d). Chlorination was at rapid mix at a dose of 1.3 mg/l. The influent water temperature and pH were 14.5°C and 8.2, respectively. The water temperature increased to 19°C by the end of sedimentation and then decreased to 16°C by the end of treatment (effluent). The pH was immediately elevated to 8.6 at rapid mix (lime addition) but remained between 8.1 and 8.3 through the remaining treatment processes.

The influent organic precursor concentration (as TOC) was 1.3 mg/l (Figure 32). During treatment, precursor levels fluctuated considerably, but some of the differences in the concentrations might be attributed to sampling time and location (grab samples, not composite samples, were obtained). Influent precursor concentrations monitored hourly during sampling produced little variation, indicating a constant precursor source. From the end of flocculation to the filter influent precursor concentration increased from 1.3 to 2.3 and then declined to 0.8 mg/l. The increase in organic precursor concentration through the sedimentation basin may have been due to the resuspension of settled material. The sedimentation basin has a split level configuration which minimizes depth but sometimes resuspends the floc at capacity flows (Big Cottonwood plant personnel 1983). Rapid sand filtration then removed 1.3 mg/l of precursor. The overall removal of organic precursor through the treatment plant was 0.4 mg/l (31 percent).

The free chlorine residual concentration after rapid mix was 1.0 mg/l, hence the initial chlorine demand (based

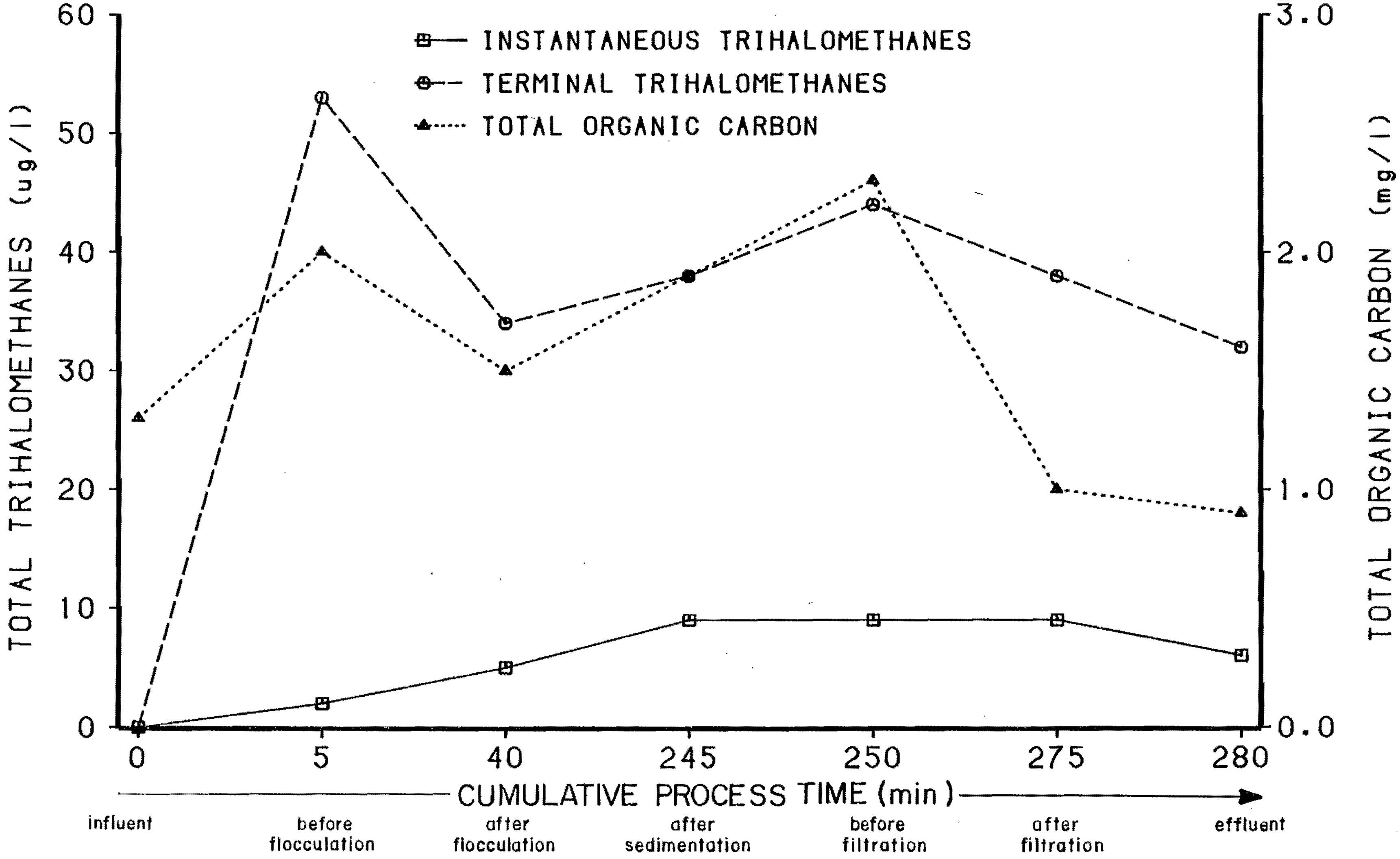

Figure 32. Trihalomethane formation and total organic carbon reduction at the Big Cottonwood water treatment plant on July 1, 1981.

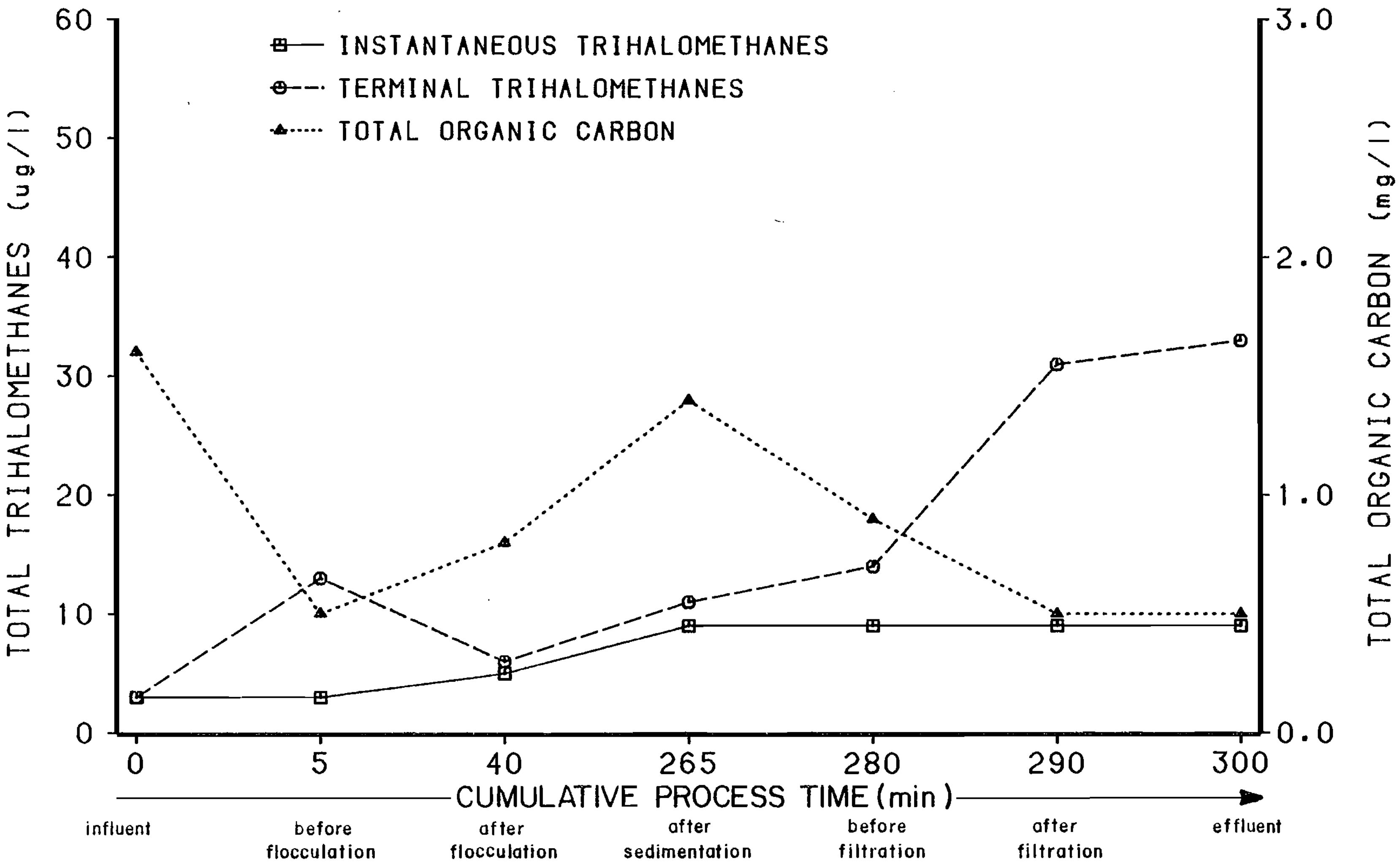

Figure 33. Trihalomethane formation and total organic carbon reduction at the Big Cottonwood water treatment plant on September 24, 1981.

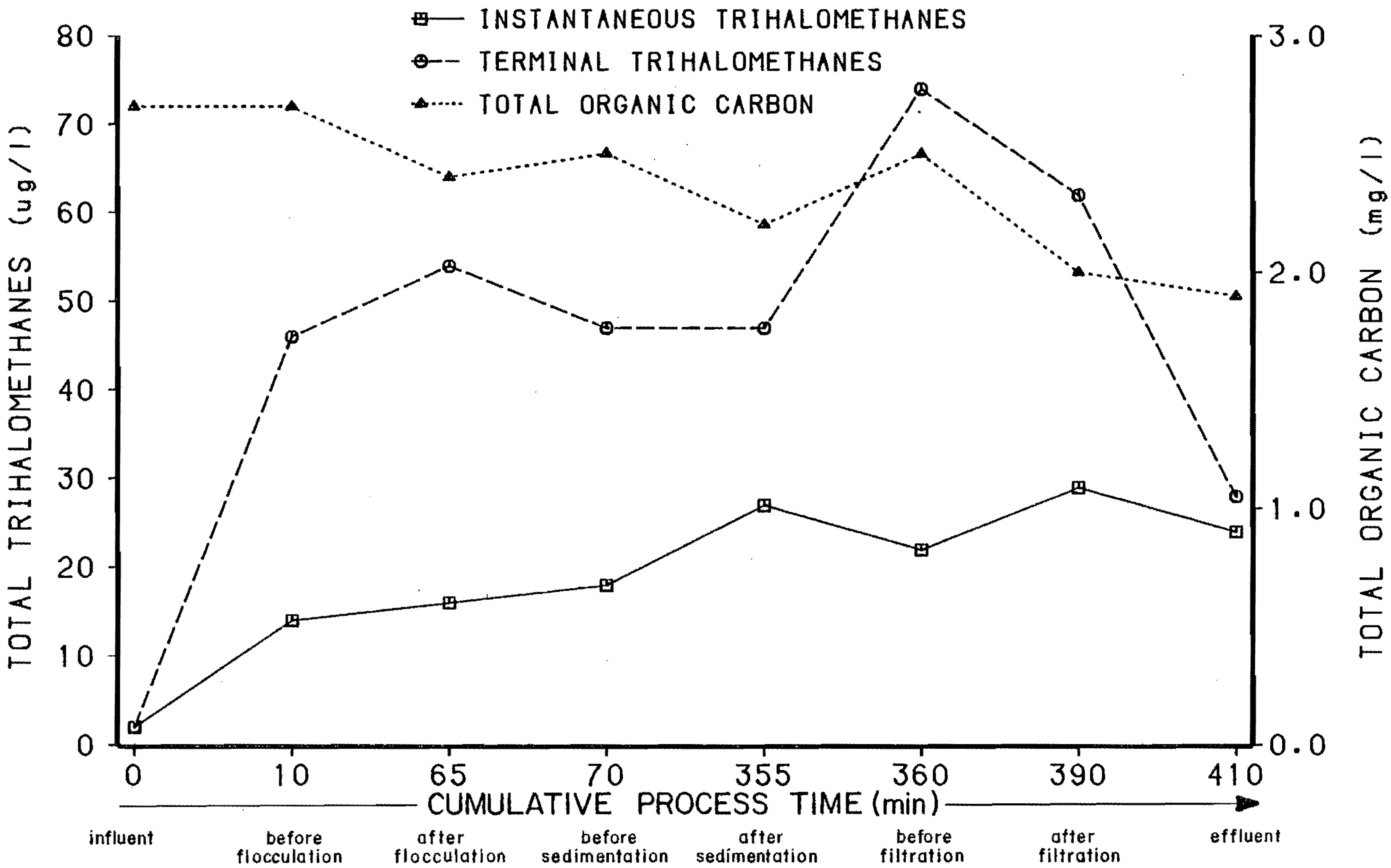

Figure 34. Trihalomethane formation and total organic carbon reduction at the Parleys water treatment plant on July 1, 1981.

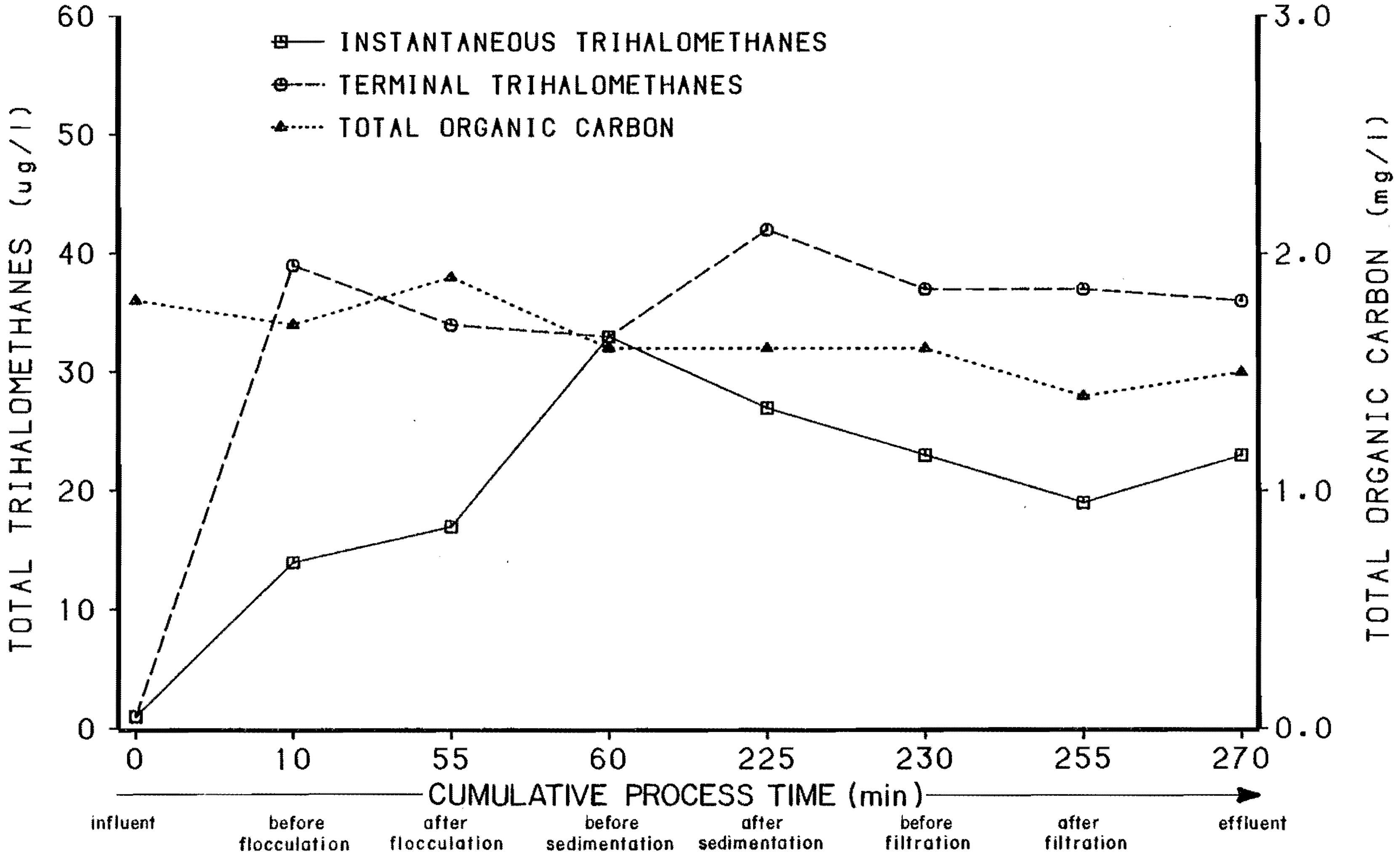

Figure 35. Trihalomethane formation and total organic carbon reduction at the Parleys water treatment plant on September 24, 1981.

