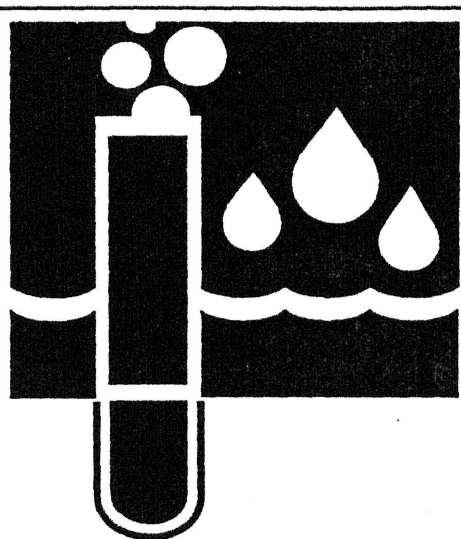# KANSAS WATER RESOURCES RESEARCH INSTITUTE

OCCURRENCE AND CONTROL OF ATRAZINE DEGRADATION PRODUCTS IN KANSAS DRINKING WATER SUPPLIES - YEAR 2

PATRICIA V. ADAMS
STEPHEN J. RANDTKE

WATER RESOURCES RESEARCH CONDUCTED AT	
KANSAS STATE UNIVERSITY	UNIVERSITY OF KANSAS
MANHATTAN, KANSAS	LAWRENCE, KANSAS

Report No.
G2020-07B

OCCURRENCE AND CONTROL OF ATRAZINE
DEGRADATION PRODUCTS
IN KANSAS DRINKING WATER SUPPLIES

Report of Year 2 Results, Part B:

Atrazine Removal from Drinking Water by
Point-of-Use Activated Carbon Filters

by

Patricia V. Adams and Stephen J. Randtke
Civil Engineering Department, University of Kansas

for

U.S. Department of the Interior
Geological Survey

A Research Project Conducted
by

Kansas Water Resources Research Institute
Kansas State University
Manhattan, KS 66506

In Cooperation With

Water Resources Institute
University of Kansas
Lawrence, KS 66045

Contribution No. 297B

May, 1993

PREFACE

This two-year research effort was designed to: 1) document the types and concentrations of atrazine degradation products present in raw and conventionally treated drinking water supplies, especially those known to contain traces of atrazine; 2) examine the ability of various water treatment processes, including ozonation and granular activated carbon (GAC) adsorptin, to remove atrazine and atrazine degradation products from drinking water supplies; and 3) determine the extent to which any additional atrazine degradation products are formed during treatment.

During the first hear of this study, an extensive investigation of the reaction of ozone with atrazine was completed, and preliminary studies were conducted to examine the removal of atrazine and its degradation products by GAC adsorption, coagulation, and softening. The results of these efforts are described in detail in the Year 1 report (Craig D. Adams' Ph.D. thesis), available through the Kansas Water Resources Research Institute as Contribution No. 290.

During the first year and continuing into the second, samples of raw and treated water were collected from several drinking water treatment plants, including those operated by Johnson County (KS) Water District No. 1; the City of Lawrence, KS; the U.S. Army Corps of Engineers (Bllomington Area, Clinton Lake, KS); the Rathbun (Iowa) Regional Water Association; and the Pennsylvania American Water Company in Hershey, PA. In addition, bench-scale studies were performed to examine the removal of atrazine and its degradation products by powdered activated carbon (PAC) adsorption, ion exchange, and oxidation using potassium permanganate. Both the plant sampling data and bench test results are presented in Part A of the Year 2 report (Aaron Witt's M.S. thesis), designated as Contribution No. 297A.

During Year 2 of the study, the ability of eight point-of-use activated carbon filters to remove atrazine from Lawrence tap water was examined in a laboratory study employing simulated home use conditions. The results are presented in this part (Part B) of the Year 2 report (Patricia Adams' M.S. thesis), designated as Contribution No. 297B.

ABSTRACT

Occurrence and Control of Atrazine Degradation Products in Kansas Drinking Water Supplies

Report of Year 2 Results, Part B:

Atrazine Removal From Drinking Water By Point-Of-Use Activated Carbon Filters

Atrazine (2-chloro-4-ethylamino-6-isopropylamino-s-triazine) is a widely used, selective herbicide. After heavy rainfall events that occur following atrazine application, surface water atrazine concentrations can exceed 3 $\mu g/L$, EPA's maximum contaminant level (MCL) for drinking water. Since many Midwestern communities depend on surface waters for drinking water supplies, there is public concern about treating atrazine contaminated waters to meet the MCL, which became enforceable in July, 1992.

Private well users and small rural communities are at greatest risk for atrazine contamination. Many small systems do not have the financial resources to immediately modify treatment facilities or to regularly monitor treated water atrazine levels. Large municipal water treatment plants have successfully used granular activated carbon (GAC) and powdered activated carbon (PAC) to reduce atrazine and atrazine metabolite concentrations. Properly designed and maintained point-of-use (POU) activated carbon filters may provide small rural systems and private well users with the same effective treatment option.

The objective of this study was to evaluate the ability of POU activated carbon filters to remove atrazine from drinking water. In addition to this, filter reductions of total organic carbon (TOC), total chlorine residual (TCR), and two common atrazine metabolites (hydroxyatrazine and deethylatrazine) were also examined. Eight POU activated carbon filters were tested. The tests were conducted under simulated home use conditions over a four month period. Filter influent and effluent samples were collected at regular intervals and analyzed to determine atrazine, hydroxyatrazine, deethylatrazine, TOC, and TCR.

Atrazine challenge concentrations of 12.3 $\mu g/L$ were reduced to nondetectable levels by the PAC block-type and dual cartridge POU filters tested. TCR levels were reduced by more than 90 percent. Effective TOC removal was primarily limited to the first few weeks of use. The most effective POU filters were characterized as having more than 500 grams of activated carbon, an empty bed contact time (EBCT) in excess of 18 seconds, well distributed influent flow, and a rated capacity that corresponded to fewer than 5000 bed volumes.

ACKNOWLEDGEMENTS

TABLE OF CONTENTS

Chapter	Title	Page

TABLE OF CONTENTS (CONT'D)

TABLE OF CONTENTS (CONT'D)

TABLE OF CONTENTS (CONT'D)

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (CONT'D)

CHAPTER 1

INTRODUCTION

Atrazine is the most heavily used herbicide in the United States (Gianessi and Puffer, 1991).   It is a selective herbicide used to control broadleaf and certain grass weeds, primarily in corn and grain sorghum fields (Carney, 1991).   From 1987-1989, in the ten state Midwestern corn producing region, the atrazine application rate was estimated at 45.3 million pounds per year (as atrazine) (Gianessi and Puffer, 1991).   In Kansas, atrazine is annually applied to approximately 1.2 million acres of corn and 2 million acres of grain sorghum (Regehr, 1992), at a rate of 4.7 million pounds per year (as atrazine) (Gianessi and Puffer, 1991).

Atrazine is a relatively persistent synthetic organic chemical (SOC).   The soil half-life of atrazine is about 60 days under warm, moist conditions (Regehr, 1992).   Because atrazine is water soluble (33 mg/L at 22 °C) and present in treated fields for extended periods, portions of it are transported into surface water systems during late spring and early summer rains (Thurman et al., 1991).   While the highest concentrations of atrazine in surface water supplies are detected in May, June, and July; detectable concentrations are found year-round in most Midwestern streams sampled (Goolsby et al., 1991b). The combination of widespread use, persistence, and water solubility accounts for the frequent detection of atrazine in surface waters.

Prior to January 1991, the U.S. Environmental Protection Agency's (EPA) nonenforceable drinking water standard for atrazine was 150 µg/L. Since atrazine concentrations in water supplies were much less than this health advisory level (HAL), there was no apparent problem. In

1991, the EPA proposed an enforceable maximum contaminant level (MCL) of 3 µg/L atrazine in drinking water. A U.S. Geological Survey (USGS) study of 122 Midwestern river basins, during a two-year period from 1989-1990, found that 52 percent of the 149 sites sampled exceeded the promulgated MCL of 3 µg/L atrazine (Thurman et al., 1991). Other studies also document atrazine concentrations exceeding the 3 µg/L level in Midwestern surface water supplies (Goolsby et al., 1991a; Carney et al., 1991; and Cowles, 1991). Since many Midwest communities rely on surface water for public water supplies, there is increased concern about treating atrazine contaminated waters to meet the new standard, which became enforceable in July 1992.

Previous research shows that conventional water treatment methods, including coagulation, lime softening, clarification, recarbonation, filtration, and chlorination are ineffective in removing atrazine from drinking water (Adams, 1991; Miltner et al., 1989). However, both granular activated carbon (GAC) and powdered activated carbon (PAC) have been used successfully to treat atrazine contaminated waters (Miltner, 1989). The Safe Drinking Water Act (SDWA) amendments state that the EPA must list the best available technology (BAT) capable of meeting the MCL regulations. The BAT for synthetic organic chemicals (SOCs), such as atrazine, is GAC (Lykins et al., 1992).