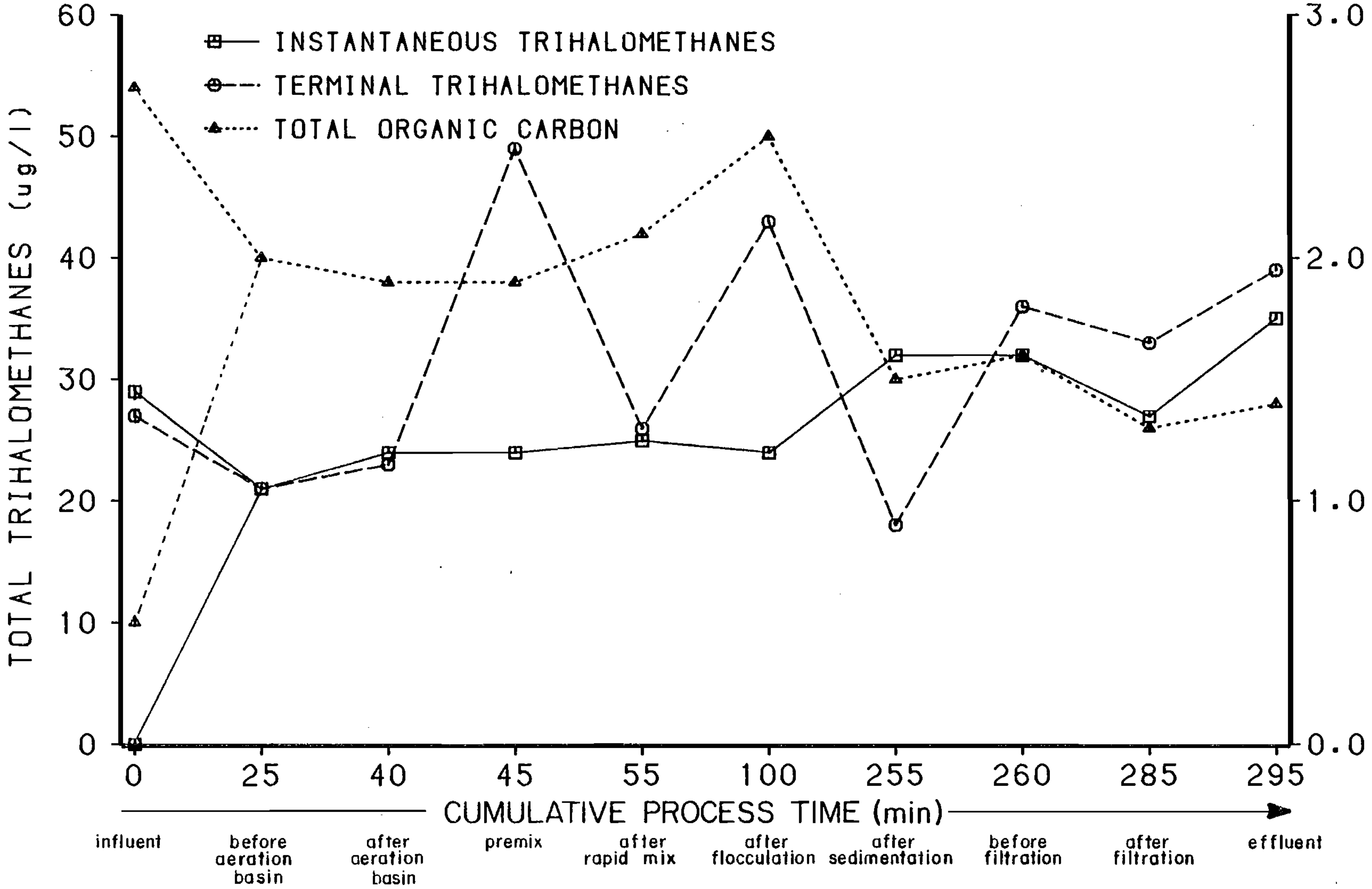

Figure 36. Trihalomethane formation and total organic carbon reduction at the Little Cottonwood water treatment plant on June 30, 1981.

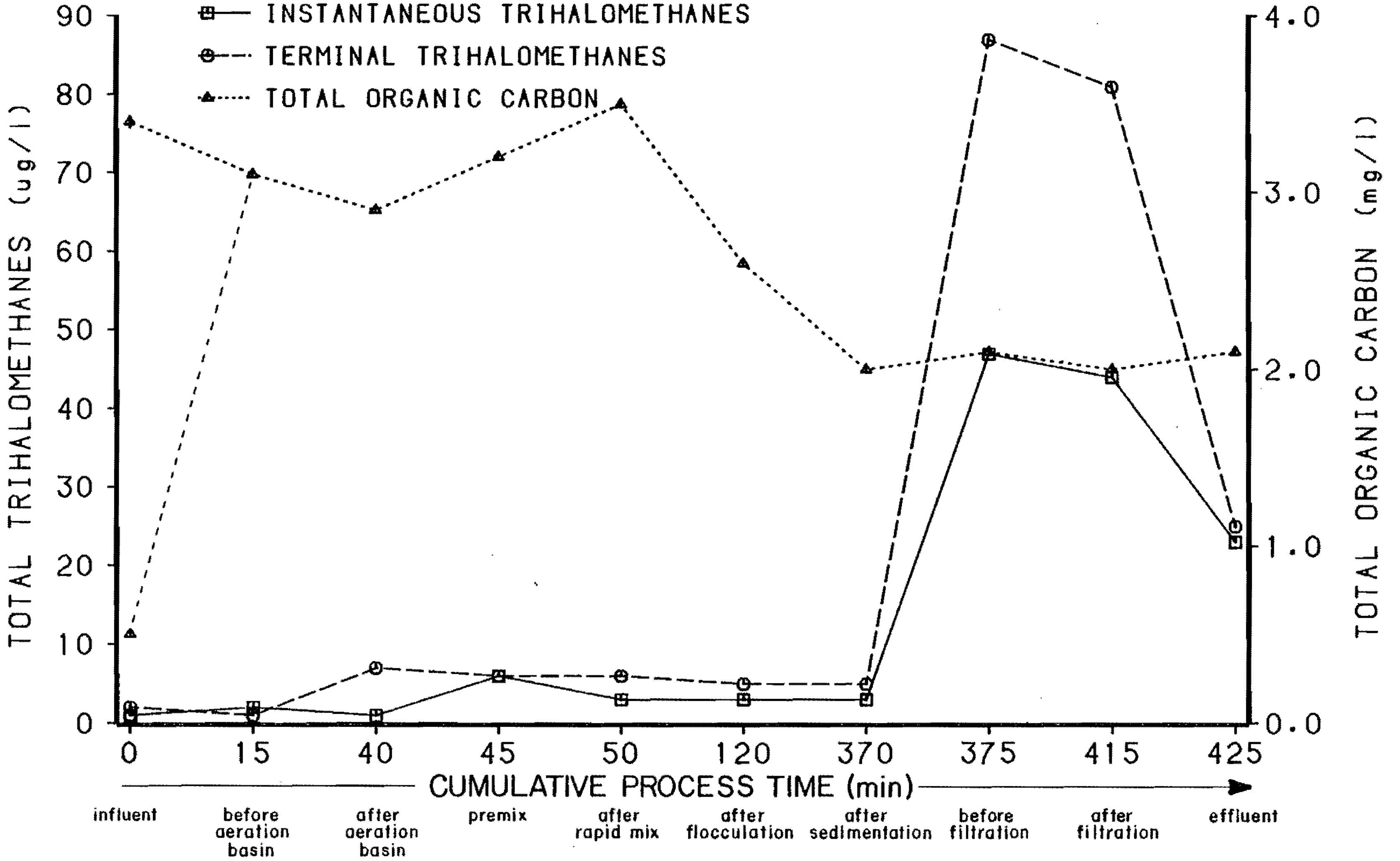

Figure 37. Trihalomethane formation and total organic carbon reduction at the Little Cottonwood water treatment plant on September 24, 1981.

on chlorine dose) was only 0.3 mg/l. During the remainder of treatment, the free chlorine concentration was between 0.70 and 0.90 mg/l. TTHM formation occurred after chlorine application at rapid mix (Figure 32). Inst-TTHM formation exhibited a steady increase with contact time until filtration. The inst-TTHM concentration was 9 μg/l through filtration and then dropped to 6 μg/l in the clearwell effluent, probably because of mixing with the other effluent waters. Filtration was either effective in removing TTHMs or else further inst-TTHM formation did not occur. Term-TTHM formation immediately after chlorination was 53 μg/l, the highest value measured during treatment. The pH and free chlorine residual concentration were greatest at this time. Term-TTHMs fluctuated with organic precursor concentration through the treatment process. Since free chlorine residuals were relatively constant after flocculation, organic precursor concentration most likely governed term-TTHM formation and may have reduced it some during treatment. The effluent term-TTHM concentration was 32 μg/l. TTHM levels at the Tanner storage reservoir supplied by this plant were 11 μg/l inst-TTHMs and 31 μg/l term-TTHMs. A higher water temperature (21°C) and longer contact time apparently increased inst-TTHMs from 6 to 11 μg/l. Term-TTHM formation was limited by low precursor concentrations and possibly the chemical nature of the precursor compounds.

On September 24, 1981, the Big Cottonwood Creek treatment plant was operating at a flow of 18.5 mgd (70 x 10^3 m^3/d), but only one-half of the plant was in use. The influent pH and water temperature were 8.1 and 17.0°C, respectively. The pH remained nearly constant (7.9 to 8.1) during treatment. The water temperature increased to 20°C after flocculation, but then decreased to 15°C after sedimentation and remained at that temperature. The chlorination dose at rapid mix was 1.4 mg/l. A trace of chlorine (0.10 mg/l total chlorine) was measured in the influent water as a result of recycling some finished water.

The influent organic precursor concentration measured at the start of the monitoring was 1.6 mg/l, but hourly monitoring of the influent throughout the day gave a mean concentration of about 0.7 mg/l. The precursor concentration increased to 1.4 mg/l through flocculation/sedimentation (Figure 33). Rapid sand filtration removed some additional organic precursor.

TTHMs were detected in the plant influent prior to chlorination because of some finished water recycle. Inst-TTHMs increased (to 9 μg/l) during flocculation/sedimentation, and the organic precursor concentration increased as well. This inst-TTHM concentration was maintained through the filtration and clearwell processes. Term-TTHM levels did not fluctuate with organic precursor concentrations, and in fact, attained their highest measured concentrations from filter effluent and clearwell effluent samples where the precursor concentration was lowest. It is not clear why the TTHM formation potential increased after filtration but both filter effluent and plant effluent samples detected increased term-TTHM formation (up to 33 μg/l). During the sampling time for rapid sand filtration, the raw turbidity was being reduced from 30 turbidity units to an average of about 0.05 turbidity units; and filter backwash was not taking place. Therefore, filter performance was not suspected of causing the increased TTHM formation potential. TTHM concentrations at the Tanner storage reservoir were 15 μg/l (inst-TTHM) and 23 μg/l (term-TTHM) in the presence of a free chlorine residual. Therefore, inst-TTHMs increased from 9 (plant effluent) to 15 μg/l but the TTHM formation potential decreased.

Summary

Inst-TTHM concentrations in the unit processes of the Big Cottonwood water treatment plant had similar patterns on July 1 and September 24, 1981. The concentrations increased with contact time through flocculation/sedimentation and then remained constant through filtration. Rapid sand filtration (with anthracite coal) was either successful in reducing (removing) inst-TTHMs or further TTHM formation did not occur. Inst-TTHM concentrations reached 9 μg/l in the plant on both dates. Term-TTHMs, which are not dependent on contact time, had greater formation potential during treatment on July 1 than on September 24, but effluent term-TTHMs were nearly the same on both dates (32 and 33 μg/l). Chlorine doses were also similar. At the finished water storage reservoir, sampled after water treatment, inst-TTHM concentrations increased about 40 percent and term-TTHMs were equal to or less than the plant effluent concentrations. Rapid sand filtration was the most effective treatment process for organic precursor removal, but term-TTHMs unaccountably increased through filtration on September 24. Organic precursor and term-TTHM concentrations (to a lesser extent) increased through the sedimentation basin, probably as a result of resuspension or organic matter caused by short circuiting and sludge blanket disturbance from capacity plant flows. Precursor concentrations were greater on July 1, and removal efficiencies were about the same in July and September (30 percent).

Parleys Canyon

The design treatment capacity for the Parleys water treatment plant is 32 mgd (12 x 10^4 m^3/d). Prechlorination at rapid mix is normally practiced (see Figure 2). On July 1, 1981 the plant flow was 20 mgd (76 x 10^3 m^3/d), and the chlorine dose at rapid mix was 2.4 mg/l, higher than normal. The influent water temperature was 15°C. Minor fluctuations in water temperature occurred during treatment, and the effluent water temperature was 13.5°C. The pH remained between 7.5 and 7.7 during treatment (lime was not added). Alum and activated silica (for high turbidity) were used in July for coagulation/flocculation.

The influent (from Mountain Dell Reservoir) organic precursor concentration (as TOC) was 2.7 mg/l (Figure 34). Influent precursor concentrations monitored hourly during sampling showed little fluctuation, indicating a relatively constant precursor source. This concentration generally decreased through all treatment processes to an effluent concentration of 1.9 mg/l, a 30 percent reduction. The increase in precursor concentration shown in the launder (between sedimentation and filtration) may have been the result of sampling variability, and not representative of unit process concentrations.

The influent water contained very low concentrations of free chlorine (0.05 mg/l) and TTHMs (2 μg/l), from recirculated finished water. Upon chlorination at rapid mix, inst-TTHMs increased to 14 μg/l and continued to increase to 29 μg/l after filtration. A free chlorine residual of 0.75 mg/l just after chlorination (2.4 mg/l chlorine dose) indicated a strong chlorine demand. The unit processes did not appear to be effective inst-TTHM removal mechanisms. Inst-TTHMs and organic precursor concentrations followed the expected patterns of formation/removal for a treatment process with prechlorination, a steady increase of inst-TTHMs and a steady decrease of organic precursor. There was a pronounced increase of term-TTHMs to 46 μg/l upon chlorination at rapid mix. Another increase occurred in the launder (up to 74 μg/l). This was probably because of mixing and sample variability as the precursor concentration and chlorine residuals were also greater at this time. The term-TTHM concentration then decreased through the filters (as did organic precursor concentration), and finally through the clearwell to 28 μg/l. The clearwell sample was composed of finished water from all filters and was not necessarily representative of the individual filter sampled. Term-TTHMs at the Baskin storage reservoir, which received mostly Parleys finished water, were greater (54 μg/l) than the plant effluent but had similar residual chlorine concentrations. The measured plant effluent term-TTHM concentration was apparently not representative of the actual TTHM formation potential, possibly because of sampling variability.

On September 24, 1981, the Parleys water treatment plant was operating at 15 mgd (57 x 10^3 m^3/d), but only one side of the plant was being used (see Figure 2). This means that the hydraulic flow was near design capacity and the total hydraulic detention time was less than on July 1. The prechlorination dose was 2.2 mg/l. Water temperatures were relatively constant with treatment. The influent temperature was 19.0°C, and the effluent temperature was 18.0°C. The pH decreased from 8.1 to 7.6 during treatment, primarily during rapid mix and flocculation.

The influent organic precursor concentration (1.8 μg/l) was less than on July 1 (Figure 35). Influent concentrations remained at about this level during sampling. Precursor concentrations again decreased during treatment, but only by about 17 percent. The organic precursor may have been almost totally in a dissolved form and therefore difficult to remove by conventional water treatment processes. On the other hand, there may have been some inefficient sedimentation or resuspension of organic matter because of the short hydraulic detention time.

TTHM formation occurred after chlorination at rapid mix. Inst-TTHMs were within the same range of concentrations (10 to about 30 μg/l) as inst-TTHMs sampled on July 1. The peak inst-TTHM level measured was 33 μg/l at the influent to sedimentation. The residual chlorine data show that a chlorine demand occurred between rapid mix and the start of sedimentation, increasing inst-TTHM formation, but the inst-TTHM concentration (33 μg/l) at sedimentation seems high because the term-TTHM concentration was no greater at this point. Some of the TTHM samples had small air bubbles and TTHM volatilization, resulting in lower term-TTHMs, could have occurred. Filtration and possibly sedimentation reduced inst-TTHM formation to 19 μg/l. The term-TTHM concentrations were relatively constant after sedimentation, as were precursor concentrations and chlorine residuals. The term-TTHM concentration at the Baskin storage reservoir was greater (47 μg/l) than the finished water (36 μg/l), and chlorine residuals were less at the reservoir, but the reservoir was sampled prior to the finished water sample. Therefore, the difference in term-TTHM levels may be attributed to the time of sampling.

Summary

Treatment processes at the Parleys plant removed 30 percent of the influent organic precursor concentration on July 1, and 17 percent on September 24, 1981. The influent organic precursor concentration was greater in July (2.7 mg/l) than in September (1.8 mg/l), and term-TTHM formation during treatment was greater in July than in September. Chlorine doses were similar (2.2 and 2.4 mg/l). Inst-TTHM concentrations were mostly within the same range (10 to 30 μg/l) during both sampling periods.

In July, unit processes did not effectively reduce inst-TTHM formation. Term-TTHM formation was reduced slightly (12 μg/l) by rapid sand filtration and in the clearwell, but the effluent concentration (28 μg/l) was less than the concentration in the storage reservoir (54 μg/l). In September, inst-TTHM formation was apparently reduced by the sedimentation and filtraton processes. Term-TTHM (and inst-TTHM) formation was initiated by chlorination at rapid mix (as in June), and treatment processes had little or no effect on the reduction of this formation. Once again, the storage reservoir term-TTHM concentration (47 μg/l) was greater than the treatment plant effluent concentration (36 μg/l), and the effluent concentration in September was more representative of TTHM formation potential than in June. The difference in term-TTHM concentrations between the effluent and reservoir, however, could have been partly dependent on time of sampling; the storage reservoir was sampled about 1 hr before the treatment plant effluent was sampled.

Little Cottonwood Creek

The Little Cottonwood water treatment plant's design treatment capacity is 100 mgd (38 x 10^4 m^3/d). The amount of water being treated on June 30, 1981, was 115 mgd (43 x 10^4 m^3/d), 15 percent greater than rated capacity. Deer Creek Reservoir water accounted for 64 percent of the influent water, and the remaining 36 percent was from Little Cottonwood Creek. Post chlorination at the filter influents, after sedimentation, is the standard practice (see Figure 3). Chlorine addition will also occur at premix (up to about 1.0 mg/l) in combination with activated silica and lime. Aluminum sulfate (alum) is added just before coagulation at the rapid mix. On June 30 a 1.1 mg/l post chlorination dose was being used, and potassium permanganate ($KMnO_4$) was added at the raw water influent. The influent water temperature (measured from a sampling tap line) was 20°C for both sources. Water temperature decreased to 12°C after permanganate addition and then increased to 19°C through sedimentation (the sedimentation basins are not covered). The effluent temperature was 15.5°C. The influent pH was 7.8. Chemical addition at premix decreased the pH temporarily to 7.5 and sedimentation raised it to 8.1. The effluent pH was 8.0.

The influent organic precursor concentration (as TOC) from Deer Creek Reservoir (2.7 mg/l) was greater than for Little Cottonwood Creek (< 0.5 mg/l). These precursor sources remained fairly constant during sampling. The premix and flocculation processes increased the combined concentration of organic precursor to 2.5 mg/l, presumably from chemical addition, but sedimentation effectively removed organic precursor by as much as 1 mg/l (Figure 36). Rapid sand filtration provided some additional removal. Some floc carryover from less effective sedimentation may occur at hydraulic flows greater than 100 mgd (38 x 10^4 m^3/d) (Little Cottonwood plant personnel 1983), but the precursor removal data did not indicate that this was happening. The effluent organic precursor concentration was 1.4 mg/l, 30 percent less than the combined influent concentration.

The Deer Creek Reservoir influent produced 29 μg/l of inst-TTHMs because of aqueduct chlorination (0.5 mg/l chlorine). Little Cottonwood Creek had no inst-TTHMs. Even with chlorine addition at premix, inst-TTHM formation did not increase until sedimentation, although the organic precursor concentration decreased through sedimentation. The inst-TTHM concentration at the end of sedimentation was 32 μg/l. The temperature increase through sedimentation, possibly some related algal growth, and increased contact time, may have promoted the additional TTHM formation. A free chlorine demand was exerted through sedimentation. The effectiveness of filtration in removing some inst-TTHMs after chlorination is uncertain because the grab samples did not contain chlorine concentrations representative of the dose (poor dosage control has been reported by plant personnel 1983) to allow a valid comparison. Some precursor was removed. Inst-TTHMs increased with chlorine concentration and contact time in the clearwell to 35 µg/l (a composite sample of all filter effluents).

Term-TTHMs increased after premix, with the chlorine addition, to 49 µg/l. The term-TTHM concentration measured at the influent to flocculation was unexpectedly low as precursor and free residual chlorine concentrations at flocculation were similar to after premix, and these two sampling sites were very close to each other. The term-TTHM concentration (18 µg/l) measured at the end of sedimentation, which was less than the inst-TTHM concentration at the end of sedimentation, was probably the result of the very low free chlorine concentration (0.05 mg/l) and degradation of the sample before measurement. TTHM formation after chlorination at filtration was apparently limited by the free chlorine concentration (0.10 mg/l at the filter influent and effluent). Term-TTHMs (66 µg/l) were higher at the 33rd South storage reservoir for the Little Cottonwood plant than in the finished water effluent (39 µg/l), but inst-TTHMs were equal to concentrations in the plant effluent. The reservoir sample was obtained before the effluent sample and may not have accurately represented the nature of the finished water.

During sampling on September 24, 1981, the flow through the treatment plant was 66.5 mgd (25 x 10^4 m^3/d) of which 80 percent was from Deer Creek Reservoir and 20 percent from Little Cottonwood Creek. The post chlorination dose at the filters was reported to be 1.0 mg/l. Influent water temperatures (measured at sampling tap lines) were both about 22°C. After potassium permanganate addition, the influent water temperature was 19°C, where it remained during most of treatment. The influent pH of 7.5 increased to 9.2 after premix (lime addition) and then reduced during treatment to 7.8 at the effluent.

The combined average influent organic precursor concentration was 3.1 mg/l (predominantly from Deer Creek Reservoir). The hourly measurements of influent organic precursor concentration from Deer Creek Reservoir fluctuated between 3.3 and 4.0 mg/l, and this could have been responsible for some concentration variability measured during the treatment processes. The flocculation process decreased the precursor concentration to 2.6 mg/l (Figure 37), according to the data, whereas in June precursor concentration increased through flocculation. The coagulation process in September was apparently removing some of the organic precursor concentration. The detention time in the flocculation basin was approximately 25 minutes longer in September than in June and this may have enhanced precursor removal. Sedimentation provided further removal (down to 2.0 mg/l). Rapid sand filtration had little effect on the measured precursor concentration. The treatment processes were effective in removing 32 percent of the influent organic precursor concentration.

The influent TTHM concentrations from Deer Creek Reservoir were 2 µg/l or less in the presence of a free chlorine residual (0.10 mg/l). TTHM concentrations remained very low through sedimentation even though a free chlorine residual was present (up to 0.90 mg/l) from chlorination at premix. Precursor concentrations were adequate for TTHM formation, and the pH (9.2 after rapid mix) favored maximum TTHM formation. After chlorination at filtration, the free chlorine residual was 2.80 mg/l and TTHM formation increased substantially (the reported chlorine dose of 1.0 mg/l was questionable because the measured residuals were so high). Term-TTHMs reached 87 µg/l after chlorination. The greater chlorine concentration was seemingly necessary to initiate significant TTHM formation. Both inst-TTHM and term-TTHM concentrations decreased through the clearwell, as did the free available chlorine concentration (to 1.50 mg/l). Effluent inst-TTHM and term-TTHM concentrations were 23 and 25 μg/l, respectively. Oxidation processes and mixing of effluent from different filters, with varying chlorine doses, probably resulted in the lower TTHM formation in the finished water. The term-TTHM concentration in the finished water was unexpectedly low, although TTHM formation potential (term-TTHM less inst-TTHM) prior to post chlorination was very low also. Either the sample measurement was in error, or the low formation potential was due to the nature of the organic precursor. The September sampling was during the period of maximum algal biomass for the year in Deer Creek Reservoir (Little Cottonwood plant personnel 1983). The potential for TTHM formation was quite high, compared to other treatment plant data, but actual formation only occurs with a greater than normal free chlorine concentration. The influent precursor concentration from Deer Creek Reservoir (3.4 mg/l) was greater than any other measured during June/July or September sampling dates. It was not possible to sample the storage reservoir on September 24 (no access) to determine the levels of TTHMs after water treatment.

Summary

The Deer Creek Reservoir water contributed the majority of the influent organic precursor concentration during June and September. Sedimentation provided the primary removal of organic precursor. Overall precursor removal was 30 percent on June 30, and 32 percent on September 23, 1981. The Deer Creek Reservoir influent contained 29 μg/l of inst-TTHMs in June. This inst-TTHM concentration increased after sedimentation in the presence of greater pH and temperature and an available free chlorine residual. The effluent inst-TTHM concentration (35 μg/l) was only slightly greater than the Deer Creek Reservoir influent concentration (29 μg/l). Term-TTHMs on June 30 fluctuated with chlorine dose and treatment process and formation was apparently limited by the free available chlorine concentration. It was not possible to show an effect of treatment process on term-TTHM formation, except for an increase of the finished water term-TTHM concentration to 66 μg/l at the storage reservoir. A treated water flow greater than the design plant capacity may have caused some short circuiting and floc carryover in the flocculation and sedimentation processes and contributed to the widely fluctuating term-TTHM concentrations.

On September 24, 1981, the Deer Creek Reservoir influent did not contribute substantial TTHM concentrations even though its precursor concentration was high (3.4 mg/l). Significant TTHM formation did not occur until post chlorination at filtration, but a free chlorine residual had been present and a high pH (up to 9.2) favored TTHM formation. TTHM formation and formation potential were high (inst-TTHMs of 44 μg/l and term-TTHMs of 87 μg/l) after chlorination, but finished water concentrations after the clearwell were lower with almost no formation potential. Either the sample measurement was in error, or the low formation potential was due to the nature of the organic precursor. Data were not available from the storage reservoir to compare to finished water values.

Unit Processes Discussion

The original intention was to study TTHM formation during the water treatment processes during spring runoff, when TTHM precursor loads to the plants were anticipated to be at their highest, and in the late summer when recreational activities on the watersheds and reservoir algal blooms have the greatest impacts. The unit processes were first monitored about the first of July, after the May spring runoff peak. Thus the TTHM formation and concentrations may have been different than those during the peak spring runoff. The unit processes were evaluated again in late September at a time of high algal biomass in the Deer Creek Reservoir.

Two factors hindered evaluation of unit process performance on organic precursor removal and TTHM formation: 1) the one time grab samples give no information on variability, and 2) the lack of a maximum TTHM formation potential measurement (MTP) did not allow the precursor demand for chlorine to be exhausted for process comparison of TTHM formation reduction. Sampling the unit processes on a schedule matching hydraulic detention time (as closely as possible), reduced the effect of fluctuating influent precursor concentration, but short circuiting and incomplete mixing meant that it was not eliminated.

At all the water treatment plants, the unit processes reduced the influent organic precursor concentration (as TOC) by about 30 percent. Inst-TTHM concentrations usually increased with process time and appeared to be dependent on the magnitude of the chlorine dose and precursor concentration. The larger increases of inst-TTHM concentrations were during flocculation and sedimentation processes with their longer detention times. The Big Cottonwood water treatment plant had the lowest levels of inst-TTHM formation and precursor concentrations (and chlorine doses) during both sampling periods, even though some organic matter resuspension apparently occurred in the sedimentation process as a result of short hydraulic detention times. This plant used only stream water. The plants treating reservoir water, Parleys and Little Cottonwood, produced higher inst-TTHMs during water treatment, and overall higher TTHMs at the distribution storage reservoirs. These plants had slightly higher water temperatures in September. Rapid sand filtration was successful at either reducing or preventing inst-TTHM formation. Finished water (after the clearwell) TTHM concentrations (mostly term-TTHM) were frequently less than during treatment, but the finished samples were a composite of all filter effluents, whereas prior samples were from an individual treatment train. This could indicate differential filter performance for removing organic precursors.

At the Big Cottonwood treatment plant, on July 1, the organic precursor concentration apparently limited TTHM formation after the flocculation process. There was no evidence, based on inst-TTHM and term-TTHM formation at the storage reservoirs, that the precursor concentration was limiting TTHM formation after treatment at any other time for all treatment plants. The amount (and nature) of organic precursor seemed to be the key factor for TTHM formation after water treatment, provided an available free chlorine residual existed, which was always the case. The higher chlorination doses tended to increase levels of TTHM formation during treatment. Lower doses might slow TTHM formation, thereby decreasing inst-TTHM concentrations in the treatment plant effluents.

CONCLUSIONS

Watersheds

1. The mean organic precursor load during May (spring runoff) for the three primary watersheds (Parleys Canyon, Big Cottonwood, Little Cottonwood) was approximately 18 times greater than during other seasons. The greater precursor loading resulted from both a greater precursor concentration and streamflow quantity. The mean concentration of organic precursor (total organic carbon, TOC) measured during the spring was 3.4 mg/l, values for the other seasons ranged from 0.9 to 1.4 mg/l.

2. Instream precursor concentrations ranged from less than 0.5 mg/l to 7.0 mg/l at stations sampled on a regular basis.

3. Little Cottonwood and City Creeks had lower average organic precursor concentrations (1.1 and 1.3 mg/l, respectively) than Big Cottonwood, Parleys Canyon, and Red Butte Creeks (2.0, 2.0, and 2.1 mg/l, respectively).

4. Precursor concentration was determined to be significantly greater during August at stream station B4 (Big Cottonwood Creek downstream from Brighton) than stations B1 and B2, which were farther downstream. The north fork of Lambs Creek in Parleys Canyon watershed was a significant contributor to precursor concentration and loading during August also.

5. Satisfactory correlations between organic precursor concentration as total organic carbon and maximum total trihalomethanes (MTP test) were determined for Big Cottowood Creek waters and Parleys Canyon waters.

6. Stream discharge versus organic precursor concentration correlations produced a strong linear relationship (maximum r^2 = 92 percent at $\alpha = 0.005$). Average stream discharge was 76 percent of normal.

7. Organic precursor loading derived from snowmelt runoff was calculated to be no more than 3 percent of the instream loading for the time period. Loading from rainfall runoff was calculated to be 30 to 100 percent of comparable instream loading for the time period in Big Cottonwood and Lambs Creeks, respectively.

8. Surface runoff did not occur at enough times and places to examine any differences in potential organic precursor input to stream systems among surface runoff sources. Only on disturbed areas (roads, etc.) or during intense rain events did appreciable surface runoff occur.

9. Total trihalomethanes (MTP test) from stream sampling had greater concentrations during high streamflow from precipitation events.

10. Data from Mountain Dell Reservoir, its source streams and the Parleys water treatment plant suggest that the impoundment of surface water supplies increases the organic precursor concentration and TTHM formation potential.

11. Both leaf litter and surface soils were shown to be potentially significant sources of total trihalomethane (TTHM) production through leaching analysis. Organic precursor and TTHM mass concentrations (g per 100 g sample) for leaf litter were approximately 19 times those for soils. The

TTHM formation potential (determined here as the ratio of TTHM concentration to precursor concentration) for both sample types was similar. Chloroform ($CHCl_3$) was by far the dominant THM species produced from chlorination of leaf and soil leachate.

12. Deciduous vegetation produces greater mass concentrations of organic precursor and TTHM than does coniferous vegetation.

Water Treatment and Distribution

1. TTHM formation at the City Creek, Big and Little Cottonwood water treatment plants was greatest during March to June and September to October. The greater TTHM concentrations in the spring correspond to greater organic precursor concentrations in the watershed runoff. Organic precursor production from intense rainfall events, reservoir turnover, algal blooms, and leaf-fall are possible explanations for greater TTHMs in the fall.

2. Instantaneous-TTHM and terminal-TTHM formation was greatest at the Little Cottonwood water treatment plant, but even there amounts did not exceed the USEPA maximum contaminant level (MCL) of 100 μg/l for inst-TTHMs. The Deer Creek Reservoir influent water to the plant had more available organic precursor and appeared to be the primary cause of increased TTHM formation.

3. Influent organic precursor concentrations correlated poorly with effluent TTHM levels at the water treatment plants, but there was a trend toward greater TTHM concentrations with increasing precursor levels.

4. The groundwater and reservoir water sources sampled contained greater percentages at the brominated THM species ($CHClBr_2$, $CHCl_2Br$) than did the stream sources, but chloroform ($CHCl_3$) was the dominant THM species overall.

5. The water treatment plants that use stream water only, City Creek and Big Cottonwood, produced the lowest mean yearly inst-TTHM concentrations, 11 μg/l and 12 μg/l, respectively. Plants utilizing reservoir source water, Parleys and Little Cottonwood, produced mean yearly inst-TTHMs of 32 μg/l and 28 μg/l, respectively (Parleys had some missing data during winter months). Influent organic precursor concentrations were consistently greater at the Parleys and Little Cottonwood plants.

6. The maximum term-TTHM value recorded was 107 μg/l during September 1980 at the Little Cottonwood water treatment plant.

7. Inst-TTHMs at all distribution stations (not including water treatment plants) averaged less than 40 μg/l for the year (1981). The lowest mean inst-TTHM concentration (4 μg/l) occurred at a station receiving exclusively spring water (2727 E. Kentucky, station 9). Greatest concentrations were found at stations supplied by the Little Cottonwood water treatment plant. Mixing and dilution of municipal waters within the distribution system hindered comparisons of water source and distribution station data.

8. The greatest single distribution system inst-TTHM concentration found during 1981 was 64 μg/l at station 5 (8644 S. 3500 E.) in October. This was primarily Little Cottonwood treatment plant water.

9. Groundwater samples produced TTHM (MTP test) concentrations well below mean MTP-TTHM concentrations for stream and reservoir waters. The maximum TTHM concentration from the groundwater samples was 19 μg/l.

Unit Process Analysis

1. The water treatment plants reduced the influent organic precursor concentration (as TOC) by about 30 percent. Rapid sand filtration provided

the greatest precursor removal at the Big Cottonwood plant. Sedimentation was most effective at the Little Cottonwood plant.

2. Inst-TTHM concentrations usually increased with process time, with the most pronounced increases during the longer detention times for flocculation and sedimentation. Rapid sand filtration was the most successful process at reducing inst-TTHM concentrations.

3. The Parleys and Little Cottonwood plants produced higher inst-TTHMs during water treatment and overall higher TTHMs at the distribution storage reservoirs.

4. Based on organic precursor data and personal communications, some organic matter resuspension apparently occurred in the Big Cottonwood plant's sedimentation process as a result of short hydraulic detention times. Measured precursor concentrations increased through the sedimentation basin.

5. The amount (and nature) of organic precursor seemed to be the key factor for TTHM formation after water treatment, provided an available free chlorine residual existed, as it always did in this study. The higher chlorination doses tended to increase levels of TTHM formation during treatment.

RECOMMENDATIONS

Immediate Recommendations

This study, and previous work (Peters et al. 1981), found that neither water treatment plant effluent nor selected distribution site tap water instantaneous total trihalomethanes exceeded the USEPA and Utah State proposed maximum contaminant level (MCL) of 100 μg/l. Only terminal (7-day) total trihalomethanes at the Little Cottonwood water treatment plant were occasionally equal to or greater than 100 μg/l. Therefore, total trihalomethane (TTHM) formation in Salt Lake County water supplies is not a major problem, but it is one that should be watched in water supplies drawn from surface reservoirs.

The following recommendations for source control and greater treatment plant efficiency are made to minimize THM production and distribution to the consumer.

1. Disturbances of the soil surface in the stream riparian region should be minimized to reduce the influx of precursor materials (suspended solids) during rainfall or snowmelt events. Existing disturbed areas, such as along the north fork of Lambs Creek, should be evaluated for possible rehabilitation. Specific control methods include creating buffer strips between picnic, cabin, and turn-out/parking areas and the streams and stabilizing road-bank erosion.

2. Direct surface runoff from roads into stream channels should be controlled to reduce the influx of suspended solids. Runoff should initially be directed away from the stream channel and spread out over the land surface to reduce water velocity and consequent erosion and gullying, permit deposition of the wash load, and promote infiltration. Road drainage patterns are largely determined at the time of construction, and practices protecting drinking water safety are best implemented at that time.

3. During significant storm runoff events, the flows through plants treating stream water (City Creek and Big Cottonwood Creek) should be reduced to allow adequate detention time for effective sedimentation and removal of suspended solids and organics, thus minimizing additional trihalomethane formation potential. If necessary, the demand for finished water could temporarily be shifted to plants treating reservoir. Alum dosages could be altered to improve organics removal.

4. A management plan should be developed for Deer Creek Reservoir to reduce the concentration of organic precursors prior to chlorination. Possible elements include reducing nutrient input from upstream sources and improving the reservoir water quality. The use of copper sulfate to control algal growth should be considered a short-term solution on a reservoir as large as Deer Creek.

5. The TTHM concentrations from the Little Cottonwood water treatment plant during problem periods could be reduced by blending the finished water with other treated water or groundwater.