The Safe Drinking Water Act regulations apply primarily to public water supply (PWS) systems. A PWS system is defined as a supplier to at least 15 service connections, or at least 25 individuals, for at least 60 days during a year. For smaller water supply systems, and private well users wanting to meet the new MCL for atrazine, point-of-use (POU) or point-of-entry (POE) activated carbon filters may be an effective and economical treatment option. The EPA does not designate

POU or POE devices as best available technology (BAT). However, under certain conditions, POE devices are considered an acceptable means of compliance, since they provide water that meets MCLs at all points in the home. POU devices do not treat all the water in the house and are not considered an acceptable means of compliance. POU devices are acceptable as interim measures of treatment, prior to achieving full compliance (Lykins et al., 1992).

There are many POU activated carbon filters available commercially. Most of these filters are designed to improve taste and remove unpleasant odors from tap water. Few have been tested to determine how effectively, and for how long, they can remove other contaminants. Since filter designs vary widely, it is necessary to subject them to a contaminant under controlled conditions, in order to ascertain the degree of treatment possible and the operating limits.

Information available to consumers concerning different POU filters, with regard to atrazine removal, is minimal. Proper filter selection and application requires this information.

The objective of this study was to evaluate the ability of POU activated carbon filters to remove atrazine from drinking water. In addition to this, filter reductions of total organic carbon (TOC), total chlorine residual (TCR), and two atrazine metabolites, hydroxyatrazine and deethylatrazine, were also examined. Eight POU activated carbon filters of different designs, rated capacities, and carbon types were tested in the approach taken to meet the objective. The tests were conducted under simulated home use conditions over a four month period from January 2–May 6, 1992. Lawrence, Kansas tap water was spiked with an atrazine stock solution to yield a challenge water with an average atrazine concentration of 12.31 µg/L. Filter

influent and effluent samples were collected at regular intervals and analyzed to determine atrazine, hydroxyatrazine, deethylatrazine, TOC, and TCR. Individual filter performance was then evaluated by comparing effluent to influent concentrations of atrazine, TOC, and TCR to the volume of water treated and the manufacturer's rated filter capacity. Atrazine adsorptive capacity per gram of activated carbon for each filter was calculated. Statistical correlations between TOC, TCR, and atrazine removal were also examined.

CHAPTER 2

LITERATURE REVIEW

Reports of the selective herbicidal properties of certain *s*-triazines were first published in 1955. Since then, literally thousands of articles have been generated on atrazine. A thorough understanding of the chemical nature of atrazine, its application, and occurrence is fundamental to this project. Published research work on point-of-use (POU) activated carbon filters focuses on trihalomethane (THM) removal, volatile organic chemical (VOC) removal, and microbiological factors. These previous studies are relevant to this research in terms of test protocol, and as guides in determining the design and operation factors that significantly affect filter performance.

The purpose of this literature review is to:

1.   summarize the information concerning the properties, metabolites, use, occurrence in water supplies, and federal regulation of atrazine;

2.   describe the factors affecting activated carbon adsorption of atrazine and other synthetic organic compounds;

3.   review previous studies of POU activated carbon filters to determine the significant elements of filter design and operation that impact performance; and

4.   discuss the test procedures designed to objectively evaluate different activated carbon filters.

2.1 ATRAZINE BACKGROUND INFORMATION

2.1.1 CHEMICAL DESCRIPTION AND COMMERCIAL PRODUCTS

The chemical name for atrazine is 2-chloro-4-ethylamino-6-isopropylamino-s-triazine. It has a molecular weight of 215.7 g/mole. The product named Atrazine Technical is an odorless, white powder containing 97 percent active ingredient. Its physical properties are described in Table 1.

Table 1. Physical Properties of Atrazine (Ciba-Geigy, 1989)

Melting Point:	175 – 177 °C
Solubility in Water:	33 mg/L at 22 °C
Specific Gravity:	1.19 at 25 °C
Vapor Pressure:	6.6×10^{-7} mm Hg at 25 °C

Manufactured under several different trade names, various concentrations of atrazine are commercially available as a wettable powder, in granular, and in liquid form. Atrazine is also blended with other herbicides such as alachlor, bentazon, butylate, cyanazine, dicamba, or metolachlor and marketed as a premixed herbicide product. Some common atrazine product names and their active ingredients are presented in Table 2 and Table 3.

Table 2: Commercially Available Formulations of Atrazine

(Crop Protection Chemicals Reference, 1991)

PRODUCT NAME	ATRAZINE CONTENT (wt. %)	RELATED COMPOUNDS (wt. %)	INERTS (wt. %)
AAtrex® Nine-O	85.5	4.5	10.0
AAtrex® 80W	76.0	4.0	20.0
AAtrex® 4L	40.8	2.2	57.0
Atrazine 4L	40.8	2.2	57.0
Atratol® 90	85.5	4.5	10.0

Table 3. Common Atrazine Product Names and Active Ingredients

(Crop Protection Chemicals Reference, 1991)

PRODUCT NAME	ACTIVE INGREDIENTS	ATRAZINE CONTENT (wt. %)	INERTS (wt. %)
Bicep® 6L	Metolachlor/Atrazine	27.4	35.0
Laddock®	Bentazon/Atrazine	17.5	63.5
Sutazine®+	Butylate/Atrazine	13.9	29.0
Lariat®	Alachlor/Atrazine	15.5	56.5
Bullet	Alachlor/Atrazine	14.3	59.7
Extrazine®II DF	Cyanazine/Atrazine	21.4	10.0
Marksman®	Atrazine/Dicamba	22.2	61.0
Buctril®+Atrazine	Bromoxynil/Atrazine	21.6	62.6
Ramrod®+Atrazine	Propachlor/Atrazine	10.0	58.0

2.1.2 Atrazine Metabolites

The major abiotic degradation pathway for atrazine in soil is hydrolysis to hydroxyatrazine (Adams, 1991). The primary biotic degradation pathway by both fungi and bacteria is dealkylation (Adams, 1991). Deethylatrazine and deisopropylatrazine are the main biotic metabolites of atrazine (Pereira et al., 1990). Both biotic and abiotic processes are important in the degradation of atrazine. The transport path characteristics, from the point of herbicide application to the point of water supply, determine the predominant degradation process and resulting concentrations of metabolites.

Herbicides and their metabolites are transported mainly in the dissolved phase (Pereira et al., 1990). Important transport path characteristics include available microbial populations, soil retention time, temperature, pH, and various soil characteristics such as moisture content, organic matter content, and clay content (Adams, 1991). The most likely atrazine metabolites to be found in either ground or surface water supplies are deethylatrazine, deisopropylatrazine, 2-chloro-4,6-diamino-s-triazine, and 2-amino-4-chloro-s-triazine. Hydroxyatrazine is also present, though it tends to strongly adsorb to the soil (Adams, 1991). Witt (1992) found detectable levels of hydroxyatrazine and deethylatrazine year-round in a majority of raw water samples tested for seven water treatment plants. Refer to Figure 1 for structural descriptions and short-hand notation used for identifying selected s-triazine compounds.

When using short-hand notation, atrazine is written as "CIET", with C = "Chloro", I = "Isopropylamino", E = "Ethylamino", and T = "s-Triazine". Other symbols used are: O = "Hydroxy", and A = "Amino". Adams (1991) and Witt (1992) elaborate on the different nomenclatures

used for these compounds in the literature.

Figure 1.   Chemical Structure of Atrazine and Selected Metabolites
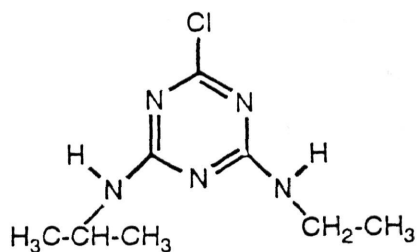
ATRAZINE
(CIET)
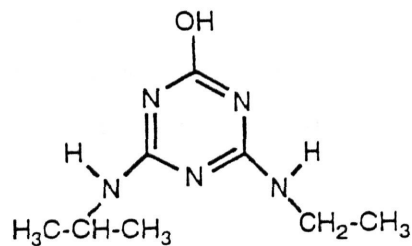
HYDROXYATRAZINE
(OIET)
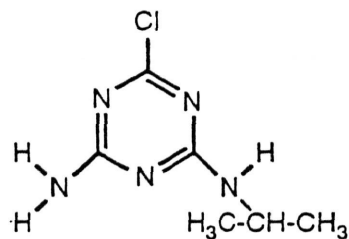
DEETHYLATRAZINE
(CIAT)
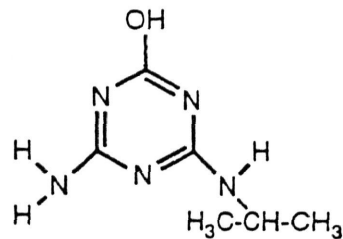
2-AMINO-4-HYDROXY-6-
ISOPROPYLAMINO-*s*-TRIAZINE
(OIAT)
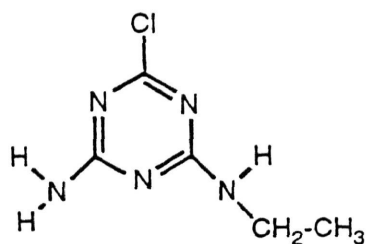
DEISOPROPYLATRAZINE
(CEAT)
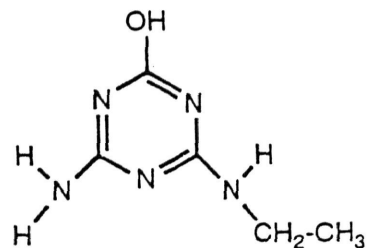
2-AMINO-4-ETHYLAMINO-6-
HYDROXY-*s*-TRIAZINE
(OEAT)

2.1.3 USE OF ATRAZINE

Over the past 30 years, atrazine has been the most heavily used herbicide in the United States (USEPA, 1989). Gianessi and Puffer (1991) reported that annual use during 1987-1989 averaged 64.2 million pounds (as atrazine). Two crops, corn and grain sorghum (milo), accounted for over 95 percent of the atrazine applied. Atrazine use was reported in 47 states; the exceptions were Alaska, Hawaii, and Nevada. Table 4 identifies the five states with the highest atrazine usage.