6. Chlorine doses at all treatment plants should be kept to the minimum necessary to meet state regulations.

This may slow the rate of TTHM formation and reduce the quantity of TTHMs by making less free chlorine available for oxidation of organic precursors.

7. The water treatment plants should be operated for greater turbidity and organics removal. For more effective coagulation/flocculation, sedimentation, and filtration, hydraulic flows through the treatment plants should be kept within design capacities. Optimum coagulation during different seasons can be evaluated with jar tests (and settling tests) and followed with a full-scale study using one treatment train and analyzing for TTHMs. This is most critical at plants treating reservoir water. It may not be possible to economically achieve effluent TOC levels much below 2 mg/l (Kavanaugh 1978).

Additional Guidelines

Additional recommendations related to water treatment plant operation are:

1. Chlorination of the Deer Creek Reservoir aqueduct raw water to the Little Cottonwood utility could be discontinued for short periods of time (specifically during late summer and early fall), on an experimental basis, to determine the effect on TTHM formation in the plant effluent. Minimal chlorination prior to flocculation/sedimentation may help to reduce final TTHM concentrations. The results of this investigation could help to determine the benefit of using an alternative disinfectant (non-haloform forming) or oxidant to control biological growth and taste and odor in the aqueduct.

2. Additional strategies for reducing TTHMs at the Little Cottonwood treatment plant include:

   a. Air stripping of halogenated organics (TTHMs) from the Deer Creek Reservoir aqueduct water during critical periods by using existing aeration equipment at the headworks. This could potentially reduce TTHMs while controlling taste and odor problems and preclude the use of potassium permanganate ($KMnO_4$) at these times.

   b. Powdered activated carbon could be added at the aeration basin intakes (in lieu of air stripping) during problem periods to reduce available precursor concentration and thus TTHM formation.

3. Chemical methods for improved coagulation and sedimentation could be investigated. Alum (aluminum sulfate) doses higher than those normally used for turbidity removal, and pH reduction to near 5.0 in the rapid mix, may be needed to obtain the best organics removal (Semmens and Field 1980; Singer et al. 1982). The effluent pH would have to be adjusted. Activated silica used alone or in conjunction with an alum dose of 80 mg/l has been shown to reduce TTHM formation potential (Batchelor and Yang 1982). Also, the use of activated silica prior to alum, during periods of high turbidity caused by precipitation events, could enhance flocculation and the removal of increased turbidity and organics. Two other possibilities for improving organics removal are lime-soda softening, which is most effective with increased pH and decreased concentrations of TOC (Randtke et al. 1982), and alkaline polyaluminum chloride (APAC), which is reported to have several advantages over alum and can also be used as a flocculant aid (Knoppert et al. 1980).

4. Copper sulfate has apparently reduced algal growth, and thus precursor concentrations and TTHM formation, in the Mountain Dell Reservoir. Further study could develop more effective dosages and application procedures (Hanson et al. 1983).

5. Pre and post chlorination practices have been investigated at the Parleys water treatment plant (Peters et al. 1981) and elsewhere. Some studies have concluded that post chlorination results in lower TTHM concentrations in the finished water than does prechlorination. Frequently, inst-TTHMs were measured without considering ultimate TTHM formation, which is a more appropriate comparison, thus making the validity of these results questionable. Peters found ultimate TTHM formation to be about the same for both processes, and term-TTHMs for post chlorination to be consistently greater than for prechlorination. Therefore, considering known TTHM levels at the three conventional water treatment plants (City Creek, Parleys, Big Cottonwood), changing to post chlorination should not be considered at this time. The Little Cottonwood plant should continue its post chlorination practice while seeking to minimize overall chlorine dosages.

6. In the event that TTHM formation becomes a significant problem at the Little Cottonwood water treatment plant, an alternative approach to disinfection would be to use chlorine dioxide (ClO_2). ClO_2 has been proven as a good disinfectant. Existing chlorine sources could be used to generate ClO_2, and the required USEPA maximum total effluent residual concentration of 0.5 mg/l would probably be reasonably attainable when treating the relatively high quality Salt Lake County drinking waters.

Monitoring Procedures

Watersheds

Watershed monitoring should be conducted monthly from early spring through late fall to continue evaluation of TTHM precursor loading. The basic sampling should monitor normal flow conditions, and supplemental sampling should cover major precipitation events one week-day and one weekend day to assess canyon usage patterns, and composite sampling, during daylight hours. Mechanical or grab techniques can be used to take water from streams where good mixing occurs.

For City Creek, the critical monitoring stations are instream at the treatment plant influent, and the finished water effluent. To characterize the organic precursor concentration of the influent water, dissolved organic carbon (DOC) should be measured. This can be done by washing and ashing standard glass fiber (GF/C) filters and filtering an aliquot of sample prior to analysis. Organic carbon still appears to be the most practical parameter for precursor monitoring. Ultraviolet absorbance could be utilized as another surrogate parameter (Singer et al. 1982; Shindala and Mowry 1981) to back up organic carbon measurements. Turbidity and/or total suspended solids measurements should also be taken to correlate to DOC and streamflow. Influent measurements should include DOC, turbidity or TSS, possibly ultraviolet absorbance, temperature, and streamflow. Effluent measurements should include these same parameters (measure TOC instead of DOC) in addition to inst-TTHM and term-TTHM and chlorine residuals. The chlorine dose should be recorded.

At Big Cottonwood Creek the critical monitoring locations are the 6.1 m (20 ft) Parshall flume upstream from the treatment plant, the power plant effluent (when in use), and treatment plant finished water effluent. Influent and effluent analyses would be the same as for City Creek.

On Parleys watershed, the mouths of Parleys and Mountain Dell Creeks can be sampled (at the existing gaging stations), along with Parleys treatment plant raw and finished water. Analyses would be the same as for City Creek.

Little Cottonwood Creek can be monitored at the Wasatch Resort diversion and the 4.6 m (15 ft) Parshall flume, near the lower treatment plant intake, when streamflow occurs there. Deer Creek Reservoir influent raw water and finished water effluent should be monitored at the Little Cottonwood plant. The Deer Creek Reservoir influent water is chlorinated and should be analyzed for TTHMs. Other analyses would be the same as for City Creek.

Additional locations are the north fork of Lambs Creek in Parleys Canyon and the Brighton recreational area. Potential problem areas should be watched by monitoring upstream and downstream of the location.

Deer Creek Reservoir

Source streams to Deer Creek Reservoir need to be monitored to assess their impact on reservoir water quality and eutrophication problems. The monitoring should be weekly on a year-round basis. Initial results can be used to improve the design of the monitoring network. Measurements should cover the major forms of nitrogen and phosphorus, temperature, dissolved organic carbon, and stream discharge. Measured amounts could be correlated to algal counts (plankton profiles) to help assess the impact of nutrient loading on reservoir water quality. Finally, specific watershed management techniques can be applied to control identified problem nutrient loadings.

Distribution

Distribution sites receiving finished water from the Little Cottonwood water treatment plant should be monitored from spring through late summer to better evaluate TTHM levels to consumers. System design should reflect the range of residence times for distribution. Groundwater or other sources of dilution should be taken into consideration when necessary.

As long as the Salt Lake County water distribution system meets USEPA TTHM requirements, the monitoring may be reduced to a minimum of one sample analyzed for TTHMs per quarter and taken at a point reflecting the maximum residence time of the water in the system. Alternatively, these sites could be sampled monthly, to correlate to watershed and treatment plant monitoring. Distribution sites should be sampled at the same time as water treatment plants. Potential distribution sites (Table 8) to be monitored include station 14 (1855 South Industrial Road 1800 West) station 15 (145 Wright Brothers Drive, Salt Lake International Center, Business), and station 7 (3616 Hermes 4135 South), all with reportedly longer distribution residence times. A distribution site characterizing Parleys treated water may need to be determined. Analyses should include TOC, inst-TTHM, temperature, and chlorine residuals.

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Appendix A

Salt Lake County Watersheds Stream Sampling Station Data

Table A-1. Salt Lake County watersheds sampling station, temperature, stream flow, total organic carbon, and mass loading quarterly data, 1980-1981.

Station	Date	Time	Temperature (°C)	Flow (cfs)	TOC (mg/l)	Mean TOC (mg/l)	Mass Load (kg/d)	Mean Mass Load (kg/d)	Mass Load Standard Deviation
L1	5/23/81	10:00	8.0	91.1	5.4		1203.5		
	5/24/81	8:15	7.5	102.0	3.2		798.5		
	5/25/81	10:00	8.5	132.0	1.7	3.4	548.9	850.4	330.3
L2	11/14/80	9:15	2.0	18.9	0.7		32.4		
	11/15/80	12:50	2.0	15.3	<0.5		18.7		
	11/16/80	10:00	2.0	17.0	<0.5	≤0.6	20.8	24.0	7.4
	2/21/81	6:00	4.0	15.0	<0.5		18.4		
	2/22/81	4:00	4.5	15.0	0.7		25.7		
	2/23/81	2:40	5.0	14.2	<0.5	≤0.6	17.4	20.5	4.6
	5/23/81	10:15	7.0	116.0	5.0		1419.8		
	5/24/81	8:30	7.0	125.8	2.6		800.2		
	5/25/81	9:40	8.0	152.8	2.0	3.2	747.7	989.0	373.3
	8/12/81	11:50	12.5	23.6	<0.5		28.9		
	8/13/81	10:45	12.5	22.8	<0.5		27.9		
	8/14/81	10:10	11.5	22.4	<0.5	<0.5	27.4	28.1	0.8
L3	5/23/81	12:00	7.5	44.6	4.2		458.3		
	5/24/81	9:00	7.5	47.5	4.0		464.8		
	5/25/81	9:15	6.0	58.9	1.9	3.4	273.8	398.0	108.5
	8/12/81	11:15	10.0	12.4	<0.5		15.2		
	8/13/81	10:15	9.5	10.2	<0.5		12.5		
	8/14/81	10:00	8.5	11.0	<0.5	<0.5	13.5	13.7	1.4

Table A-1. Continued.

Station	Date	Time	Temperature (°C)	Flow (cfs)	TOC (mg/l)	Mean TOC (mg/l)	Mass Load (kg/d)	Mean Mass Load (kg/d)	Mass Load Standard Deviation
L4	11/14/80	9:30	2.0	13.6	2.2		73.2		
	11/15/80	1:10	2.0	14.1	<0.5		17.3		
	11/16/80	10:15	2.0	6.4*	<0.5	≤1.0	7.8	45.2	39.6
	2/21/81	6:25	3.0	7.0	<0.5		8.6		
	2/22/81	4:20	5.0	7.0	<0.5		8.6		
	2/23/81	3:00	6.0	7.0	2.2*	≤1.0	37.7	25.7	15.2
	5/23/81	11:00	7.0	27.8	1.1		74.8		
	5/24/81	9:15	5.5	33.4	2.1		171.6		
	5/25/81	9:00	5.5	42.2	1.8	1.7	185.8	144.1	60.4
	8/12/81	10:45	10.0	9.5	<0.5		11.6		
	8/13/81	9:55	9.5	9.5	<0.5		11.6		
	8/14/81	9:45	8.5	9.5	<0.5	<0.5	11.6	11.6	0
L5	11/14/80	10:00	0.0	3.2	1.3		10.2		
	11/15/80	1:30	0.0	3.2	<0.5		3.9		
	11/16/80	10:40	0.0	3.2	<0.5	≤0.8	3.9	6.0	3.6
	2/21/81	ICED	UP	-	-	-			
	5/23/81	11:30	5.0	14.6	1.0		35.7		
	5/24/81	9:30	4.0	14.7	3.0		107.9		
	5/25/81	8:15	4.0	22.0	2.2	2.1	118.4	87.3	45.0
	8/12/81	10:00	10.0	1.4	<0.5		1.7		
	8/13/81	9:30	9.5	1.8	<0.5		2.2		
	8/14/81	9:30	9.0	1.5	0.7	0.6	2.6	2.2	0.5

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*Questionable value.

Table A-1. Continued.

Station	Date	Time	Temperature (°C)	Flow (cfs)	TOC (mg/l)	Mean TOC (mg/l)	Mass Load (kg/d)	Mean Mass Load (kg/d)	Mass Load Standard Deviation
B1	11/14/80	10:55	3.0	28.3	<0.5		34.6		
	11/15/80	11:10	3.0	26.1	<0.5		31.9		
	11/16/80	11:00	3.0	27.3	<0.5	<0.5	33.4	33.3	1.35
	2/21/81	3:50	4.0	22.2	2.5		135.8		
	2/22/81	1:34	4.0	21.9	1.9		101.8		
	2/23/81	11:50	4.0	22.6	0.8	1.7	44.2	94.9	45.9
	5/23/81	1:00	10.0	152.6	2.0		746.7		
	5/24/81	11:15	9.0	147.5	2.8		1010.4		
	5/25/81	11:45	10.0	154.0	2.4	2.4	904.2	887.1	132.7
	8/12/81	2:40	14.0	45.6	<0.5		55.8		
	8/13/81	1:10	13.0	36.5	<0.5		44.7		
	8/14/81	11:40	12.5	34.1	0.7	≤0.6	58.4	60.5	24.9
B2	11/14/80	11:15	3.0	16.0	0.6		23.5		
	11/15/80	11:15	3.0	16.0	<0.5		19.6		
	11/16/80	11:15	3.0	16.0	<0.5	≤0.6	19.6	20.9	2.3
	2/21/81	4:05	3.5	11.0	1.8		48.4		
	2/22/81	2:00	5.0	11.0	0.9		24.2		
	2/23/81	12:20	5.0	11.0	0.6	1.1	16.1	29.6	16.8
	5/23/81	1:30	9.0	41.9	3.4		348.5		
	5/24/81	11:30	8.0	43.3	3.2		339.0		
	5/25/81	11:00	8.5	50.0	2.6	3.1	318.1	335.2	15.6
	8/12/81	2:20	13.5	29.5	0.8		57.7		
	8/13/81	12:55	13.0	23.5	<0.5		28.7		
	8/14/81	11:20	12.0	23.5	0.8	0.7	46.0	44.1	14.6

Table A-1. Continued.

Station	Date	Time	Temperature (°C)	Flow (cfs)	TOC (mg/l)	Mean TOC (mg/l)	Mass Load (kg/d)	Mean Mass Load (kg/d)	Mass Load Standard Deviation
B3	11/14/80	11:30	3.0	9.1	0.9		20.0		
	11/15/80	11:35	3.0	8.0	<0.5		9.8		
	11/16/80	11:25	3.0	8.6	<0.5	≤0.6	10.5	13.4	5.7
	2/21/81	4:40	2.5	8.8	1.3		28.0		
	2/22/81	2:10	4.0	6.8	1.8		29.9		
	2/23/81	12:50	5.0	6.7	0.7	1.3	11.5	23.1	10.2
	5/23/81	1:45	8.0	27.1	5.8		384.5		
	5/24/81	11:00	7.0	30.2	4.0		295.5		
	5/25/81	10:45	8.0	31.7	3.6	4.5	279.2	319.7	56.7
	8/12/81	2:00	13.5	23.2	2.0		113.5		
	8/13/81	12:30	13.0	19.0	0.9		41.8		
	8/14/81	11:10	12.0	19.0	1.8	1.6	83.7	79.7	36.0
B4	11/14/80	12:00	0	0.6	3.4		5.0		
	11/15/80	12:00	0	0.9	2.4		5.3		
	11/16/80	11:45	0	0.6	2.9	2.9	4.3	4.8	0.5
	2/21/81	5:15	0.5	0.6	2.5		3.7		
	2/22/81	2:45	1.0	0.3	3.7		2.7		
	2/23/81	1:10	1.0	0.3	2.2	2.8	1.6	2.7	1.0
	5/23/81	2:30	8.5	3.2	6.3		49.3		
	5/24/81	10:40	5.5	4.5	4.6		50.6		
	5/25/81	10:30	7.0	5.3	4.5	5.1	58.3	52.7	4.9
	8/12/81	1:30	11.0	8.5	2.0		44.6		
	8/13/81	12:00	14.0	5.7	2.1		29.3		
	8/14/81	10:50	13.0	6.0	3.3	2.5	48.4	39.8	36.5

Table A-1. Continued.

Station	Date	Time	Temperature (°C)	Flow (cfs)	TOC (mg/l)	Mean TOC (mg/l)	Mass Load (kg/d)	Mean Mass Load (kg/d)	Mass Load Standard Deviation
P1	11/14/80	5:30	6.1	17.0	1.4		58.2		
	11/15/80	10:45	6.1	11.0	1.4		37.7		
	11/16/80	2:00	5.5	12.7	0.8	1.2	24.9	40.3	16.8
	2/21/81	OFF-LINE	(no samples taken)						
	5/23/81	3:30	14.0	1.9	4.3		20.0	20.0	0
	5/24/81	12:30	13.5	0.0	2.4		0.0		
	5/25/81	2:30	13.5	0.0	1.7	2.8	0.0		
	8/12/81	6:00	18.0	6.8	1.8		29.9		
	8/13/81	4:15	19.0	22.1	1.9		102.7		
	8/14/81	2:00	19.5	16.2	1.8	1.8	71.3	68.0	36.5
P2	11/14/80	4:00	3.0	4.3	0.7		7.4		
	11/15/80	10:10	3.0	4.3	0.6		6.3		
	11/16/80	1:00	3.0	4.5	0.6	0.6	6.6	6.8	0.54
	2/21/81	9:45	0.5	3.2	1.6		12.5		
	2/22/81	9:20	0.5	2.9	1.9		13.5		
	2/23/81	9:10	0.5	2.9	1.0	1.5	7.1	11.0	3.32
	5/23/81	4:30	13.0	15.2	6.9		256.6		
	5/24/81	3:00	12.5	15.7	5.0		192.1		
	5/25/81	1:50	12.5	15.2	4.1	3.7	152.5	200.4	52.5
	8/12/81	5:15	14.0	3.5	0.7		6.0		
	8/13/81	3:35	15.0	2.6	1.2		7.6		
	8/14/81	1:30	16.0	2.6	1.0	1.0	6.4	6.7	0.8
P3	5/23/81	4:15	14.5	0.3	8.1	8.1	5.9	5.9	-

Table A-1. Continued.

Station	Date	Time	Temperature (°C)	Flow (cfs)	TOC (mg/l)	Mean TOC (mg/l)	Mass Load (kg/d)	Mean Mass Load (kg/d)	Mass Load Standard Deviation
P4	5/24/81	2:30	11.0	14.0	4.5		154.1		
	5/25/81	1:30	11.5	13.6	4.1	4.3	136.4	145.3	12.5
	8/12/81	5:00	14.0	3.5	0.9		7.7		
	8/13/81	3:20	14.0	3.5	0.6		5.1		
	8/14/81	12:45	13.5	3.5	0.7	0.7	6.0	6.3	1.3
P5	11/14/80	3:30	2.0	0.4	2.1		2.1		
	11/15/80	9:55	2.0	0.4	2.1		2.1		
	11/16/80	1:10	2.0	0.4	1.6	1.9	1.6	1.9	0.3
	2/21/81	10:15	0.5	0.4	3.3		3.2		
	2/22/81	9:40	0.5	0.5	2.9		3.5		
	2/23/81	9:20	1.0	0.4	2.3	2.8	2.3	3.0	0.7
	5/23/81	5:00	14.0	2.6	3.9		24.8		
	5/24/81	2:00	7.5	3.0	4.1		30.1		
	5/25/81	1:10	13.0	3.3	3.8	3.9	30.7	28.5	3.3
	8/12/81	4:15	17.0	1.0	2.3		5.6		
	8/13/81	3:05	16.0	1.0	1.8		4.4		
	8/14/81	12:30	16.5	1.0	1.9	2.0	4.6	4.9	0.6
P6	2/21/81	10:45	0.5	0.3	3.6		2.6		
	2/22/81	10:00	0.5	0.2	3.4		1.7		
	2/23/81	9:40	0.5	0.3	2.3	3.1	1.7	2.0	0.6

Table A-1. Continued.

Station	Date	Time	Temperature (°C)	Flow (cfs)	TOC (mg/l)	Mean TOC (mg/l)	Mass Load (kg/d)	Mean Mass Load (kg/d)	Mass Load Standard Deviation
P7	11/14/80	2:00	3.0	3.1	<0.5		3.8		
	11/15/80	9:00	3.0	1.7	<0.5		2.1		
	11/16/80	1:30	3.0	2.8	<0.5	<0.5	3.4	3.1	0.9
	2/21/81	11:15	2.5	2.0	2.0		9.8		
	2/22/81	10:25	2.0	2.0	1.8		8.8		
	2/23/81	10:00	2.5	2.0	1.0	1.6	4.9	7.9	2.6
	5/23/81	6:40	10.5	12.5	3.9		119.3		
	5/24/81	1:45	10.0	13.3	4.0		130.2		
	5/25/81	12:50	9.5	12.6	3.8	3.9	117.1	122.2	7.0
	8/12/81	4:00	13.0	4.6	0.8		9.0		
	8/13/81	2:55	10.0	4.8	<0.5		5.9		
	8/14/81	12:25	12.5	4.8	1.2	0.8	14.1	9.7	4.1
P8	11/14/80	2:30	2.0	0.5	<0.5		0.6		
	11/15/80	9:25	2.0	0.3	0.7		0.5		
	11/16/80	1:40	2.0	0.4	<0.5	≤0.6	0.5	0.5	0.1
	2/21/81	11:50	2.0	0.4	1.8		1.8		
	2/22/81	10:45	2.0	0.3	1.8		1.3		
	2/23/81	10:10	2.5	0.3	0.3	1.3	1.0	1.1	0.8
	5/23/81	5:50	9.0	1.6	2.2		8.6		
	5/24/81	1:30	8.5	3.7	2.5		22.6		
	5/25/81	12:35	9.0	4.1	1.8	2.2	18.1	16.4	7.2
	8/12/81	2:35	12.5	2.0	<0.5		2.4		
	8/13/81	2:30	10.0	2.3	<0.5		2.8		
	8/14/81	12:15	11.0	2.3	<0.5	<0.5	2.8	2.7	0.2

Table A-1. Continued.

Station	Date	Time	Temperature (°C)	Flow (cfs)	TOC (mg/l)	Mean TOC (mg/l)	Mass Load (kg/d)	Mean Mass Load (kg/d)	Mass Load Standard Deviation
P9	11/14/80	2:45	2.0	1.1	<0.5		1.3		
	11/15/80	9:40	2.0	0.7	0.8		1.4		
	11/16/80	1:50	2.0	0.9	<0.5	≤0.6	1.1	1.3	0.2
	2/21/81	12:10	0.5	0.8	3.3		6.5		
	2/22/81	10:50	0.5	0.9	2.0		4.4		
	2/23/81	10:20	1.0	0.9	1.0	2.1	2.2	4.5	2.1
	5/23/81	5:30	10.0	2.4	6.3		37.0		
	5/24/81	1:15	9.5	4.3	5.7		60.0		
	5/25/81	12:20	10.0	4.2	4.5	5.5	46.2	47.7	11.6
	8/12/81	3:10	13.0	1.7	1.9		7.9		
	8/13/81	2:10	12.0	1.6	1.9		7.4		
	8/14/81	12:05	12.5	1.6	2.0	1.9	7.8	7.7	0.3
P10	5/23/81	6:15	8.0	0.4	5.2		5.1		
	5/24/81	12:50	7.5	0.4	4.8		4.7		
	5/25/81	12:10	8.0	0.2	4.4	4.8	2.2	4.0	1.6
P11	11/14/80	4:00	4.5	2.6	0.6		3.8		
	11/15/80	10:20	4.5	2.3	1.0		5.6		
	11/16/80	12:30	4.5	2.6	<0.5	0.7	3.2	4.2	1.3
	2/21/81	1:55	4.0	2.6	1.6		10.2		
	2/22/81	11:40	2.5	2.7	1.5		9.9		
	2/23/81	10:50	2.5	2.7	1.4	1.5	9.2	9.9	0.4
	5/23/81	7:30	13.0	26.1	4.8		306.5		
	5/24/81	3:30	13.0	24.8	4.0		242.7		
	5/25/81	2:20	12.0	24.8	3.7	4.2	224.5	257.9	43.1
	8/12/81	5:55	17.0	1.7	1.8		7.5		
	8/13/81	4:05	16.0	1.7	1.9		7.9		
	8/14/81	1:50	22.5*	1.7	1.3	1.7	5.4	6.9	1.3

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*Questionable value.

Table A-1. Continued.

Station	Date	Time	Temperature (°C)	Flow (cfs)	TOC (mg/l)	Mean TOC (mg/l)	Mass Load (kg/d)	Mean Mass Load (kg/d)	Mass Load Standard Deviation
P12	11/14/80	4:15	4.5	1.5	0.5		1.8		
	11/15/80	10:30	4.5	1.0	0.5		1.2		
	11/16/80	12:40	4.5	0.8	<0.5	≤0.5	1.0	1.3	0.4
	2/21/81	2:00	4.0	0.9	1.5		3.3		
	2/22/81	11:50	2.5	0.8	2.1		4.1		
	2/23/81	11:00	3.0	0.7	0.9	1.5	1.5	3.0	1.3
	5/23/81	7:10	11.0	25.8	4.0		252.5		
	5/24/81	3:15	12.0	25.0	3.8		232.4		
	5/25/81	2:10	11.5	22.8	3.2	3.7	178.5	221.1	38.3
	8/12/81	5:30	17.0	1.9	0.8		3.7		
	8/13/81	3:50	16.0	1.5	0.9		3.3		
	8/14/81	1:40	17.5	1.5	1.4	1.0	5.1	4.0	1.0
R1	11/15/80	12:00	7.0	1.0	0.8		2.0		
	11/16/80	12:00	7.0	1.0	<0.5	≤0.6	1.2	1.6	0.5
	5/24/81	5:00	13.0	9.2	2.8		63.0		
	5/25/81	4:30	12.5	9.0	3.1	3.0	68.3	65.7	3.8
	8/13/81	5:30	14.5	1.7	2.3		9.6		
	8/14/81	2:00	16.5	1.7	2.2	2.3	9.2	9.4	0.3
R2	11/15/80	12:30	1.5	1.9	0.7		3.3		
	11/16/80	12:45	1.5	2.0	<0.5	≤0.6	2.5	2.9	0.6
	5/23/81	4:45	15.5	9.6	4.8		112.7		
	5/24/81	4:15	14.0	8.4	4.5	4.65	92.5	102.6	14.3
	8/12/81	7:15	13.0	1.9	1.2		5.6		
	8/13/81	5:30	14.5	1.9	1.7	1.45	7.9	6.8	1.6

Table A-1. Continued.

Station	Date	Time	Temperature (°C)	Flow (cfs)	TOC (mg/l)	Mean TOC (mg/l)	Mass Load (kg/d)	Mean Mass Load (kg/d)	Mass Load Standard Deviation
R3	11/15/80	1:00	2.0	1.1	0.6		1.6		
	11/16/80	12:30	2.0	1.1	<0.5	≤0.5	1.4	1.5	0.2
	5/23/81	4:15	14.0	4.8	4.7		55.2		
	5/24/81	4:00	12.0	4.8	4.8	4.8	56.4	55.8	0.85
	8/12/81	6:45	14.0	0.8	<0.5		1.0		
	8/13/81	5:00	14.0	0.8	0.8	0.65	1.6	1.3	0.42
C1	11/15/80	9:30	2.0	6.8	<0.5		8.3		
	11/16/80	10:00	2.0	6.7	<0.5	<0.5	8.2	8.3	0.10
	5/23/81	6:30	11.0	29.9	-				
	5/24/81	6:00	10.5	30.7	3.5	3.5	262.9	262.9	-
	8/13/81	7:30	12.0	9.5	<0.5		11.6		
	8/14/81	3:45	13.5	9.3	<0.5	<0.5	10.2	10.9	1.0
C2	11/15/80	10:00	2.0	2.8	<0.5		3.4		
	11/16/80	10:30	2.0	2.7	<0.5	<0.5	3.3	3.4	0.1
	5/23/81	6:00	9.5	24.6	2.7		162.5		
	5/24/81	5:30	9.0	28.8	1.7	2.2	119.8	141.2	30.2
	8/13/81	6:25	11.0	3.9	1.1		10.5		
	8/14/81	3:30	13.0	4.0	<0.5	0.8	4.9	7.7	4.0

Table A-2. Parleys Canyon watershed temperature, streamflow, total organic carbon, and mass loading monthly data, 1980-1981.

Station	Date	Temperature (°C)	Flow (cfs)	TOC (mg/l)	Mass Load (kg/d)
P1	8/28/80	18.0	31.7	2.4	186.1
	11/08/80	-	-	-	-
	12/11/80	4.0	14.2	1.9	66.0
	1/10/81	2.8	14.5	1.4	49.7
	2/07/81	-	-	-	-
	3/07/81	-	-	-	-
	4/04/81	-	-	-	-
	5/02/81	-	-	-	-
	7/06/81		13.9	3.1	105.6
P2	8/28/80	9.0	10.4	2.0	50.9
	11/08/80	7.5	4.3	1.0	10.5
	12/11/80	0.5	3.5	1.0	8.6
	1/10/81	0	3.2	0.7	5.5
	2/07/81	0	3.5	0.6	5.1
	3/07/81	2.0	3.0	1.1	7.4
	4/04/81	2.0	4.5	1.3	14.3
	5/02/81	-	21.2	5.6	290.5
	6/06/81	9.0	13.7	3.8	127.4
	7/06/81	12.0	7.7	3.1	58.4
	8/01/81	10.0	7.5	-	-
P4	8/28/80	9.0	3.7*	0.7	6.3*
	5/02/81	-	17.2	3.4	143.1
	6/06/81	8.3	21.0*	3.4	174.7
	7/06/81	10.0	17.9*	2.6	113.9
	8/01/81	10.0	5.6	-	-
P5	11/08/80	8.0	0.3	2.6	1.9
	12/11/80	-	0.4	2.1	2.1
	1/10/81	0	0.6	1.6	2.3
	2/07/81	0	-	1.8	-
	3/07/81	2.0	0.2	2.4	1.2
	4/04/81	1.5	1.4	3.1	10.6
	5/02/81	-	2.2	3.4	18.3
	6/06/81	10.5	5.7	3.3	46.0
	7/06/81	10.0	0.8*	3.9	7.6*
	8/01/81	12.0	1.4	-	-

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*Questionable value.

Table A-2. Continued.

Station	Date	Temperature (°C)	Flow (cfs)	TOC (mg/l)	Mass Load (kg/d)
P7	8/28/80	8.0	2.3	1.0	5.6
	11/08/80	6.5	3.2	0.8	6.3
	12/11/80	2.0	2.5	0.5	3.1
	1/10/81	0.5	3.2	<0.5	3.9
	2/07/81	1.0	2.8	<0.5	3.4
	3/07/81	3.0	2.5	1.0	6.1
	4/04/81	1.5	5.8*	1.0	14.2*
	5/02/81	-	19.2	3.6	169.1
	6/06/81	8.0	14.8*	3.0	108.6*
	7/06/81	10.0	8.2*	2.6	52.2*
	8/01/81	9.0	4.9	-	-
P11	8/28/80	10.0	2.5	1.1	6.7
	11/08/80	8.0	2.6	1.4	8.9
	12/11/80	0.0	3.2	0.9	7.0
	1/10/81	0.0	2.6	0.9	5.7
	2/07/81	1.0	2.1	0.7	3.6
	3/07/81	3.0	3.6	1.0	8.8
	4/04/81	2.5	6.0	1.3	19.1
	5/02/81	-	12.2	2.9	86.6
	6/06/81	9.5	13.1	2.7	86.5
	7/06/81	13.0	4.0	2.8	27.4
	8/01/81	11.0	3.2	-	-
P12	8/28/80	9.0	1.0	1.3	3.2
	11/08/80	8.0	1.5	0.9	3.3
	12/11/80	0.0	0.8	1.4	2.7
	1/10/81	0.0	0.6	<0.5	0.7
	2/07/81	1.0	0.4	0.8	0.8
	3/07/81	2.5	0.8	0.9	1.8
	4/04/81	3.0	1.8	1.3	5.7
	5/02/81	-	12.3*	2.2	66.2
	6/06/81	8.5	6.3	2.6	40.1
	7/06/81	11.0	4.3*	2.3	24.2*
	8/01/81	10.0	1.4	-	-

*Questionable value.

Appendix B

Salt Lake County Area Water Treatment Plant and Distribution Station Monthly Monitoring Data

Table B-1. Salt Lake County area trihalomethanes and total organic carbons (when available).

SEPTEMBER 26, 1980

SAMPLE LOCATIONS (inst THM / term THM)	TRIHALOMETHANES µg/l (PPB)					OTHER PARAMETERS		
	CHLOROFORM	DICHLOROBROMO-METHANE	DIBROMOCHLORO-METHANE	BROMOFORM	TOTAL THMs	FREE CHLORINE mg/l	TOTAL CHLORINE mg/l	T.O.C. (Total Organic Carbon) mg/l
Little Cottonwood Water Treatment Plant Deer Creek Influent	41 54	11 13	1 1	<1 <1	53 68			2.6
Little Cottonwood Water Treatment Plant Little Cottonwood Creek Influent	<1 -	<1 -	<1 -	<1 -	<1 -			
Little Cottonwood Water Treatment Plant Effluent	46 88	12 17	1 2	<1 <1	59 107			1.9
Parleys Water Treatment Plant OFF LINE								
City Creek, Big Cottonwood Water Treatment Plant Influent	<1 -	<1 -	<1 -	<1 -	<1 -			1.2 <0.5
City Creek Water Treatment Plant Effluent	8 25	2 6	1 1	<1 <1	11 32			<0.5
Big Cottonwood Water Treatment Plant Effluent	12 42	2 5	<1 <1	<1 <1	14 47			0.9
3300 South 2475 East	41 -	11 -	1 -	<1 -	53 -			1.9
Salt Lake International Center	38 -	9 -	2 -	<1 -	49 -			1.0
Salt Palace	56 -	11 -	1 -	<1 -	68 -			1.4
Capitol Building	15 -	4 -	<1 -	<1 -	19 -			1.1
Salt Lake County Water Cons. District 60th West Reservoir	38 -	10 -	2 -	<1 -	50 -			1.2
West Jordan City 7800 S. 4000 West Reservoir	22 -	5 -	2 -	<1 -	29 -			0.7
Taylorsville District 6200 S. 5600 West Reservoir	11 -	3 -	<1 -	<1 -	14 -			1.1

Table B-1. Continued.

OCTOBER 27, 1980

SAMPLE LOCATIONS	TRIHALOMETHANES µg/l (PPB)										OTHER PARAMETERS		
	CHLOROFORM		DICHLOROBROMO-METHANE		DIBROMOCHLORO-METHANE		BROMOFORM		TOTAL THMs		FREE CHLORINE mg/l	TOTAL CHLORINE mg/l	T.O.C. (Total Organic Carbon) mg/l
inst THM / term THM	inst THM	term THM	inst THM	term THM	inst THM	term THM	inst THM	term THM	inst THM	term THM			
Little Cottonwood Water Treatment Plant Deer Creek Influent	24	28	7	8	1	1	<1	<1	32	37			2.5
Little Cottonwood Water Treatment Plant Little Cottonwood Creek Influent	<1	-	<1	-	<1	-	<1	-	<1	-			<0.5
Little Cottonwood Water Treatment Plant Effluent	21	68	5	10	<1	2	<1	1	26	80			0.8
City Creek, Parley and Big Cottonwood Water Treatment Plants Influents	<1	-	<1	-	<1	-	<1	-	<1	-			<0.5 1.7 <0.5
City Creek Water Treatment Plant Effluent	9	37	2	5	<1	<1	<1	<1	11	42			0.9
Parley Water Treatment Plant Effluent	17	38	10	16	3	6	<1	<1	30	60			1.2
Big Cottonwood Water Treatment Plant Effluent	5	34	1	4	<1	<1	<1	<1	6	38			<0.5
3300 South 2475 East	9	-	<1	-	<1	-	<1	-	9	-			
Capitol Building	11	-	2	-	<1	-	<1	-	13	-			
Salt Palace	25	-	7	-	2	-	<1	-	34	-			
Salt Lake International Center	29	-	5	-	1	-	<1	-	35	-			
Salt Lake Water Cons. District 60th West Reservoir	35	-	6	-	1	-	<1	-	42	-			
Taylorsville District 6200 So. 5600 West Reser.	<1	-	<1	-	<1	-	<1	-	<1	-			
West Jordan City District 7800 So. 4000 West Reserv.	25	-	6	-	2	-	<1	-	33	-			

Table B-1. Continued.