Table 4:   Top Five States in Atrazine Usage
(Gianessi and Puffer, 1991)

STATE	ANNUAL USE (lbs. Atrazine)
Illinois	8,503,397
Nebraska	7,061,584
Indiana	5,683,924
Iowa	5,583,992
Kansas	4,701,537

Atrazine is a selective herbicide that effectively controls broadleaf weeds and certain grass weeds without harming actively growing corn or milo. Atrazine is widely used because it provides economical and long-lasting control of many weeds, reducing the risk of crop losses due to weed interference (Regehr et al., 1992).

Atrazine provides long-lasting weed control because it persists in the soil for most of the growing season. Studies of atrazine soil

concentrations, following initial application, have determined that the time required to reduce the herbicide level by 50 percent ranges from one month to over five months (Carney et al., 1991). Since farmers cannot mechanically reduce weeds after corn and sorghum plants reach a certain height, this persistence is very desirable (Wulfkuhle, 1992).

Atrazine may be used as a preplant, preemergent, or postemergent herbicide. It is usually dissolved in water and applied using conventional ground sprayers equipped with nozzles to provide accurate and uniform application. Aerial application and application using liquid fertilizer for part or all of the water carrier is also practiced. Application rates per acre depend on the soil texture, the crop being treated, the season, and on the rate limits established by certain states (Crop Protection Chemicals Reference, 1991). According to the new 1993 product label, the maximum annual application rate is 2 lb per acre (Horstmeier, 1993).

After atrazine is applied to soil, it must be moved into the top few inches of soil and dissolved in the soil water so that it can be absorbed through the root system of weed seedlings. Rainfall is required for this process to occur. Heavy rainfall and subsequent loss of atrazine in surface runoff poses the greatest risk immediately after herbicide application (Regehr et al., 1992).

Atrazine and herbicide mixtures containing atrazine have been classified by the EPA as "restricted use" herbicides since January, 1990. This means that products containing atrazine may only be sold retail to certified applicators or those under their direct supervision and only for uses covered by the certified applicator's certification (Crop Protection Chemicals Reference, 1991). Atrazine users are

prohibited from mixing, loading, or applying the herbicide within 50 feet of wells or sink holes. Application through irrigation systems is also banned. These restrictions were made because of groundwater contamination concerns (Carney et al., 1991).

2.1.4   OCCURRENCE OF ATRAZINE IN WATER SUPPLIES

Atrazine is primarily applied to fields in April or May, when most of the corn is planted. During the late spring rains that follow, portions of the applied herbicide are transported by surface runoff into streams and rivers. This phenomenom is often referred to as the "spring flush" (Thurman et al., 1991; Goolsby et al., 1991b). In the Midwest, where millions of acres of corn and milo are grown and atrazine is widely used, the spring flush results in surface water contamination on a regional scale. Studies conducted in this agricultural region by the United States Geological Survey (USGS), found that 52 percent of the 149 sites sampled exceeded the maximum contaminant level (MCL) of 3 μg/L for atrazine. Detectable levels of atrazine occurred in 91 percent of the preplanting samples and 76 percent of the harvest samples (Thurman et al., 1991). Another USGS study of 8 sites on the Mississippi River and its major tributaries (146 water samples), done in April, May, and June 1991, detected atrazine in every sample. Median atrazine concentrations ranged from 0.29 μg/L to 3.2 μg/L (Goolsby et al., 1991a). Atrazine has been found in the surface waters of 31 states and in the groundwaters of 13 states (USEPA, 1989).

In Kansas, atrazine is the most frequently detected herbicide in surface waters. A 1986 study of five community water supplies in

eastern Kansas found atrazine in 80 percent of the samples tested; 58 percent (48 samples) of these atrazine detections exceeded the MCL (Carney et al., 1991). Between 1977 and 1990, 208 lakes were sampled by the Kansas Department of Health and Environment (KDHE). Detectable levels of atrazine were found in 41 percent of the lakes (Carney et al., 1991). In a study which sampled fifteen water treatment facilities in Kansas during June and July 1991, seven public water supply systems (PWSS) had atrazine levels that equalled or exceeded the MCL of 3 µg/L (Cowles, 1991).

Due to its wide use and environmental persistence, detectable atrazine concentrations occur year-round in Midwestern surface waters, with peak levels found in June and July following the late spring rains. Thurman et al. (1991) hypothesize that herbicide-contaminated surface waters may significantly contribute to alluvial groundwater contamination. Groundwater contamination is thought to occur during the springtime, when rivers run bank full and groundwater gradients may reverse, allowing contaminated water to flow into adjoining alluvial aquifers. Another proposed pathway is by aquifer recharge from flood waters and upland runoff. Once the stream levels recede, the groundwater gradients reverse back and allow contaminated water to reenter the stream system, resulting in persistently detectable levels of atrazine and atrazine metabolites throughout the year (Thurman et al., 1991; Squillace and Thurman, 1992).

2.1.5 FEDERAL REGULATIONS

The Safe Drinking Water Act of 1974 (SDWA) was passed by Congress because of concern about drinking water contaminants and inadequate state supervision of public water supplies (Cotruvo and Vogt, 1990).

The SDWA required the United States Environmental Protection Agency (EPA) to set enforceable standards, that applied to all public water systems, for health related drinking water contaminants (Cotruvo and Vogt, 1990). A "public water system" was defined as a system that had 15 or more service connections or regularly served at least 25 people for 60 or more days per year. The enforceable standards were called maximum contaminant levels (MCLs) (Pontius, 1990; Stacha and Pontius, 1984).

Major amendments to the SDWA were made in 1986. The 1986 amendments mandated the establishment of various new drinking water regulations according to specific timetables. Under these new amendments, maximum contaminant level goals (MCLGs) and MCLs were required for 83 contaminants. Atrazine made its regulatory debut in this group. The EPA proposed the required regulations for atrazine, twenty-nine other synthetic organic chemicals (SOCs), and eight inorganic chemicals (IOCs) in May 1989 (Pontius, 1990). The Phase II Rule (Synthetic Organic and Inorganic Chemicals Rule), as it was called, was published in its final form in January 1991 and became effective 18 months later in July 1992. Refer to Appendix A for the calculation procedure used to determine the MCL of 3 µg/L for atrazine.

When it is not feasible to monitor contaminant levels, treatment may be required. The EPA had to establish a feasible treatment technology for each regulated contaminant, taking cost into consideration (Adams et al., 1989). According to the 1986 SDWA amendments, granular activated carbon (GAC) is considered the best available technology (BAT) treatment technique for SOC control (Lykins et al., 1992). Other processes may be used, as long as the MCL is met.

2.2 FACTORS AFFECTING ACTIVATED CARBON ADSORPTION

2.2.1 TYPE OF ACTIVATED CARBON

The adsorption rate and capacity of a particular carbon is strongly influenced by its specific surface area, pore size distribution, surface chemistry, and particle size (Snoeyink, 1990; Weber, 1972). Because adsorption is a surface phenomena, the more finely divided and porous the carbon is, the greater the amount of adsorption per unit weight of adsorbent (Weber, 1972). Commercial activated carbons used for drinking water treatment in the United States are predominantly made from wood, peat, lignite, subbituminous coal, and bituminous coal (Snoeyink, 1990). Both the pore size distribution and chemical surface activity of activated carbons are influenced by the choice of base material and the method and temperature of activation (J.M. Montgomery, 1985). Activated carbon particle size is important because it determines the time required for an adsorbate to reach the available adsorption sites (Snoeyink, 1990).