NOVEMBER 27, 1980

SAMPLE LOCATIONS (inst THM / term THM)	TRIHALOMETHANES µg/l (PPB) CHLOROFORM	DICHLOROBROMO-METHANE	DIBROMOCHLORO-METHANE	BROMOFORM	TOTAL THMs	OTHER PARAMETERS FREE CHLORINE mg/l	TOTAL CHLORINE mg/l	T.O.C. (Total Organic Carbon) mg/l
Little Cottonwood Water Treatment Plant Little Cottonwood Creek Influent	<1 -	<1 -	<1 -	<1 -	<1 -			<0.5
Little Cottonwood Water Treatment Plant Deer Creek Influent	31 39	10 11	2 2	<1 <1	43 52			1.8
Little Cottonwood Water Treatment Plant Effluent	13 39	5 8	<1 1	<1 <1	18 48			<0.5
Parleys, Big Cottonwood and City Creek Water Treatment Plants Influent	<1 -	<1 -	<1 -	<1 -	<1 -			1.0 - <0.5
Parleys Water Treatment Plant Effluent	14 28	9 12	4 5	<1 -	27 45			<0.5
Big Cottonwood Water Treatment Plant Effluent	4 31	<1 3	<1 <1	<1 <1	4 34			<0.5
City Creek Water Treatment Plant Effluent	7 35	2 3	<1 <1	<1 <1	9 38			0.8
Salt Palace	24 -	7 -	2 -	<1 -	33 -			
Capitol Building	9 -	2 -	<1 -	<1 -	11 -			
Salt Lake International Center	25 -	5 -	1 -	<1 -	31 -			
3300 S. and 2575 E.	9 -	2 -	<1 -	<1 -	11 -			
Salt Lake Water Cons. District, 60 W. Reservoir	18 -	4 -	<1 -	<1 -	22 -			
Taylorsville	<1 -	<1 -	<1 -	<1 -	<1 -			
West Jordon City 4000 W. 7800 S. Res.	19 -	6 -	2 -	<1 -	27 -			

Table B-1. Continued.

DECEMBER 31, 1980

SAMPLE LOCATIONS	TRIHALOMETHANES µg/l (PPB)										OTHER PARAMETERS		
	CHLOROFORM		DICHLOROBROMO-METHANE		DIBROMOCHLORO-METHANE		BROMOFORM		TOTAL THMs		FREE CHLORINE mg/l	TOTAL CHLORINE mg/l	T.O.C. (Total Organic Carbon) mg/l
	inst THM	term THM	inst THM	term THM	inst THM	term THM	inst THM	term THM	inst THM	term THM			
Little Cottonwood Water Treatment Plant Dear Creek Influent	29	29	12	10	3	2	<1	<1	44	41			4.4
Little Cottonwood Water Treatment Plant Little Cottonwood Creek Influent	<1	-	<1	-	<1	-	<1	-	<1	-			1.8
Little Cottonwood Water Treatment Plant Effluent	21	41	9	11	2	3	<1	<1	32	55	0.70		1.8
Parleys, Big Cottonwood and City Creek Water Treatment Plant Influent	<1	-	<1	-	<1	-	<1	-	<1	-			2.4 1.1 1.4
Parleys Water Treatment Plant Effluent	12	29	9	12	5	5	<1	<1	26	46	0.80		1.6
Big Cottonwood Water Treatment Plant Effluent	6	19	2	2	<1	<1	<1	<1	8	21	0.80		0.8
City Creek Water Treatment Effluent	7	20	2	3	<1	<1	<1	<1	9	23	0.80		0.9
Salt Palace	26	-	10	-	3	-	<1	-	39	-	0.10		
3300 S. and 2575 E.	17	-	4	-	1	-	<1	-	22	-	0.80		
Salt Lake International Center	16	-	7	-	3	-	<1	-	26	-	0.45		
Capitol Building	8	-	2	-	<1	-	<1	-	10	-	0.40		

Table B-1. Continued.

JANUARY 31, 1981

SAMPLE LOCATIONS (inst THM / term THM)	TRIHALOMETHANES µg/l (PPB)					OTHER PARAMETERS		
	CHLOROFORM	DICHLOROBROMO-METHANE	DIBROMOCHLORO-METHANE	BROMOFORM	TOTAL THMs	FREE CHLORINE mg/l	TOTAL CHLORINE mg/l	T.O.C. (Total Organic Carbon) mg/l
Little Cottonwood Water Treatment Plant Little Cottonwood Creek Influent	<1 / -	<1 / -	<1 / -	<1 / -	<1 / -			1.7
Little Cottonwood Water Treatment Plant Deer Creek Influent	13 / 20	7 / 7	2 / 2	<1 / <1	22 / 29			2.7
Little Cottonwood Water Treatment Plant Effluent	13 / 40	6 / 10	2 / 3	<1 / <1	21 / 53	0.75		1.9
Salt Lake Metropolitan Water District 33 So. Terminal Reservoir (IN)	15 / -	6 / -	2 / -	<1 / -	23 / -	0.65		
Salt Lake Metropolitan Water District 33 So. Terminal Reservoir (OUT)	24 / -	9 / -	2 / -	<1 / -	35 / -	0.55		
Parleys Off Line								
Big Cottonwood and City Creek Water Treatment Plants Influent	<1 / -	<1 / -	<1 / -	<1 / -	<1 / -			0.8 1.4
Big Cottonwood Water Treatment Plant Effluent	3 / 9	1 / 2	<1 / <1	<1 / <1	4 / 11	0.75		0.7
City Creek Water Treatment Plant Effluent	5 / 21	2 / 4	<1 / <1	<1 / <1	7 / 25	0.90		0.9
1855 Industrial Rd. (1855 So. near 1800 W.)	13 / -	5 / -	2 / -	<1 / -	20 / -	0.45		
2727 E. Kentucky Ave. (2727 near 4600 So.)	<1 / -	<1 / -	<1 / -	<1 / -	<1 / -	N.D.*		
Salt Lake International Center	15 / -	6 / -	3 / -	<1 / -	24 / -			
Utah Capital Building	7 / -	3 / -	<1 / -	<1 / -	10 / -	0.50		
2475 E. 3300 So.	11 / -	3 / -	<1 / -	<1 / -	14 / -			
Liberty Park	12 / -	5 / -	2 / -	<1 / -	19 / -	0.45		

*N.D.-None Detected

Table B-1. Continued.

FEBRUARY 26, 1981

SAMPLE LOCATIONS	TRIHALOMETHANES μg/l (PPB)										OTHER PARAMETERS		
	CHLOROFORM		DICHLOROBROMO-METHANE		DIBROMOCHLORO-METHANE		BROMOFORM		TOTAL THMs		FREE CHLORINE mg/l	TOTAL CHLORINE mg/l	T.O.C. (Total Organic Carbon) mg/l
	inst THM	term THM	inst THM	term THM	inst THM	term THM	inst THM	term THM	inst THM	term THM			
Little Cottonwood Water Treatment Plant Little Cottonwood Creek Influent	<1	-	<1	-	<1	-	<1	-	<1	-			<0.5
Little Cottonwood Water Treatment Plant Deer Creek Influent	20	24	9	10	2	3	<1	<1	31	37			2.3
Little Cottonwood Water Treatment Plant Effluent	16	45	8	12	2	3	<1	<1	26	60	-	0.85	1.6
Parleys Water Treatment Plant (off line)	-	-	-	-	-	-	-	-	-	-			-
City Creek, Big Cottonwood Water Treatment Plant Influent	<1	-	<1	-	<1	-	<1	-	<1	-			2.2 0.8
City Creek Water Treatment Plant Effluent	6	24	2	4	<1	<1	<1	<1	8	28	0.80	0.90	<0.5
Big Cottonwood Water Treatment Plant Effluent	11	31	3	5	<1	<1	<1	<1	14	36	0.65		0.9
Capital Building	7	-	2	-	<1	-	<1	-	9	-	0.65	0.70	
Bonneville Golf Course 900 South near 2100 East	15	-	7	-	2	-	<1	-	24	-	0.10	0.15	
3616 East Hermes 4135 South	1	-	<1	-	<1	-	<1	-	1	-	ND*	ND*	
2727 East Kentucky Ave. 4600 South	<1	-	<1	-	1	-	<1	-	1	-	0.10	0.15	
8644 Russell Park Road 3500 East	16	-	8	-	2	-	<1	-	26	-	0.90	0.80	
Liberty Park 600 East near 1300 South	12	-	6	-	2	-	<1	-	20	-	0.55	0.60	
Salt Lake International Center 5300 West North Temple	21	-	7	-	2	-	<1	-	30	-	ND*	0.10	
2475 East 3300 South	2	-	1	-	<1	-	<1	-	3	-	0.05	0.05	
1855 South Industrial Rd 1800 West	14	-	6	-	2	-	<1	-	22	-	0.45	0.55	

*N.D.-None Detected

Table B-1. Continued.

MARCH 29, 1981

SAMPLE LOCATIONS	TRIHALOMETHANES µg/l (PPB)										OTHER PARAMETERS		
	CHLOROFORM		DICHLOROBROMO-METHANE		DIBROMOCHLORO-METHANE		BROMOFORM		TOTAL THMs		FREE CHLORINE mg/l	TOTAL CHLORINE mg/l	T.O.C. (Total Organic Carbon) mg/l
inst THM / term THM	inst THM	term THM	inst THM	term THM	inst THM	term THM	inst THM	term THM	inst THM	term THM			
Little Cottonwood Water Treatment Plant Little Cottonwood Creek Influent	-	-	-	-	-	-	-	-	-	-	-	-	<0.5
Little Cottonwood Water Treatment Plant Deer Creek Influent	20	18	10	9	4	4	<1	<1	34	31	-	-	2.3
Little Cottonwood Water Treatment Plant Effluent	13	41	6	9	3	4	<1	<1	22	54	2.50	2.55	<0.5
Salt Lake Metro Water District 33 South Terminal Reservoir (IN)	14	-	7	-	3	-	<1	-	24	-	-	-	
Salt Lake Metro Water District 33 South Terminal Reservoir (OUT)	26	-	11	-	5	-	<1	-	42	-	1.10	1.20	
Parleys OFF LINE													
Big Cottonwood and City Creek Water Treatment Plant Influent	<1	-	<1	-	<1	-	<1	-	<1	-			1.3 3.8
Big Cottonwood Water Treatment Plant Effluent	7	35	2	7	<1	2	<1	<1	9	44	0.80	0.85	<0.5
City Creek Water Treatment Plant Effluent	18	42	3	6	<1	1	<1	<1	21	49	0.75	0.80	0.6
1855 South Industrial Road (near 1800 West)	16	-	6	-	3	-	<1	-	25	-	0.60	0.70	
2727 East Kentucky (near 4600 South)	1	-	1	-	2	-	<1	-	3	-	0.05	0.05	
21st West North Temple the above site was sampled in place of Salt Lake International Center*	11	-	5	-	2	-	<1	-	18	-	0.60	0.65	
Capital Building	15	-	4	-	1	-	<1	-	20	-	0.45	0.60	
2475 East 3300 South	13	-	4	-	1	-	<1	-	18	-	0.80	0.85	
Liberty Park	15	-	6	-	2	-	<1	-	33	-	0.60	0.65	
Bonneville Golf Course	15	-	6	-	3	-	<1	-	24	-	0.10	0.10	
3616 East 4135 South	5	-	2	-	2	-	<1	-	9	-	<0.05	<0.05	
8644 South 3500 East	30	-	10	-	5	-	<1	-	45	-	0.65	0.75	

*It was not possible to sample at the Salt Lake International Center on this date.

Table B-1. Continued.

APRIL 27, 1981

SAMPLE LOCATIONS	TRIHALOMETHANES µg/l (PPB)										OTHER PARAMETERS		
	CHLOROFORM		DICHLOROBROMO-METHANE		DIBROMOCHLORO-METHANE		BROMOFORM		TOTAL THMs		FREE CHLORINE mg/l	TOTAL CHLORINE mg/l	T.O.C. (Total Organic Carbon) mg/l
	inst THM	term THM	inst THM	term THM	inst THM	term THM	inst THM	term THM	inst THM	term THM			
Little Cottonwood Water Treatment Plant Little Cottonwood Creek Influent	<1	-	<1	-	<1	-	<1	-	<1	-			0.8
Little Cottonwood Water Treatment Plant Deer Creek Influent	13	15	5	7	2	2	<1	<1	20	24			1.4
Little Cottonwood Water Treatment Plant Effluent	22	70	6	13	1	2	<1	<1	29	85	1.00	1.10	0.9
Salt Lake Metro Water District 33 So. Term. Res. (IN)	23	-	7	-	2	-	<1	-	32	-			
33 So. Terminal Reservoir (OUT)	33	-	8	-	2	-	<1	-	43	-	0.85	0.95	
Parleys Water Treatment Plant Influent	4	-	2	-	<1	-	<1	-	6	-			2.8
Parleys Water Treatment Plant Effluent	25	36	13	16	3	4	<1	<1	41	56	0.45	0.50	0.7
Big Cottonwood and City Creek Water Treatment Plant Influent	<1	-	<1	-	<1	-	<1	-	<1	-			0.9 0.6
Big Cottonwood Water Treatment Plant Effluent	32	64	3	5	<1	<1	<1	<1	35	69	0.85	1.00	0.5
City Creek Water Treatment Plant Effluent	15	40	3	6	<1	<1	<1	<1	18	46	0.85	0.90	<0.5
1855 So. Industrial Rd. (near 1800 W.)	31	-	12	-	3	-	<1	-	46	-	0.45	0.50	
2727 E. Kentucky (near 4600 So.)	4	-	2	-	<1	-	<1	-	6	-	0.10	0.15	
Express Deli 145 Wright Brothers Dr. Salt Lake International Center	30	-	12	-	3	-	<1	-	45	-	0.45	0.45	
Capitol Building	18	-	3	-	<1	-	<1	-	21	-	0.65	0.70	
2475 E. 3300 So.	30	-	6	-	1	-	<1	-	37	-	0.80	0.95	
Liberty Park	28	-	9	-	2	-	<1	-	39	-	0.60	0.70	
Bonneville Golf Course	29	-	7	-	2	-	<1	-	38	-	0.45	0.55	
3616 E. 4135 So.	9	-	3	-	2	-	<1	-	14	-	0.05	0.05	
8644 So. 3500 E.	28	-	7	-	2	-	<1	-	37	-	1.50	1.60	

Table B-1. Continued.

MAY 28, 1981

SAMPLE LOCATIONS (inst THM / term THM)	TRIHALOMETHANES µg/l (PPB) CHLOROFORM	DICHLOROBROMO-METHANE	DIBROMOCHLORO-METHANE	BROMOFORM	TOTAL THMs	OTHER PARAMETERS FREE CHLORINE mg/l	TOTAL CHLORINE mg/l	T.O.C. (Total Organic Carbon) mg/l
Little Cottonwood Water Treatment Plant Little Cottonwood Creek Influent	<1 / -	<1 / -	<1 / -	<1 / -	<1 / -			1.9
Little Cottonwood Water Treatment Plant Deer Creek Influent	21 / 27	8 / 10	2 / 3	<1 / <1	31 / 40			1.6
Little Cottonwood Water Treament Plant Effluent	31 / 92	4 / 7	<1 / 1	<1 / <1	35 / 100	1.20	1.45	1.6
Salt Lake Metro Water District 33 South Terminal Reservoir IN	39 / -	4 / -	<1 / -	<1 / -	43 / -			
Salt Lake Metro Water District 33 South Terminal Reservoir OUT	38 / -	4 / -	<1 / -	<1 / -	42 / -	0.50	0.50	
Parleys Water Treatment Plant Influent	3 / -	1 / -	<1 / -	<1 / -	4 / -			0.9
Parleys Water Treatment Plant Effluent	43 / 48	19 / 20	6 / 6	<1 / <1	68 / 74			1.8
Big Cottonwood and City Creek Water Treatment Plant Influent	<1 / -	<1 / -	<1 / -	<1 / -	<1 / -			2.8 1.9
Big Cottonwood Water Treatment Plant Effluent	17 / 40	2 / 3	<1 / <1	<1 / <1	19 / 43	1.10	1.15	0.5
City Creek Water Treatment Plant Effluent	9 / 38	2 / 5	<1 / <1	<1 / <1	11 / 43	1.00	1.15	0.5
1855 So. Industrial Road (near 1800 West)	32 / -	3 / -	<1 / -	<1 / -	35 / -	0.40	0.40	
2727 East Kentucky (near 4600 South)	5 / -	1 / -	<1 / -	<1 / -	6 / -	0.10	0.10	
145 Wright Brothers Drive Salt Lake International Center	32 / -	4 / -	<1 / -	<1 / -	36 / -	0.40	0.40	
Capitol Building	18 / -	3 / -	<1 / -	<1 / -	21 / -	0.60	0.70	
2475 East 3300 South	34 / -	4 / -	<1 / -	<1 / -	38 / -	0.65	0.70	
Liberty Park	28 / -	3 / -	<1 / -	<1 / -	31 / -	0.45	0.50	
Bonneville Golf Course	20 / -	2 / -	<1 / -	<1 / -	22 / -	0.45	0.45	
3616 East 4135 South	11 / -	2 / -	<1 / -	<1 / -	13 / -	0.06	0.07	
8644 South 3500 East	38 / -	4 / -	<1 / -	<1 / -	42 / -	1.00	1.00	
851 East No. Crest Drive	16 / -	3 / -	<1 / -	<1 / -	19 / -	1.00	1.10	

Table B-1. Continued.

JUNE 23, 1981

SAMPLE LOCATIONS	TRIHALOMETHANES µg/l (PPB)					OTHER PARAMETERS		
inst THM / term THM	CHLOROFORM	DICHLOROBROMO-METHANE	DIBROMOCHLORO-METHANE	BROMOFORM	TOTAL THMs	FREE CHLORINE mg/l	TOTAL CHLORINE mg/l	T.O.C. (Total Organic Carbon) mg/l
Little Cottonwood Water Treatment Plant Little Cottonwood Creek Influent	<1 / -	<1 / -	<1 / -	<1 / -	<1 / -			0.5
Little Cottonwood Water Treatment Plant Deer Creek Influent	21 / 21	10 / 10	2 / 2	<1 / <1	33 / 33			2.9
Little Cottonwood Water Treatment Plant Effluent	20 / 75	6 / 13	2 / 2	<1 / <1	28 / 90	1.50	1.55	1.2
Salt Lake Metro Water District 33 South Terminal Reservoir IN	22 / -	7 / -	1 / -	<1 / -	30 / -			
Salt Lake Metro Water District 33 South Terminal Reservoir OUT	30 / -	6 / -	1 / -	<1 / -	37 / -	1.00	1.05	
Parleys Water Treatment Plant Influent	<1 / -	<1 / -	<1 / -	<1 / -	<1 / -			4.1
Parleys Water Treatment Plant Effluent	16 / 47	7 / 16	2 / 2	<1 / <1	25 / 65	0.85	0.90	2.3
Big Cottonwood and City Creek Water Treatment Plants Influent	<1 / -	<1 / -	<1 / -	<1 / -	<1 / -			2.8 1.0
Big Cottonwood Water Treatment Plant Effluent	8 / 28	1 / 4	<1 / <1	<1 / <1	9 / 32	0.85	0.85	0.5
City Creek Water Treatment Plant Effluent	8 / 28	3 / 8	<1 / <1	<1 / <1	11 / 36	1.05	1.10	1.6
1855 So. Industrial Road (near 1800 West)	29 / -	6 / -	1 / -	<1 / -	36 / -	1.10	1.20	
2727 East Kentucky (near 4600 South)	3 / -	2 / -	<1 / -	<1 / -	5 / -	0.20	0.20	
145 Wright Brothers Drive Salt Lake International Center	28 / -	7 / -	1 / -	<1 / -	36 / -	0.80	0.85	
Capital Building	14 / -	3 / -	<1 / -	<1 / -	17 / -	0.55	0.60	
2475 East 3300 South	20 / -	4 / -	<1 / -	<1 / -	24 / -	0.75	0.75	
Liberty Park	14 / -	5 / -	2 / -	<1 / -	21 / -	0.40	0.40	
Bonneville Golf Course	15 / -	6 / -	1 / -	<1 / -	22 / -	0.55	0.55	
3616 East 4135 South	18 / -	5 / -	1 / -	<1 / -	24 / -	0.50	0.50	
8644 South 3500 East	25 / -	7 / -	1 / -	<1 / -	33 / -	1.50	1.60	
851 East No. Crest Drive	4 / -	2 / -	<1 / -	<1 / -	6 / -	1.00	1.00	

Table B-1. Continued.

JULY 28, 1981

SAMPLE LOCATIONS (inst THM / term THM)	TRIHALOMETHANES µg/l (PPB)					OTHER PARAMETERS		
	CHLOROFORM	DICHLOROBROMO-METHANE	DIBROMOCHLORO-METHANE	BROMOFORM	TOTAL THMs	FREE CHLORINE mg/l	TOTAL CHLORINE mg/l	T.O.C. (Total Organic Carbon) mg/l
Little Cottonwood Water Treatment Plant Little Cottonwood Creek Influent	<1 -	<1 -	<1 -	<1 -	<1 -			0.8
Little Cottonwood Water Treatment Plant Deer Creek Influent	14 16	6 6	2 2	<1 <1	22 24			NO DATA
Little Cottonwood Water Treatment Plant Effluent	22 46	6 12	1 2	<1 <1	29 60	1.00	1.10	2.6
Salt Lake Metro Water District 33 South Terminal Reservoir IN	5 -	7 -	1 -	<1 -	13 -			
Salt Lake Metro Water District 33 South Terminal Reservoir OUT	16 -	6 -	2 -	<1 -	24 -	0.95	1.00	
Parleys Water Treatment Plant Influent	<1 -	<1 -	<1 -	<1 -	<1 -			2.6
Parleys Water Treatment Plant Effluent	12 26	6 11	2 3	<1 <1	20 40	0.85	0.90	2.6
Big Cottonwood and City Creek Water Treatment Plants Influent	<1 -	<1 -	<1 -	<1 -	<1 -			1.9 7.2*
Big Cottonwood Water Treatment Plant Effluent	4 19	<1 4	<1 1	<1 <1	4 24	0.90	1.00	1.1
City Creek Water Treatment Plant Effluent	4 13	2 4	<1 1	<1 <1	6 18	0.80	0.90	0.5
1855 So. Industrial Road (near 1800 West)	10 -	4 -	2 -	<1 -	16 -	0.65	0.70	
2727 East Kentucky (near 4600 South)	<1 -	1 -	<1 -	<1 -	1 -	0.40	0.45	
145 Wright Brothers Drive Salt Lake International Center	22 -	7 -	2 -	<1 -	31 -	0.75	0.75	
Capitol Building	9 -	3 -	<1 -	<1 -	12 -	0.60	0.70	
2475 East 3300 South	24 -	8 -	1 -	<1 -	33 -	0.95	1.10	
Liberty Park	13 -	5 -	2 -	<1 -	20 -	0.70	0.70	
Bonneville Golf Course	13 -	5 -	1 -	<1 -	19 -	0.45	0.50	
3616 East 4135 South	7 -	3 -	<1 -	<1 -	10 -	0.40	0.45	
8644 South 3500 East	29 -	9 -	2 -	<1 -	40 -	1.30	1.30	
851 East No. Crest Drive	4 -	2 -	<1 -	<1 -	6 -	0.75	0.90	

*Questionable value

Table B-1. Continued.

AUGUST 31, 1981

SAMPLE LOCATIONS	TRIHALOMETHANES µg/l (PPB)										OTHER PARAMETERS		
	CHLOROFORM		DICHLOROBROMO-METHANE		DIBROMOCHLORO-METHANE		BROMOFORM		TOTAL THMs		FREE CHLORINE mg/l	TOTAL CHLORINE mg/l	T.O.C. (Total Organic Carbon) mg/l
	inst THM	term THM	inst THM	term THM	inst THM	term THM	inst THM	term THM	inst THM	term THM			
Little Cottonwood Water Treatment Plant Little Cottonwood Creek Influent	<1	-	<1	-	<1	-	<1	-	<1	-			<0.5
Little Cottonwood Water Treatment Plant Deer Creek Influent	7	7	2	2	<1	<1	<1	<1	9	9			3.6
Little Cottonwood Water Treatment Plant Effluent	19	54	5	11	1	2	<1	<1	25	67	1.05	1.05	2.0
Salt Lake Metro Water District 33 South Terminal Reservoir IN	24	-	6	-	1	-	<1	-	31	-			
Salt Lake Metro Water District 33 South Terminal Reservoir OUT	29	-	6	-	1	-	<1	-	36	-	0.50	0.60	
Parleys Water Treatment Plant Influent	<1	-	<1	-	<1	-	<1	-	<1	-			2.0
Parleys Water Treatment Plant Effluent	17	32	8	13	3	4	<1	<1	28	49	0.60	0.65	1.1
Big Cottonwood and City Creek Water Treatment Plant Influent	<1	-	<1	-	<1	-	<1	-	<1	-			0.8 0.8
Big Cottonwood Water Treatment Plant Effluent	7	29	2	3	<1	<1	<1	<1	9	32	0.65	0.75	<0.5
City Creek Water Treatment Plant Effluent	4	20	2	4	<1	<1	<1	<1	6	24	0.80	0.85	<0.5
1855 So. Industrial Road (near 1800 West)	10	-	3	-	2	-	<1	-	15	-	0.50	0.55	
2727 East Kentucky (near 4600 South)	10	-	2	-	<1	-	<1	-	12	-	0.45	0.45	
145 Wright Brothers Drive Salt Lake International Center	23	-	5	-	1	-	<1	-	29	-	0.50	0.50	
Capitol Building	19	-	4	-	<1	-	<1	-	23	-	0.10	0.15	
2475 East 3300 South	23	-	5	-	<1	-	<1	-	28	-	0.65	0.70	
Liberty Park	13	-	4	-	<1	-	<1	-	17	-	0.40	0.45	
Bonneville Golf Course	15	-	4	-	1	-	<1	-	20	-	0.40	0.45	
3616 East 4135 South	18	-	4	-	<1	-	<1	-	22	-	0.40	0.40	
8644 South 3500 East	26	-	7	-	1	-	<1	-	34	-	0.90	1.00	
851 East North Crest Drive	5	-	2	-	<1	-	<1	-	7	-	0.70	0.75	

Table B-1. Continued.

SEPTEMBER 28, 1981

SAMPLE LOCATIONS inst THM / term THM	TRIHALOMETHANES µg/l (PPB)					OTHER PARAMETERS		
	CHLOROFORM	DICHLOROBROMO-METHANE	DIBROMOCHLORO-METHANE	BROMOFORM	TOTAL THMs	FREE CHLORINE mg/l	TOTAL CHLORINE mg/l	T.O.C. (Total Organic Carbon) mg/l
Little Cottonwood Water Treatment Plant Little Cottonwood Creek Influent	<1 / -	<1 / -	<1 / -	<1 / -	<1 / -			<0.5
Little Cottonwood Water Treatment Plant Deer Creek Influent	NO DATA AVAILABLE							4.1
Little Cottonwood Water Treatment Plant Effluent	19 / 78	8 / 18	3 / 4	<1 / <1	30 / 100	1.35	1.45	2.0
Salt Lake Metro Water District 33 South Terminal Reservoir IN	23 / -	10 / -	3 / -	<1 / -	36 / -			
Salt Lake Metro Water District 33 South Terminal Reservoir OUT	29 / -	11 / -	3 / -	<1 / -	43 / -	0.50	0.60	
Parleys Water Treatment Plant Influent	<1 / -	<1 / -	<1 / -	<1 / -	<1 / -			2.2
Parleys Water Treatment Plant Effluent	12 / 30	9 / 16	4 / 7	<1 / <1	25 / 53	0.70	0.85	1.5
Big Cottonwood and City Creek Water Treatment Plant Influent	<1 / -	<1 / -	<1 / -	<1 / -	<1 / -			0.8 0.9
Big Cottonwood Water Treatment Plant Effluent	7 / 11	2 / 2	<1 / <1	<1 / <1	9 / 13	0.75	0.85	<0.5
City Creek Water Treatment Plant Effluent	7 / 10	2 / 2	<1 / <1	<1 / <1	9 / 12	0.90	1.00	<0.5
1855 South Industrial Road (near 1800 West)	9 / -	5 / -	2 / -	<1 / -	16 / -	0.45	0.50	
2727 East Kentucky (near 4600 South)	3 / -	<1 / -	<1 / -	<1 / -	3 / -	0.40	0.45	
145 Wright Brothers Drive Salt Lake International Center	21 / -	10 / -	4 / -	<1 / -	35 / -	0.15	0.20	
Capitol Building	10 / -	5 / -	1 / -	<1 / -	16 / -	0.45	0.50	
2475 East 3300 South	11 / -	5 / -	2 / -	<1 / -	18 / -	0.50	0.55	
Liberty Park	14 / -	8 / -	3 / -	<1 / -	25 / -	0.40	0.45	
Bonneville Golf Course	11 / -	8 / -	3 / -	<1 / -	22 / -	0.50	0.50	
3616 East 4135 South	11 / -	7 / -	3 / -	<1 / -	21 / -	0.10	0.15	
8644 South 3500 East	19 / -	9 / -	3 / -	<1 / -	31 / -	0.90	0.90	
851 East North Crest Drive	6 / -	2 / -	<1 / -	<1 / -	8 / -	0.85	0.90	

Table B-1. Continued.

OCTOBER 30, 1981

SAMPLE LOCATIONS	TRIHALOMETHANES µg/l (PPB)										OTHER PARAMETERS		
	CHLOROFORM		DICHLOROBROMO-METHANE		DIBROMOCHLORO-METHANE		BROMOFORM		TOTAL THMs		FREE CHLORINE mg/l	TOTAL CHLORINE mg/l	T.O.C. (Total Organic Carbon) mg/l
	inst THM	term THM	inst THM	term THM	inst THM	term THM	inst THM	term THM	inst THM	term THM			
Little Cottonwood Water Treatment Plant Little Cottonwood Creek Influent	<1	-	<1	-	<1	-	<1	-	<1	-			<0.5
Little Cottonwood Water Treatment Plant Deer Creek Influent	32	42	13	16	2	4	<1	<1	47	62			3.3
Little Cottonwood Water Treatment Plant Effluent	28	64	10	14	3	4	<1	<1	41	82	1.4	1.5	1.5
Salt Lake Metro Water District 33 South Terminal Reservoir IN	24	-	9	-	2	-	<1	-	35	-			
Salt Lake Metro Water District 33 South Terminal Reservoir OUT	31	-	10	-	3	-	<1	-	44	-	0.80	0.90	
Parleys Water Treatment Plant Influent	<1	-	<1	-	<1	-	<1	-	<1	-			2.6
Parleys Water Treatment Plant Effluent	16	43	11	21	5	7	<1	<1	32	71	0.80	0.90	1.9
Big Cottonwood and City Creek Water Treatment Plant Influent	<1	-	<1	-	<1	-	<1	-	<1	-			1.5 0.7
Big Cottonwood Water Treatment Plant Effluent	13	50	2	6	<1	<1	<1	<1	15	56	0.65	0.80	1.3
City Creek Water Treatment Plant Effluent	12	48	2	6	<1	<1	<1	<1	14	54	0.70	0.80	0.9
1855 So. Industrial Road (near 1800 West)	30	-	10	-	3	-	<1	-	43	-	0.40	0.50	
2727 East Kentucky (near 4600 South)	<1	-	1	-	1	-	<1	-	2	-	0.30	0.40	
147 Wright Brothers Drive Salt Lake International Center	29	-	10	-	3	-	<1	-	42	-	0.30	0.40	
Capitol Building	44	-	10	-	2	-	<1	-	56	-	0.40	0.50	
2475 East 3300 South	19	-	4	-	<1	-	<1	-	23	-	0.90	1.10	
Liberty Park	24	-	9	-	3	-	<1	-	36	-	0.50	0.60	
Bonneville Golf Course	24	-	10	-	4	-	<1	-	38	-	0.35	0.40	
3616 East 4135 South	8	-	4	-	2	-	<1	-	14	-	0.10	0.10	
8644 South 3500 East	44	-	16	-	4	-	<1	-	64	-	1.20	1.40	
851 East North Crest Drive	16	-	3	-	<1	-	<1	-	19	-	0.40	0.50	

Table B-1. Continued.

NOVEMBER 27, 1981

SAMPLE LOCATIONS	TRIHALOMETHANES µg/l (PPB)										OTHER PARAMETERS		
	CHLOROFORM		DICHLOROBROMO-METHANE		DIBROMOCHLORO-METHANE		BROMOFORM		TOTAL THMs		FREE CHLORINE mg/l	TOTAL CHLORINE mg/l	T.O.C. (Total Organic Carbon) mg/l
	inst THM	term THM	inst THM	term THM	inst THM	term THM	inst THM	term THM	inst THM	term THM			
Little Cottonwood Water Treatment Plant Little Cottonwood Creek Influent	<1	-	<1	-	<1	-	<1	-	<1	-			1.0
Little Cottonwood Water Treatment Plant Deer Creek Influent	30	38	14	16	4	4	<1	<1	48	58			2.5
Little Cottonwood Water Treatment Plant Effluent	13	48	7	13	2	3	<1	<1	22	64	1.15	1.20	1.0
Salt Lake Metro Water District 33 South Terminal Reservoir IN	16	-	7	-	2	-	<1	-	25	-			
Salt Lake Metro Water District 33 South Terminal Reservoir OUT	33	-	10	-	3	-	<1	-	46	-	0.60	0.80	
Parleys Water Treatment Plant Influent	<1	-	<1	-	<1	-	<1	-	<1	-			3.1
Parleys Water Treatment Plant Effluent	14	30	12	21	6	8	<1	<1	32	59	0.60	0.70	1.9
Big Cottonwood and City Creek Water Treatment Plant Influent	<1	-	<1	-	<1	-	<1	-	<1	-			0.6 0.7
Big Cottonwood Water Treatment Plant Effluent	9	37	3	6	<1	<1	<1	<1	12	43	0.85	1.00	<0.5
City Creek Water Treatment Plant Effluent	8	29	3	7	<1	1	<1	<1	11	37	1.00	1.00	<0.5
1855 So. Industrial Road (near 1800 West)	NO ACESS												
2727 East Kentucky (near 4600 South)	<1	-	1	-	1	-	<1	-	2	-	0.30	0.30	
145 Wright Brothers Drive Salt Lake International Center	NO ACCESS												
Capitol Building	9	-	3	-	<1	-	<1	-	12	-	0.75	0.80	
2475 East 3300 South	11	-	4	-	1	-	<1	-	16	-	0.80	0.90	
Liberty Park	16	-	8	-	3	-	<1	-	27	-	0.40	0.45	
Bonneville Golf Course	17	-	11	-	5	-	<1	-	33	-	0.00	0.00	
3616 East 4135 South	1	-	<1	-	<1	-	<1	-	1	-	0.00	0.00	
8644 East North Crest Drive	33	-	10	-	3	-	<1	-	46	-	0.65	0.70	
351 East North Crest Drive	8	-	3	-	1	-	<1	-	11	-	0.90	1.00	

Table B-1. Continued.