The extremely large internal surface area, relative to the small external surface area, of activated carbon particles is attributed to a network of internal pores (Weber, 1972). While the specific surface area gives an indication of the carbon's capacity, it is the effective area available for adsorption that determines the maximum capacity for a particular compound (Snoeyink, 1990). The effective area is determined by the minimum pore size that adsorbate molecules can pass into. Thus, the pore size distribution controls the carbon's adsorptive capacity for different adsorbates (Lee et al., 1981; J.M. Montgomery, 1985).

The pore size distribution of a particular carbon also determines whether it is best suited for adsorbing impurities from a gas or a

liquid.   Activated carbons that exhibit a system of almost all micropores (pore radius between 5 and 50 angstroms) are best for gas purification (Fornwalt and Hutchins, 1966a). Good examples of these are coconut shell-based carbons which have a higher density and finer pore size distribution than other carbons (J.M. Montgomery, 1985). Typical carbons suitable for liquid purification contain a range of pore sizes varying from 5 to 10,000 angstroms. The large pores and transitional pores provide ready access for liquids into the system of micropores facilitating adsorption (Fornwalt and Hutchins, 1966a). Lee et al. (1981) reported that pore-size distribution was an important parameter in determining carbon capacity for humic substances.

Carbon surface chemistry affects adsorption rate and capacity because of specific interactions between surface functional groups and particular adsorbates.   These groups include carboxylic, carbonyl, phenolic, hydroxyl, and peroxide groups (J.M. Montgomery, 1985). Weber (1972) reported that the evidence for surface chemical interaction between carbonyl and carboxyl groups and organic adsorbates was convincing.

Powdered activated carbon (PAC) and granular activated carbon (GAC) are distinguished from each other by particle size. The PACs are pulverized so that 95 to 100 percent will pass a 100-mesh U.S. sieve and, depending on the grade, between 50 and 95 percent will pass a 325-mesh sieve.   GAC particles are larger than 150 mesh and come in a variety of mesh sizes.   The choice of GAC mesh size is usually determined by the viscosity and flow rate of the liquid to be treated (Fornwalt and Hutchins, 1966a; J.M. Montgomery, 1985). It is desirable to use the smallest particle size that operating conditions allow, so that the adsorption rate is maximized (Snoeyink, 1990; Weber, 1972).

2.2.2 EQUILIBRIUM ADSORPTIVE CAPACITY

The design of carbon adsorption systems requires equilibrium data. These data are obtained almost entirely from isotherm experiments. In isotherm experiments, carbon capacities are frequently represented by the Freundlich equation: $q_e = K(C_e)^{1/n}$, where q_e is the solid-phase equilibrium concentration expressed in micrograms (μg) adsorbed solute per gram (g) carbon; C_e is the liquid-phase equilibrium concentration expressed in μg solute per liter (L) solution; and K and 1/n are the Freundlich constants. The liquid-phase concentration is determined analytically. The solid-phase concentration is determined by mass balance on the isotherm reactor: $q_e = (V/m)(C_o - C_e)$, where V is the isotherm reactor volume expressed in liters; m is the mass of the carbon expressed in grams (g); and C_o is the analytically determined initial concentration (μg/L) (Speth and Miltner, 1990). A review of potential problems and proper procedures for conducting batch isotherm experiments to evaluate the adsorptive capacity of granular activated carbon (GAC) is given by Randtke and Snoeyink (1983).

Isotherm data are evaluated to assess the feasibility of using activated carbon in a particular application and to compare the performance of one type of carbon to another (Randtke and Snoeyink, 1983). If the isotherm capacity and the treatment objective are known, the minimun required carbon dosage can be determined (Crittenden et al., 1987). The effect of different waters on isotherm data for atrazine is illustrated in Table 5.

Table 5. Isotherm Data for Atrazine at 24 °C

   (Speth and Miltner, 1990)

SOLVENT	EQUILIBRIUM CONC. RANGE	FREUNDLICH CONSTANTS	
	(μg/L)	K	1/n
Distilled,			
Deionized Water	908 – 4.2	38,700	0.291
Groundwater	317 – 0.6	25,100	0.356

2.2.3 EFFECT OF COMPETITIVE ORGANIC CHEMICALS

Competitive adsorption is important in drinking water treatment because many adsorbable compounds coexist in natural waters (Snoeyink, 1990). The extent of competition depends upon the relative affinities of the competing molecules for the carbon, the initial concentrations of these molecules, and the type of activated carbon (Snoeyink, 1990). Adsorption of many compounds is a reversible process. Desorption can occur when molecules with high carbon affinity displace weakly adsorbed molecules. Desorption can also occur when influent concentrations decrease (Snoeyink, 1990).

Najm et al. (1991) reported that one of the main factors affecting the equilibrium capacity of activated carbon for synthetic organic chemicals (SOCs) was the presence of background organic matter (BOM) in natural waters. When isotherm data for a particular SOC were determined using distilled water, the isotherm was not a function of the initial SOC concentration. Isotherm data determined using natural or finished water were dependent on the initial SOC concentration. For a constant BOM concentration, a decrease in the initial SOC

concentration decreased the equilibrium capacity of the carbon for that SOC (Najm et al., 1991). Data showing this effect on atrazine adsorption from Ohio River water are given in Table 6. Since only 1.5 hours of contact time were allowed during the jar tests, these adsorptive capacities should not be considered true equilibrium values.

Table 6. Effect of Initial Atrazine Concentration on Adsorption
          (Miltner et al., 1989)

INITIAL CONC.	REMOVAL	PAC DOSE	PAC CAPACITY
($\mu g/L$)	(%)	(mg/L)	(mg ATRAZINE/g PAC)
85.4	64	16.7	3.27
125	64	16.7	4.79
85.4	82	33.3	2.10
125	82	33.3	3.08

Activated carbon, in powdered or granular form, strongly adsorbs atrazine in distilled water solution. Activated carbon also removes deethylatrazine and deisopropylatrazine from distilled water (Adams et al., 1990). However, naturally occurring organic matter (NOM) appears to actively compete with atrazine, effectively reducing the adsorptive capacity of the carbon (Adams et al., 1990). Since the adsorbability of NOM, also referred to as BOM, in surface and groundwater varies widely, variation in the extent of competition is to be expected (Snoeyink, 1990).

Speth (1990) reported that very hydrophobic compounds may complex with natural organic matter and the resultant species may exhibit

different treatment characteristics than the unbound contaminant. His data showed that a compound (i.e. glyphosate) could be strongly adsorbed by activated carbon as a single solute in distilled water, but weakly adsorbed in a natural water. Kuennen et al. (1989) speculated that compounds rapidly adsorbed by activated carbon in distilled water might be complexed with NOM in natural water, effectively slowing and reducing the extent of adsorption. Senesi and Chen (1989) present a detailed report of the interaction of synthetic organic chemicals with humic substances.

2.2.4 EFFECT OF INORGANIC CHEMICALS

Most of the cations and anions found in natural waters are not adsorbed by activated carbon. However, adsorption of mercury, arsenic, lead, and radon onto activated carbon has been reported (Lykins et al., 1992; Sigworth and Smith, 1972). Metals can react at oxygenated functional groups on carbon surfaces, displacing hydrogen ions or common cations. Carbon surfaces can also precipitate metal salts. Reduced metals in the carbon structure can react with metals in ionic solution, reducing and depositing them (Sigworth and Smith, 1972). Inorganic precipitates may interfere with adsorption if they deposit on the adsorbent (Snoeyink, 1990).

Activated carbon is intentionally used to remove oxidants such as free chlorine, chloramines, and chlorine dioxide from drinking water. After a certain period of use, the activated carbon filter effluent concentration of these compounds approaches the influent level. This is presumably due to the buildup of surface oxides that effectively eliminate possible reaction sites and reduce the adsorptive capacity of the carbon (Snoeyink, 1990; Yohe et al., 1981).

2.2.5 EFFECT OF pH

The pH of a solution from which adsorption occurs may influence the extent of adsorption. Generally, the adsorption of organic contaminants from water is increased with decreasing pH. This may result from neutralization of carbon surface negative charges with increasing hydrogen ion concentration. Hindrance to diffusion is thereby reduced and more active surface area is made available (Weber, 1972).

Soil experiments, investigating the binding of atrazine and hydroxyatrazine by Laurentian soil, determined that protonated carboxylic groups are essential to atrazine binding. As pH increases, carboxylate groups deprotonate and soil binding capacity for atrazine decreases (Wang et al., 1992). The adsorbent behavior of activated carbon surfaces for organic adsorbates is also related to the presence of significant amounts of carboxyl and carbonyl groups (Weber, 1972). If the adsorptive behavior of atrazine with activated carbon is similar to that with soil, adsorptive capacity would be expected to increase with decreasing pH.

2.2.6 EFFECT OF TEMPERATURE

Adsorptive capacity of activated carbon is temperature dependent. Adsorption is generally an exothermic process, hence adsorptive capacity usually increases as temperature decreases (Alben et al., 1990; Weber, 1972). The magnitude of the change in adsorptive capacity, as a function of temperature, varies for different compounds. Alben et al. (1990) conducted batch experiments to study GAC adsorption of chloroform, trichloroethylene (TCE), atrazine, and 2,4-D, between 5 and 42 °C. The relevant aqueous phase atrazine concentration range was

from 0.5 to 25 µg/L. In single solute batch tests, the variation in adsorptive capacity for atrazine was 20 percent. Carbon adsorptive capacity varied the least for atrazine, in the temperature range examined. In comparison, the adsorptive capacity for chloroform varied 44 percent over the same temperature range. The precision of isotherms determined for atrazine was reported as 36 percent and the authors cautioned that was not good enough to observe a statistically significant effect of temperature (Alben et al., 1990).

Biological activity on activated carbon may also be influenced by temperature. Both coliform and standard plate counts (SPCs) in GAC filter-adsorber effluent have been found to increase above influent levels when water temperatures are greater than 10 °C. This occurs even with 1-2 mg/L of residual chlorine in the influent water. With influent water temperatures less than 10 °C, no bacterial regrowth is noted (Snoeyink, 1990).

Biological activity on GAC may shift the contaminant removal pathway from adsorption to biodegradation, thus enhancing the apparent adsorptive capacity of the carbon (DeWaters and DiGiano, 1990; Snoeyink, 1990; Speitel et al., 1989).

Microbiological evaluations of POU activated carbon filters have shown that Pseudomonas bacteria can colonize in them for prolonged periods (Geldrich et al., 1985; Reasoner et al., 1987; and Sandberg, 1977). Behki and Khan (1986) reported that Pseudomonas bacteria were capable of utilizing atrazine as their carbon source, with deisopropylation as the primary degradation pathway. Cook and Hütter (1981) reported that deisopropylatrazine could be metabolized by the combined action of Rhodococcus and Pseudomonas, with all the nitrogen being converted to cell mass.

2.2.7 SOLUBILITY OF ADSORBATE

Organic contaminants vary in how readily they adsorb onto activated carbon. According to Lundelius' rule, the less soluble a substance is, the more readily it adsorbs. Solubility is, to a large extent, a controlling factor for adsorption equilibria (Weber, 1972).

Whether the sorptive process is due to solute partitioning or true adsorption depends primarily on the aqueous solubility of the organic compound. The extent of sorption by soil can be estimated by relating sorption coefficients of organic compounds between soil organic carbon and water (K_{oc}), to octanol/water partition coefficients (K_{ow}) or water solubilities (Chiou, 1989). The less soluble a compound is in water, the higher its partition coefficient. Pereira and Rostad (1990) reported that experimentally determined K_{oc} values for atrazine in Mississippi River suspended sediments varied considerably between different sample sites. Generally, the K_{oc} values determined for atrazine were less than 1000, indicating that the largest fraction of atrazine (99.5 percent) was found in the dissolved phase.

Miltner et al. (1989) reported that coagulation and clarification provided no significant removal of atrazine from spiked test water. Because of this, they indicated that atrazine was neither strongly sorbed to particulates, nor complexed with humic materials that were sorbed to particulates.

For solubility data of atrazine in selected solvents, refer to Table 7.

Table 7.   Solubility of Atrazine in Selected Solvents at 27 °C

          (Adams, 1991)

Solvent	Solubility (mg/L)
Water	33
n-Pentane	360
Methanol	18,000
Ethyl Acetate	28,000

2.2.8   MOLECULAR SIZE OF ADSORBATE

The extent of adsorption increases as a molecule becomes larger through the addition of hydrophobic groups such as $-CH_2-$, until molecular size inhibits entrance to the carbon pores. At this point, even though solubility continues to decrease with increasing molecular weight, adsorptive capacity also decreases because the molecules are excluded from some of the carbon pores (Weber, 1972; Snoeyink, 1990).

2.2.9   ADSORBATE POLARITY

The polarity of organic compounds is a function of charge separation within the molecule. Almost any asymmetric compound will be somewhat polar, however several types of functional groups tend to produce fairly high polarities in compounds: 1) hydroxyl, $-OH$; 2) carboxyl, $-COOH$; 3) nitro, $-NO_2$; 4) nitrile, $-CN$; 5) carbonyl, $-CO$; 6) sulfonic, $-SO_3H$; and 7) amines, $-NH_2$, $-NH$, $-N$ (Weber, 1972). The relative polarities of compounds containing these functional groups may affect adsorbability and the degree of competition for activated

carbon, a somewhat polar adsorbent.

When water is the solvent, activated carbon adsorption normally decreases as the adsorbate polarity increases (Weber, 1972). Atrazine is a neutral, polar organic compound (Wang et al., 1992). Atrazine metabolites may contain hydroxyl, and/or amine functional groups. The relative polarities of atrazine and these metabolites may affect their adsorbability on activated carbon.

2.2.10   TRANSPORT MECHANISMS

Physical adsorption of organic compounds on activated carbon occurs in a series of steps: 1. bulk solution transport; 2. film diffusion transport; 3. pore transport; and 4. adsorption. Each of these steps can affect the rate of adsorption, but it is the slowest step that controls the rate. The rate limiting step can also change over the useful life of the adsorbent (Snoeyink, 1990).

Pore transport, also called intraparticle transport, may occur by molecular diffusion through the solution in the carbon pores (pore diffusion) or by diffusion along the carbon pore surfaces (surface diffusion) (Snoeyink, 1990). Crittenden et al. (1987) reported that intraparticle diffusion usually controls the adsorption rate and thus determines the time required to reach equilibrium. Randtke and Snoeyink (1983) noted that when intraparticle diffusion controls, the time to reach equilibrium depends on the carbon particle diameter. They suggested that several years might be required to reach equilibrium for large GAC particles and slowly diffusing adsorbates. They also reported that using pulverized GAC greatly reduced the time to reach equilibrium in isotherm experiments.

2.2.11 EFFECT OF CONTACT TIME

Equilibrium data are of limited value when determining the actual amount of activated carbon necessary in water treatment applications. Batch equilibrium isotherms frequently overestimate the actual adsorptive capacity attainable under dynamic conditions. This is because equilibrium is not likely to be reached, in jar tests or in full-scale treatment, due to insufficient contact time. Miltner et al. (1989) found that the PAC adsorptive capacities for atrazine, determined by jar tests (1.5 hours contact time), were approximately two orders of magnitude lower than those observed in batch equilibrium isotherm tests. The difference was attributed to the relatively brief contact time used in the jar tests.

Snoeyink (1990) stated, "the most important GAC adsorber design parameter is the contact time". Contact time is usually described in terms of empty bed contact time (EBCT), which is equal to the bulk volume of carbon in the contactor, divided by the volumetric flow rate to the contactor (Snoeyink, 1990). For every adsorbable contaminant, there exists a critical depth of GAC, and a corresponding minimum EBCT, that must be exceeded before the adsorber will produce any water meeting the desired effluent criteria. As the EBCT increases above the minimum requirement, the adsorber bed life (expressed in bed volumes of product water to breakthrough) increases, until a maximum is reached (Snoeyink, 1990). Fornwalt and Hutchins (1966b) discuss how to scale up and arrange GAC purifying systems from laboratory data. Kuennen et al. (1989) reported that, for many adsorbable compounds, an EBCT of only a few seconds could meet treatment objectives, provided that only a small number of bed volumes were treated.

2.3 POINT-OF-USE (POU) ACTIVATED CARBON FILTERS

2.3.1 DEFINITION

The National Sanitation Foundation (NSF) Standard 53 defines a point-of-use (POU) unit as plumbed-in or faucet-mounted unit used to treat the water at a single tap or multiple taps, but not for an entire facility. A batch unit is also a point-of-use unit (NSF, 1990).

2.3.2 STANDARD EVALUATION METHODS FOR POU FILTERS

The NSF Standard 53 established reliable laboratory methods for evaluating the performance of drinking water treatment units designed to reduce specific contaminants from public or private water supplies. Manufacturers of drinking water treatment units use the NSF Standard 53 test procedures to substantiate claims for contaminant reduction and treatment of drinking water for specific health effects (NSF, 1990).

The NSF test procedure, for chemical reduction performance, is an accelerated use test done over a 4 or 5 day period. Duplicate units are tested simultaneously. Influent flow, of known contaminant concentration, is delivered in cycles of "on" and "off" time. An 8 hour stagnation period is required daily. Influent and effluent samples are collected at predetermined intervals, based on the filter's rated throughput capacity. Units are tested at the maximum flow rate attainable with a static system pressure of 60 psig. Special procedures are detailed for evaluating batch treatment units (NSF, 1990).

The NSF Standard 42 defines the test procedures used to evaluate drinking water treatment units for aesthetic effects such as taste and odor removal and particulate reduction. This standard determines rated filter capacity (filter useful life) based on chlorine reduction

performance data (Van Dyke and Kuennen, 1987). Since many POU filters are primarily designed to remove objectionable taste and odors, advertised rated capacity is frequently stated on this basis.

2.3.3   PREVIOUS STUDIES OF POINT-OF-USE (POU) FILTERS

The major focus of previous POU activated carbon filter studies has been in three areas: 1) trihalomethane (THM) reduction;   2) volatile organic chemical (VOC) reduction; and 3) microbiological characteristics.