DECEMBER 30, 1981

SAMPLE LOCATIONS (inst THM / term THM)	TRIHALOMETHANES µg/l (PPB)					OTHER PARAMETERS		
	CHLOROFORM	DICHLOROBROMO-METHANE	DIBROMOCHLORO-METHANE	BROMOFORM	TOTAL THMs	FREE CHLORINE mg/l	TOTAL CHLORINE mg/l	T.O.C. (Total Organic Carbon) mg/l
Little Cottonwood Water Treatment Plant, Little Cottonwood Creek Influent	<1 -	<1 -	<1 -	<1 -	<1 -			<0.5
Little Cottonwood Water Treatment Plant Deer Creek Influent	33 26	11 10	3 3	<1 <1	47 39			2.9
Little Cottonwood Water Treatment Plant Effluent	14 51	6 10	2 2	<1 <1	22 63	0.90	1.00	1.5
Salt Lake Metro Water Distric 33 South Terminal Reservoir IN	15 -	6 -	2 -	<1 -	23 -			
Salt Lake Metro Water District 33 South Terminal Reservoir OUT	20 -	7 -	2 -	<1 -	29 -	0.90	0.90	
Parleys Water Treatment Plant Influent	<1 -	<1 -	<1 -	<1 -	<1 -			2.7
Parleys Water Treatment Plant Effluent	8 16	7 11	4 5	<1 <1	19 32	0.70	0.70	1.6
Big Cottonwood and City Creek Water Treatment Plant Influent	<1 -	<1 -	<1 -	<1 -	<1 -			0.8 1.1
Big Cottonwood Water Treatment Plant Effluent	6 27	2 4	<1 <1	<1 <1	8 31	0.80	0.80	<0.5
City Creek Water Treatment Plant Effluent	7 34	2 4	<1 <1	<1 <1	9 38	0.80	0.85	<0.5
1855 So. Industrial Road (near 1800 West)	14 -	5 -	2 -	<1 -	21 -	0.55	0.55	
2727 East Kentucky (near 4600 South)	<1 -	1 -	1 -	<1 -	2 -	0.30	0.30	
145 Wright Brothers Drive Salt Lake International Center	10 -	4 -	2 -	<1 -	16 -	0.55	0.55	
Capitol Building	9 -	2 -	<1 -	<1 -	11 -	0.55	0.55	
2475 East 3300 South	11 -	3 -	<1 -	<1 -	14 -	0.65	0.65	
Liberty Park	10 -	4 -	1 -	<1 -	15 -	0.50	0.50	
Bonneville Golf Course	NO ACCESS							
3616 East 4135 South	<1 -	<1 -	<1 -	<1 -	<1 -	N.D.	N.D.	
8644 South 3500 East	13 -	5 -	2 -	<1 -	20 -	1.30	1.30	
851 East North Crest Drive	10 -	3 -	1 -	<1 -	14 -	0.55	0.65	

*N.D.-None Detected

Table B-2. Salt Lake County area trihalomethanes and total organic carbons (when available) for the months of June and September, 1981.

SAMPLE LOCATIONS inst THM / term *THM	TRIHALOMETHANES μg/l(PPB)					OTHER PARAMETERS			
	CHLOROFORM	DICHLOROBROMOMETHANE	DIBROMOCHLOROMETHANE	BROMOFORM	TOTAL THMs	Temperature °C	Water Surface Elevation (feet)		T.O.C. mg/l (TOTAL ORGANIC CARBON)
(June 18, 1981) Groundwater Well 1657 (shallow)	<1 7	<1 7	<1 5	<1 <1	<1 19	10	+10		<0.5
Groundwater Well 1651 (deep)	<1 7	<1 3	<1 1	<1 <1	<1 11	7	-270		<0.5
(September 18, 1981) Groundwater Well 1657 (shallow)	<1 10	<1 5	<1 2	<1 <1	<1 17	14	+4.3		3.0
Groundwater Well 1651 (deep)	<1 5	<1 4	<1 3	<1 <1	<1 12	13	-270		0.5

Appendix C

Salt Lake County Water Treatment Plant Unit Processes and Storage Reservoir Analyses

Table C-1. Big Cottonwood water treatment plant unit process analysis.

	Unit Process						
Parameter	Influent Raw	Post Rapid Mix	End of Coagulation	End of Sedimentation	Filter Influent	Filter Effluent	Clearwell Effluent - Finished
Date	7/01/81	7/01/81	7/01/81	7/01/81	7/01/81	7/01/81	7/01/81
Time	3:25	3:30	4:05	7:30	7:35	8:00	8:05
Temperature (°C)	14.5	16.0	16.0	19.0	18.0	18.0	16.0
pH	8.2	8.6	8.3	8.2	8.3	8.2	8.1
Free chlorine (mg/l)	0.00	1.00	0.80	0.90	0.80	0.70	0.90
Total chlorine (mg/l)	0.00	1.10	0.90	1.00	0.90	0.95	1.00
TOC (mg/l)	1.3	2.0	1.5	1.9	2.3	1.0	0.9
Inst-TTHM (μg/l)	0	2	5	9	9	9	6
Term-TTHM (μg/l)	0	53	34	38	44	38	32
Chlorine dose (mg/l)		1.3					
Flow (MGD)	40	40	40	40	40	40	40
Date	9/24/81	9/24/81	9/24/81	9/24/81	9/24/81	9/24/81	9/24/81
Time	11:00	11:05	11:40	3:25	3:40	3:50	4:00
Temperature (°C)	17.0	16.0	20.0	15.0	15.0	15.0	15.0
pH	8.1	8.0	8.0	7.9	8.1	8.0	8.0
Free chlorine (mg/l)	0.05	0.70	0.55	0.45	0.80	0.75	0.60
Total chlorine (mg/l)	0.10	0.95	0.90	0.85	0.80	0.75	0.70
TOC (mg/l)	1.6	0.5	0.8	1.4	0.9	<0.5	0.5
Inst-TTHM (μg/l)	3	3	5	9	9	9	9
Term-TTHM (μg/l)	3	13	6	11	14	31	33
Chlorine dose (mg/l)		1.4					
Flow (MGD)	18.5	18.5	18.5	18.5	18.5	18.5	18.5

Table C-2. Parleys water treatment plant unit process analysis.

	Unit Process							
Parameter	Influent Tap - Raw	Start of Coagulation	End of Coagulation	Start of Sedimentation	End of Sedimentation	Filter Influent	Filter Effluent	Clearwell Effluent - Finished
Date	7/01/81	7/01/81	7/01/81	7/01/81	7/01/81	7/01/81	7/01/81	7/01/81
Time	9:50	10:00	10:55	11:00	3:45	3:50	4:20	4:40
Temperature (°C)	15.0	14.5	14.5	14.0	14.0	16.0	12.5	13.5
pH	7.7	7.5	7.5	7.6	7.6	7.6	7.5	7.5
Free chlorine (mg/l)	0.05	0.75	0.55	0.75	0.30	0.75	0.65	0.55
Total chlorine (mg/l)	0.05	1.20	0.95	1.15	0.55	1.15	0.95	0.85
TOC (mg/l)	2.7	2.7	2.4	2.5	2.2	2.5	2.0	1.9
Inst-TTHM (μg/l)	2	14	16	18	27	22	29	24
Term-TTHM (μg/l)	2	46	54	47	47	74	62	28
Chlorine dose (mg/l)		2.4						
Flow (MGD)	20	20	20	20	20	20	20	20
Date	9/24/81	9/24/81	9/24/81	9/24/81	9/24/81	9/24/81	9/24/81	9/24/81
Time	12:50	1:00	1:45	1:50	3:35	3:40	4:05	4:20
Temperature (°C)	19.0	18.5	18.5	17.5	18.5	18.5	18.0	18.0
pH	8.1	7.8	7.6	7.6	7.6	7.6	7.6	7.6
Free chlorine (mg/l)	0.00	1.40	0.80	0.55	0.60	0.65	0.50	0.50
Total chlorine (mg/l)	0.00	1.55	1.10	0.80	0.90	0.95	0.80	0.75
TOC (mg/l)	1.8	1.7	1.9	1.6	1.6	1.6	1.4	1.5
Inst-TTHM (μg/l)	<1	14	17	33	27	23	19	23
Term-TTHM (μg/l)	<1	39	34	33	42	37	37	36
Chlorine dose (mg/l)		2.2						
Flow (MGD)	15	15	15	15	15	15	15	15

Table C-3. Little Cottonwood water treatment plant unit process analysis.

	Unit Process										
Parameter	Influent Raw - Little Cottonwood Creek	Influent Raw - Deer Creek Reservoir	Start of Aeration	End of Aeration	Post Rapid Mix	Start of Coagulation (Post Alum)	Start of Sedimentation	End of Sedimentation	Filter Influent	Filter Effluent	Clearwell Effluent - Finished
Date	6/30/81	6/30/81	6/30/81	6/30/81	6/30/81	6/30/81	6/30/81	6/30/81	6/30/81	6/30/81	6/30/81
Time	10:30	10:30	10:55	11:10	11:15	11:25	12:10	2:45	2:50	3:15	3:25
Temperature (°C)	20.0	20.0	12.0	12.0	13.0	12.5	12.5	19.0	18.5	16.0	15.5
pH	7.8	7.8	7.8	7.8	7.8	7.5	7.5	8.1	7.9	7.9	8.0
Free chlorine (mg/l)	0.00	0.00	0.20	0.20	0.60	0.60	0.50	0.05	0.10	0.10	1.10
Total chlorine (mg/l)	0.00	0.00	0.35	0.35	0.70	0.80	0.70	0.10	0.20	0.15	1.30
TOC (mg/l)	<0.5	2.7	2.0	1.9	1.9	2.1	2.5	1.5	1.6	1.3	1.4
Inst-TTHM (μg/l)	0	29	21	24	24	25	24	32	32	27	35
Term-TTHM (μg/l)	0	27	21	23	49	26	43	18	36	33	39
Chlorine dose (mg/l)									1.13		
Flow (MGD)	115	115	115	115	115	115	115	115	115	115	115
Date	9/24/81	9/24/81	9/24/81	9/24/81	9/24/81	9/24/81	9/24/81	9/24/81	9/24/81	9/24/81	9/24/81
Time	11:50	11:50	12:05	12:30	12:35	12:40	1:50	6:00	6:05	6:45	6:55
Temperature (°C)	22.0	22.5	20.0	19.0	18.5	18.5	19.0	18.0	18.0	19.0	22.5
pH	7.5	7.5	7.6	7.6	9.2	8.6	8.4	8.6	7.8	7.8	7.8
Free chlorine (mg/l)	0.00	0.10	0.60	0.90	0.85	0.70	0.25	0.25	2.80	2.80	1.50
Total chlorine (mg/l)	0.00	0.50	1.20	1.50	1.80	1.00	1.30	1.35	2.80	2.80	1.55
TOC (mg/l)	<0.5	3.4	3.1	2.9	3.2	3.5	2.6	2.0	2.1	2.0	2.1
Inst-TTHM (μg/l)	<1	1	2	<1	6	3	3	3	47	44	23
Term-TTHM (μg/l)	<1	2	<1	7	6	6	5	5	87	81	25
Chlorine dose (mg/l)									1.0		
Flow (MGD)	66.5	66.5	66.5	66.5	66.5	66.5	66.5	66.5	66.5	66.5	66.5

Table C-4. Water treatment plant storage reservoir data and descriptions for unit process analysis.

	Parameter								
Reservoir	Date	Time	Temperature (°C)	pH	Free Chlorine (mg/l)	Total Chlorine (mg/l)	TOC (mg/l)	Inst-TTHM (μg/l)	Term-TTHM (μg/l)
33 South Terminal	7/01/81	12:30	20.5	8.0	1.00	1.00	-	35	66
Baskin	7/01/81	6:30	20.0	7.8	0.60	0.70	1.2	24	54
Tanner	7/01/81	8:30	21.0	8.0	0.70	0.70	1.1	11	31
33 South Terminal	9/28/81	3:20	16.5	-	0.50	0.60	2.1	43	-
Baskin	9/24/81	3:30	17.5	8.1	0.30	0.30	-	26	47
Tanner	9/24/81	5:15	14.0	8.1	0.55	0.65	0.7	15	23

Reservoir Location and Storage:

<u>33 South Terminal</u> - Little Cottonwood treatment plant water
<u>Baskin</u> - at Bonneville Golf Course near Foothill Drive and 13 South, predominantly Parleys treatment plant water
<u>Tanner</u> - near Holladay and 62 South, predominantly Big Cottonwood treatment plant water

Appendix D

Quality Assurance Data

Table D-1. EPA audit and internal quality control quality assurance data.

	EPA Audit WS-007 February 1981		EPA Audit WS-008 July 1981		EPA Audit WS-009 November 1982	
	Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2
Chloroform (g/l)						
"True" value	14.9	44.7	76.6	10.2	25.5	
Acceptable range	12.0-18.0	36.0-54.0	61.0-92.0	8.2-12.0	20.0-31.0	-
Reported value	12.8	39.6	80.0	11.0	23.2	
Acceptable (yes or no)	Yes	Yes	Yes	Yes	Yes	
Bromoform (g/l)						
"True" value	24.5	61.4	98.7	32.9	11.0	
Acceptable range	20.0-29.0	49.0-74.0	79.0-120.0	26.0-39.0	8.8-13.0	-
Reported value	23.0	56.8	106.0	33.9	13.2	
Acceptable (yes or no)	Yes	Yes	Yes	Yes	No	
Bromodichloromethane (g/l)						
"True" value	94.9	18.4	91.2	22.8	13.7	
Acceptable range	76.0-110.0	15.0-23.0	73.0-110.0	18.0-27.0	11.0-16.0	-
Reported value	67.4	19.0	97.8	25.2	15.3	
Acceptable (yes or no)	No	Yes	Yes	Yes	Yes	
Dibromochloromethane (g/l)						
"True" value	11.3	84.8	71.1	11.8	5.9	
Acceptable range	9.0-14.0	68.0-100.0	57.0-85.0	9.4-14.0	4.7-7.1	-
Reported value	10.4	75.2	81.5	13.9	6.8	
Acceptable (yes or no)	Yes	Yes	Yes	Yes	Yes	
Total THM (g/l)						
"True" value	145.1	209.8	337.6	77.7	56.1	
Acceptable range	120.0-170.0	170.0-250.0	270.0-410.0	62.0-93.0	45.0-67.0	-
Reported value	114.0	191.0	293.0	156.0	58.0	
Acceptable (yes or no)	No	Yes	Yes	No	Yes	

Table D-1. Continued.

	EPA Audit WS-010 May 1982		Internal Quality Control 2nd Quarter 1981		Internal Quality Control 3rd Quarter 1981	
	Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2
Chloroform (g/l)						
"True" value	61.3	20.4	11.0	45.6	11.0	45.6
Acceptable range	49.0-74.0	16.0-24.0	8.8-13.2	36.5-54.7	8.8-13.2	36.5-54.7
Reported value	53.0	17.6	9.0	45.8	9.6	38.5
Acceptable (yes or no)	Yes	Yes	Yes	Yes	Yes	Yes
Bromoform (g/l)						
"True" value	82.3	21.9	2.8	10.4	2.8	10.4
Acceptable range	66.0-99.0	18.0-26.0	2.2-3.4	8.3-12.5	2.2-3.4	8.3-12.5
Reported value	80.0	18.3	2.7	11.7	3.0	10.8
Acceptable (yes or no)	Yes	Yes	Yes	Yes	Yes	Yes
Bromodichloromethane (g/l)						
"True" value	73.0	27.4	1.7	8.6	1.7	8.6
Acceptable range	58.0-88.0	22.0-33.0	1.4-2.0	6.9-10.3	1.4-2.0	6.9-10.3
Reported value	73.0	26.4	1.8	9.9	2.0	9.8
Acceptable (yes or no)	Yes	Yes	Yes	Yes	Yes	Yes
Dibromochloromethane (g/l)						
"True" value	53.3	23.7	2.4	12.0	2.4	12.0
Acceptable range	43.0-64.0	19.0-28.0	1.9-2.9	9.6-14.4	1.9-2.9	9.6-14.4
Reported value	54.0	23.0	2.6	14.0	2.7	14.0
Acceptable (yes or no)	Yes	Yes	Yes	Yes	Yes	Yes
Total THM (g/l)						
"True" value	269.9	93.4	17.9	76.6	17.9	76.6
Acceptable range	220.0-320.0	75.0-110.0	14.3-21.5	61.3-91.9	14.3-21.5	61.3-91.9
Reported value	260.0	85.0	16.1	81.4	17.3	73.1
Acceptable (yes or no)	Yes	Yes	Yes	Yes	Yes	Yes

Table D-1. Continued.

	Internal Quality Control 4th Quarter 1981		Internal Quality Control 1st Quarter 1982		Internal Quality Control 2nd Quarter 1982	
	Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2
Chloroform (g/l)						
"True" value	10.7	20.1	10.7	70.1	11.0	45.6
Acceptable range[a]	8.4-13.1	54.3-85.9	8.4-13.1	54.3-85.9	8.6-13.4	35.3-55.9
Reported value	10.6	70.8	8.0	73.0	10.0	41.0
Acceptable (yes or no)	Yes	Yes	No	Yes	Yes	Yes
Bromoform (g/l)						
"True" value	12.3	3.5	12.3	3.5	2.8	10.4
Acceptable range [a]	9.8-14.7	2.3-4.8	9.8-14.7	2.3-4.8	1.8-3.8	8.3-12.5
Reported value	14.4	2.9	10.8	3.0	1.0	10.5
Acceptable (yes or no)	Yes	Yes	Yes	Yes	No	Yes
Bromodichloromethane (g/l)						
"True" value	4.5	18.5	4.5	18.5	1.7	8.6
Acceptable range[a]	2.6-6.4	15.0-22.0	2.6-6.4	15.0-22.0	1.0-2.4	5.0-12.2
Reported value	4.2	20.2	4.0	15.5	2.0	9.5
Acceptable (yes or no)	Yes	Yes	Yes	Yes	Yes	Yes
Dibromochloromethane (g/l)						
"True" value	6.5	18.7	6.5	18.7	2.4	12.0
Acceptable range[a]	4.6-8.3	14.7-22.7	4.6-8.3	14.7-22.7	1.7-3.1	9.4-14.6
Reported value	6.9	20.9	5.7	16.1	2.7	12.0
Acceptable (yes or no)	Yes	Yes	Yes	Yes	Yes	Yes
Total THM (g/l)						
"True" value	33.9	110.8	33.9	110.8	17.9	76.6
Acceptable range[a]	25.4-42.4	86.3-135.3	25.4-42.4	86.3-135.3	13.1-22.7	58.1-95.1
Reported value	36.1	114.8	28.5	107.6	15.7	73.0
Acceptable (yes or no)	Yes	Yes	Yes	Yes	Yes	Yes

[a] One standard deviation