The first significant evaluation of POU activated carbon filters was the Gulf South Research Institute (GSRI) project (Smith et al., 1979; Perry et al., 1980; Perry et al., 1981). This project consisted of three phases, progressing from laboratory protocol development to actual field studies.   These studies addressed organic chemical reduction efficiencies, as well as microbiological and endotoxin concentrations in filter effluents (Bell et al., 1984). Trihalomethane (THM) and nonpurgeable total organic carbon (NPTOC) reductions were determined for thirty (30) commercially available activated carbon filters.   Measurements of heterotrophic bacterial populations and endotoxin levels were also made during all phases of the project.

The experimental protocols developed in the GSRI project incorporated input from the EPA, filter manufacturers, and industrial users.   Each unit was installed on the test manifold and plumbed according to the manufacturer's recommendations.   Suggested startup procedures were completed prior to initiating each test run.   Influent water pressure was held constant at 40 psi.   The normal maximum flow rate was applied to each model during each test run.   Individual filter unit capacity and flow rate determined the schedule for sampling and

test run duration. This established the total number of gallons to be processed by each unit per day. A minimum of five samples was taken during the life of each filter tested. These sampling events corresponded to approximately 0, 25, 50, 75, and 100 percent of the rated filter life. The filters were run intermittently for 16 hours, then held stagnant for 8 hours, on a daily cycle designed to simulate home use. The running time was limited to approximately 6 minutes per hour, for a total of 96 minutes of "on" time per day. The units were run until the manufacturer's rated gallonage was processed or until the unit failed due to premature clogging (Perry et al., 1981).

The GSRI experiments determined that the extent of THM removal appeared to be a function of the quantity of carbon relative to the amount of water processed, the type of carbon, the contact time, and other filter design features (Perry et al., 1981). Most of the filters tested were less effective in removing NPTOC than THMs. As a group, larger filters had higher percentage removals of both NPTOC and THMs (Perry et al., 1981). The relative unit performance ranking determined in laboratory tests was maintained throughout the field studies, regardless of the source water (Perry et al., 1981).

Sandberg (1977) conducted a study at the University of Kansas to determine the chlorine reduction efficiency of three POU activated carbon filters in the laboratory and two filters in actual home use. Additionally, standard plate counts (SPCs) and pH measurements were made on all influent and effluent samples. Nonroutine measurements were made of turbidity, conductivity, and temperature.

In Sandberg's study, the filters tested in the laboratory were challenged with a continuous flow of municipal tap water at approximately 2 gallons per minute, 24 hours per day, until testing was

terminated. Total water processed ranged from 81,942 to 137,452 gallons, depending on the filter. The two field-tested filters showed varied usage and substantially less total water processed (380 and 831 gallons). The laboratory-tested filters averaged 39 to 42 percent total chlorine reduction during the 6 to 8 week test period. The one field-tested unit examined averaged 56 percent total chlorine reduction over an 8 week period. In most of the reported measurements, filtration by activated carbon did not alter the pH of the water processed.

Sandberg (1977) credited bacteriological activity in the activated carbon for the increased SPC level noted in the filter effluents. The genera Pseudomonas and Staphylococcus were tentatively identified in both the influent and effluent samples of all the filters tested.

In a subsequent study, two POU activated carbon filters were evaluated for chloroform reduction at the University of Kansas (Tucker, 1978). In this study, municipal tap water was continuously fed for 24 hours per day. The first filter was challenged for 30 days (71,000 gallons); the second filter was challenged for 14 days (28,000 gallons). The influent chloroform concentration depended on the city water supply, and ranged from 37 to 83.5 μg/L. This investigation concluded that initial chloroform reduction was satisfactory (70-90 percent reduction) for 40 μg/L influent chloroform. Removal performance declined with use, and after 7000 gallons of water throughput the filters removed only 30-40 percent of the influent chloroform.

Taylor et al. (1979) conducted a long-term evaluation of four different POU activated carbon filters. This study simulated home use

conditions by using seven "on" cycles ranging from 30 seconds to 3 minutes during the day, followed by 14 hours of stagnation every evening. Cincinnati, Ohio municipal drinking water was used as the challenge influent water. Standard plate counts (SPCs), free residual chlorine, THMs, and total organic carbon (TOC) were determined weekly on filter influent and effluent samples. In this study, the amount of carbon in the filters correlated very well with the effectiveness of chloroform removal. The more carbon there was, the greater the percentage removal. Because the influent TOC levels were always less than 2 mg/L and filter effluent levels were within 0.1 to 0.3 mg/L of the influent levels, no conclusions were made concerning TOC removal. The factors identified as having a definite effect on the chorine and organic removal capabilities of POU activated carbon filters included temperature, surface area of carbon, volume and velocity of flow, and time of sampling.

Regunathan et al. (1983) examined the performance of two different POU activated carbon filter devices. One was the combination of a GAC bed and precoat filter; the other was the combination of a reverse osmosis (RO) unit, prefilter, and two granular carbon units. Cycles of 5 minute filter run time followed by 30 minutes of non-use, for 8 hours per day, were used to simulate household demands. The filter influent was municipal water spiked with chloroform to an average concentration of 320 μg/L, and with carbon tetrachloride to an average concentration of 27 μg/L. Samples of filter influent and effluent were collected weekly for analysis of chloroform and carbon tetrachloride. Results for the granular carbon-precoat device showed chloroform and carbon tetrachloride reductions in excess of 80-90 percent for at least 1000 gallons of treated water.

Regunathan's test procedure for the RO-carbon device was very different from that used for the GAC bed-precoat filter. The RO-carbon unit was operated continuously, producing only 4-5 gallons per day. Deep well water, softened by ion exchange and spiked with various THMs and humic acid, was used instead of municipal water. The results indicated that no THMs were removed by the RO membrane alone. At the very low flow rates of membrane permeate, the carbon column portion of the device reduced influent levels of THM and chloroform (800-1000 μg/L and 300-600 μg/L, respectively) by 95-97 percent for at least 1300 gallons of treated water.

An RO-carbon device was also used by Regunathan et al. (1983) in a full-scale test for the removal of the pesticides endrin, methoxychlor, and lindane. Influent pesticide concentrations were approximately 2 μg/L endrine, 1000 μg/L methoxychlor, and 40 μg/L lindane. All other test parameters, sampling methods, and analytical procedures remained the same as in the THM testing. The RO membrane alone removed more than 90 percent of the endrin and methoxychlor, and 40 percent of the lindane. None of the pesticides was detected in the effluent of the GAC portion of the POU device after treatment of 1000 gallons of challenge water.

Geldreich et al. (1985) investigated four different activated carbon filters over a three year period. This study focused on the bacterial colonization of activated carbon POU filters. For the duration of the project, daily challenge water flow varied from 4 to 16 gallons per day, depending on the filter unit. Home use was simulated with six "on" cycles that ranged from 28 seconds to 3.7 minutes, followed by a 10-hour stagnant period each night. A flow meter, located on the downstream side of each filter, monitored the water

flow. Flow rates ranged from 0.26 to 1.26 gallons per minute. A
probe, located in the combined effluent flow, measured the water
temperature. Water samples were collected daily for at least four
weeks after each bacterial challenge inoculation.

Geldreich et al. (1985) found that a free-chlorine residual, in
the water supply to the treatment device, helped control the magnitude
of filter effluent bacterial concentration. For this reason, all of
the influent water used in these tests was dechlorinated. Test data
indicated wide variations in bacterial densities between units of
different design, units of the same design, and between water samples
collected at different times of the day. Filter cartridge design,
length of cartridge service, and water temperature were found to
influence the bacterial levels of each filter tested. Of the bacterial
challenges made, E. cloacae, E. coli, and S. typhimurium failed to
colonize in the filters. Citrobacter freundii, E. aerogenes,
Pseudomonas aeruginosa, and S. marcescens did colonize the units and
were detected in the filter effluent for extended periods of time.
Pseudomonas aeruginosa, the most tenacious challenge organism,
persisted for more than 150 days.

Van Dyke and Kuennen (1987) presented extensive documentation on
POU activated carbon block filters. These filters were tested and
found effective for the removal of 116 compounds, including 100 of the
EPA priority pollutants. The test protocol used to prepare this
documentation was similar to the NSF and GSRI protocol. All tests were
done on duplicate devices. Very consistent influent contaminant
concentrations were obtained by using a high performance liquid
chromatography (HPLC) injection pump, followed by a static mixer. The
filter flow rate was controlled, the temperature monitored, and

influent and effluent samples were collected for sample points spaced throughout the rated life of the filter (750 gallons). Testing was carried out to 200 percent of the rated filter life (1500 gallons). Influent challenge water was applied continuously for 8 hours per day, followed by an overnight stagnation period. Influent contaminant concentrations generally ranged from 100 to 200 $\mu g/L$. Influent chloroform was higher (averaged 414 $\mu g/L$), to approximate the NSF standard requirement (450 $\mu g/L \pm 20$ percent).

Reasoner et al. (1987) tested seven GAC filter units. The purpose of the project was to determine filter microbiological characteristics in terms of effluent quality versus influent quality. The filter units were installed in a third-faucet configuration. Influent water was dechlorinated by passage through a separate GAC filter cartridge. Electrically timed and activated solenoid valves controlled the water flow to the filters. Filter influent was delivered in seven flow periods that ranged from 30 seconds to 3.5 minutes, followed by a 13 hour nonflow period. Total flow "on" time per filter was limited to about 12.9 minutes per 24 hour period. Maximum flow rate per filter was limited to 1.5 gallons per minute. Water samples for heterotrophic plate count (HPC) and challenge organism analysis were collected morning and afternoon, twice a week.

Reasoner et al. (1987) found that bacterial colonization occurred within a matter of days after installation. Filter effluent bacterial levels varied between filter units of the same design, as well as units of different design. The development of bacterial populations in the activated carbon was affected by the length of filter cartridge service time, the water temperature, the influent flow rate, and the quality of the influent water.

Kuennen et al. (1989) used pore and surface diffusion mass transfer models to predict the breakthrough profiles of a 14-component mixture eluting from a POU activated carbon block filter. The fourteen components chosen served as surrogates for related classes or groups of chemical compounds. They were selected on the basis of molecular weight, solubility, density, chemical composition, analytical methods available, and weak adsorption affinity for GAC within their respective class or group. Polanyi adsorption potential theory was used to correct for the effects of temperature on the adsorptive capacity of GAC for use in mass transfer models. Actual breakthrough profile data for the 14-component mixture were obtained and compared to the model predictions. Adsorption isotherms were also determined for all fourteen compounds. In these tests, methanol was used to aid in the dispersion of the compounds into the water. Methanol, used in this manner, did not interfere with the adsorptive capacity of the GAC.

Kuennen et al. (1989) reported that both the particle size distribution and the effective particle size of the GAC were extremely important for providing optimum performance in an activated carbon POU filter with an EBCT of only 4 or 5 seconds. The smaller the particle size, the faster the rate of adsorption. The smallest particle size was limited by the back pressure required to maintain the flow through the filter. Water temperature was also found to be a significant factor in the adsorptive capacity of the GAC tested. Adsorptive capacity increased as water temperature decreased.

Consumer Reports (January, 1990) tested nineteen different POU activated carbon filters for chloroform removal performance. Three design-type categories where examined in this study: 1. high-volume filters; 2. faucet-mount filters; and 3. pour-through filters. The

filters were tested to determine the percentage chloroform removed after handling a specified volume of spiked (1 mg/L chloroform) test water: 600 gallons for the high-volume filters, 200 gallons for the faucet-mount filters, and 20 gallons for the pour-through models. The top performing units in this study were all high-volume filters. These filters removed all the chloroform that could be measured (at least 96 percent). The faucet-mount and pour-through filters removed less than 60 percent of the influent chloroform.

Faust et al. (1990) evaluated ten POU activated carbon filters for the removal of seven volatile organic chemicals (VOCs) from drinking water. This investigation focused on the variables affecting the performance of POU activated carbon filters. The filters were challenged with separate solutions of the seven VOCs. Initial concentrations of the compounds were approximately 250 μg/L. Even though the solution mix tank had a floating lid, volatilization of test compounds typically occurred. This decrease in the influent concentration was variable and amounted to as much as 40 percent of the initial concentration. For this reason, removal efficiencies were reported as a ratio of effluent to influent concentration. The water used to make up the test solutions was pretreated by passing it through two large capacity GAC filters to remove chlorine and other contaminants. Two POU filters, installed in parallel, were fed simultaneously during each trial. In-line water meters and flow controllers monitored the volume of water treated and controlled the flow rate to each filter. Timers controlled a pattern of 30 minutes of flow followed by 30 minutes without flow, for 20-22 hours per day.

The results of this study indicated that significant differences exist in the performance of activated carbon POU devices. The amount

of carbon present in the device was found to be an important indicator of performance. No correlation was observed between the manufacturer's rated capacity and the actual filter performance.

2.4   SUMMARY OF LITERATURE REVIEW

For many years, atrazine has been used as a selective herbicide to control weeds in corn and grain sorghum (milo) fields. Millions of acres of these two crops are grown in the midwestern United States. According to Gianessi and Puffer (1991), 66 percent of the corn and 52 percent of the sorghum crops are treated with atrazine. The result of this widespread herbicide use has been surface water contamination on a regional scale.

Atrazine concentration in surface water supplies increases in late spring and early summer. This increase corresponds with heavy rainfall events following herbicide application during the spring planting season.   During this time, surges in surface water atrazine concentration may frequently exceed the EPA's maximum contaminant level (MCL) of 3 µg/L.

Water supplies from shallow wells and surface water treatment plants serving small rural communities are at greatest risk for atrazine contamination. In many cases, these water systems do not have the financial resources to immediately modify treatment facilities or to regularly monitor finished water for atrazine. To comply with the federally mandated drinking water standards, these systems need economical treatment alternatives that can be accomplished in a minimum amount of time. Properly designed and maintained point-of-use (POU) activated carbon filters may be one of these alternatives.

POU filters are available in many different sizes and configurations. The proper selection of a POU filter requires an understanding of the design factors that influence filter performance. This literature review indicates that performance is primarily influenced by contact time within the filter, activated carbon particle size, and influent contaminant concentration. The presence of background organic matter may also significantly impact filter performance.

Adsorption isotherm and breakthrough curve studies can provide data on the theoretical capacity and breakthrough behavior of an adsorbate. However, before these results are used to design full-scale adsorption systems, the applicability of the data must be field-tested to evaluate the effect of competing organic compounds and actual adsorbate concentrations. Several studies have shown that activated carbon can effectively remove atrazine and its metabolites from drinking water. However, the design and performance limitations of POU activated carbon filters in this application, have not been well documented. To obtain this information, it is necessary to test different filter designs, under simulated home use conditions, for the capacity claimed by the manufacturer. Because the claimed capacity may be based on the removal of a different contaminant, a filter's capacity for atrazine should not be assumed. Therefore, there exists a need to evaluate the performance of a variety of POU activated carbon filters, to document the results, and to make this information available to the general public. With this information, consumers may select the most efficient and economical filter for the treatment required.

CHAPTER 3

METHODS AND MATERIALS

3.1   POINT-OF-USE ACTIVATED CARBON FILTERS

3.1.1   FILTER DESCRIPTIONS

Eight commercially available point-of-use (POU) activated carbon filters were chosen for this study. These units represented a range of sizes, configurations, rated capacities, recommended flow rates, and carbon types. Filters #1, #4, #5, and #7 were designed for upflow through a GAC bed. Filter #2 was designed for downflow through a GAC bed. Filter #8 was designed for radial flow, in cartridge 1, through a PAC/fiber block. This was then followed by downflow, in cartridge 2, through a GAC bed, into radial flow through an integral PAC/fiber block end-section. Filters #3 and #6 were designed for radial flow through a PAC carbon block.

The PureWater "Pup" (Filter #7) was a demonstration model. In the PureWater filter, the GAC portion of the filter was preceeded by a proprietary copper/zinc granular material identified as KDF-55 (ORC/KDF Technologies; Constantine, MI). KDF-55 is used to remove chlorine and metal ions upstream of the GAC. KDF-55 is reported to have no measurable effect on organic compounds, and little, if any, on inorganic anions.

A ninth filter, the activated carbon prefilter for a Culligan® H-83 Aqua-Cleer® reverse osmosis drinking water system, was briefly tested. It was determined that even a 0.25 gallons per minute (gpm) flowrate was excessive for this filter. Culligan Water Conditioning, Inc. of Olathe, Kansas provided a Culligan® Super Flavr-Gard. Model SG-2 filter assembly and Super Flavr-Gard. carbon cartridge as a replacement. The

SG-2 filter (Filter #5) was used during the remainder of the test period. Refer to Tables 8, 9, and 10 for additional filter and filter cartridge discriptions and attributes.

Table 8. Filter Descriptions

Unit	Description	Filter #	Configuration
Instapure IF-10	One GAC cartridge	#1	Stationary
Instapure F-2C	One GAC cartridge	#2	Faucet-bypass
Amway WTS III (E-9225)	One pressed carbon block cartridge	#3	Countertop Faucet-bypass
Ametek CCF-201	Two GAC cartridges	#4	Line-bypass
Culligan SG-2	One GAC cartridge	#5	Line-bypass
Multi-Pure 500B	One pressed carbon block cartridge	#6	Line-bypass
PureWater "Pup"	One GAC filter body (demonstration unit)	#7	Countertop Faucet-bypass
Ecowater Water Master	One PAC/fiber block cartridge and one GAC cartridge with PAC/fiber block end-section	#8	Line-bypass

In reference to Table 9, Filter #3 was tested at a 1 gpm flow rate because the owner's manual for the unit claimed that rate. The manufacturer's instruction and information sheet claimed a service flow rate of 0.75 gpm. All the other filters were run at or below the manufacturer's specified flow rate.

Table 9. Filter Attributes

Filter #	Rated Capacity (gallons)	Rated Flow Rate (gpm)	Test Flow Rate (gpm)	Empty Bed Contact Time (sec)
#1	1800	2.0	1.0	11.9
#2	200	0.75	0.5	3.3
#3	750	0.75	1.0	18.6
#4	1500	0.8	0.5	42.8
#5	1000	0.5	0.5	56.4
#6	500	1.0	0.5	41.1
#7	1500	1.0	0.5	8.7
#8	1500	1.0	0.5	37.9

Table 10. Filter Cartridge Attributes

Filter #	Total Carbon Weight (g)	Total Carbon Volume (cm^3)	Granular Carbon Size Range (U.S. Sieve)
#1	401	750	25 x 50
#2	57	104	25 x 50
#3	568*	1175	PAC
#4	660	1350	20 x 50
#5	815	1780	12 x 40
#6	574*	1297	PAC
#7	135	275	12 x 40
#8	183*	572	PAC/FIBER
	319	625	20 x 50

* Wt. of carbon block

3.1.2   METHOD USED TO MAKE CHALLENGE WATER

A stock solution of atrazine in methanol was prepared by dissolving 1.1708 grams (g) of Ciba-Geigy AAtrex Nine-O (Lot SG 5508JD) granules in HPLC-grade methanol (Fisher Scientific, Springfield NJ) to a final volume of 100 milliliters (mL).   The AAtrex Nine-O granules were obtained at no charge from the Overbrook Farmers Union Co-op (114 Maple St. Overbrook, Kansas).   The minimum guaranteed analysis for atrazine in AAtrex Nine-O is 85.5 percent.   Thus, the stock solution contained a minimum of 10.0 mg/mL of atrazine.   The atrazine stock solution was stored in a refrigerator at 4 °C when not in use.

The challenge water was made in 225 gallon (852 liter) batches in a 32-inch diameter fiberglass tank.   Each batch provided enough challenge water for four "on" cycles.   A total of forty batches were made during the test period.

The atrazine stock solution was allowed to come to room temperature (25 °C) prior to use.   To create an atrazine spike mix, a 1-mL volume of stock solution was combined with 1200-1400 mL of tap water.   This mixture was thoroughly stirred with a glass stirring rod, then used immediately to make a batch of challenge water.

Lawrence, Kansas tap water, prefiltered through a 20 micron sediment filter (Ametek Model PSCL with S1 sediment removal cartridge), was used to make the challenge water.   Prior to beginning each tank fill, the prefiltered tap water was wasted to a sink drain until cold water flowed out the hose end.   The hose end was equipped with a plastic diffuser to minimize splashing.   The tap water was briefly turned off, and the hose was inserted into the tank through the top. The water flow was resumed and the tank was filled approximately half-full.   At this point, the atrazine spike mix was added to the tank.

The tank was then filled to a mark, just below the overflow outlet, and the fill hose was removed.   The tank contents were mixed by recycle pumping for 30 minutes, as detailed in the next section.

3.1.3   CHALLENGE WATER DELIVERY SYSTEM

Filter influent water pressure was maintained at 50 psig using a Teel® 1/2", 5-300 psi, adjustable pressure relief valve on the discharge side of an 8-stage Teel® booster pump (Model 2P372B), and constantly recycling excess discharge flow back to the mix tank.   The recycle flow was carried back to the tank through a hose connected to the relief valve outlet.   By blocking off the main filter influent line, the arrangement allowed 100 percent of the pump discharge to be recycled back into the mix tank.   This provided the mixing action necessary for uniform batches of challenge water.   Figure 2 shows the mix tank, pump, and recycle line arrangement.

Figure 2. Mix Tank, Pump, and Recycle Line Arrangement
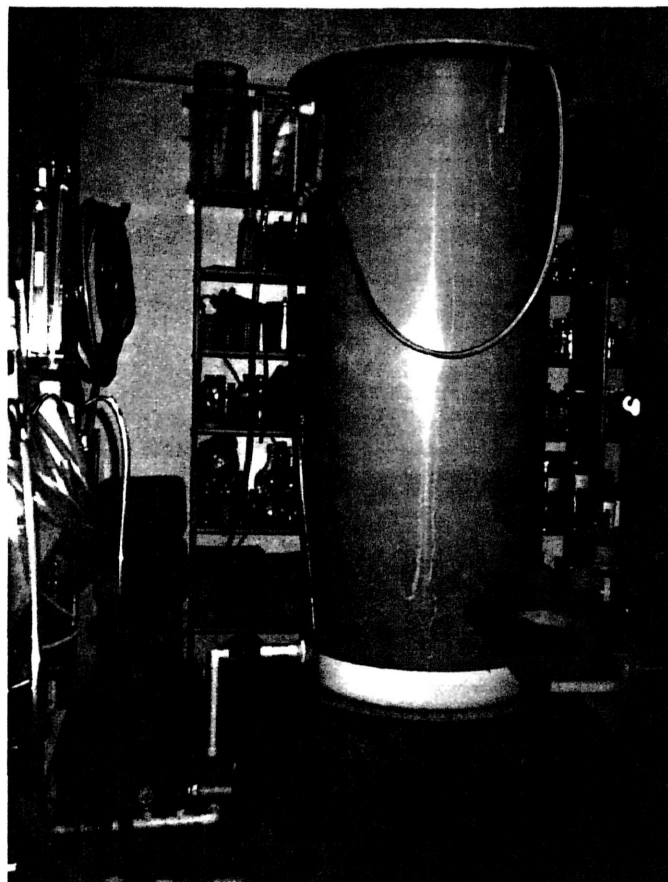
3.1.4 FILTER PERFORMANCE TESTING

Each filter unit was installed according to the manufacturer's instructions and conditioned with unspiked tap water before beginning the study.

Prior to daily operation, all the filters were bypassed and the main influent line was flushed with challenge water. Every filter received at least two "on" cycles per day of operation. "On" cycles were normally delivered at 60 minute intervals, then followed by overnight "off" periods. Each batch of challenge water provided four

complete "on" cycles of operation. A maximum of four filters operated
simultaneously. Filter influent water pressure was maintained at 50
psig. Four (4) Dwyer® Rate-Master® rotameters (0.2-2.2 gpm range) were
individually adjusted to provide constant influent flow rates during
filter "on" times. Bypass valves on the rotameter outlets prevented
flow during filter "off" times.

Samples of the challenge water were collected at the end of the
second and fourth cycles. Filter effluent samples were routinely
collected in the middle of the fourth cycle. Using clear plastic tubes
to direct the flow, the effluent from each filter was individually
collected in calibrated 5 gallon plastic jugs to verify volume
throughput. These tubes were removed during sampling. Refer to Figure
3 for filter layout and installation details. The filter operating
parameters are summarized in Table 11.

Figure 3.   Filter Layout and Installation Details
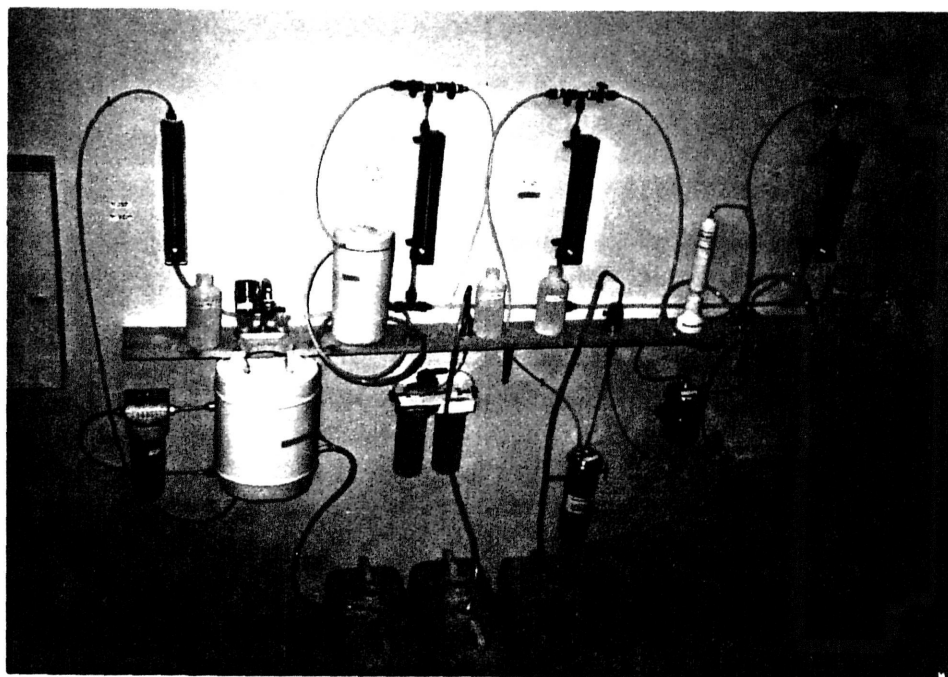
Table 11.   Filter Operation Summary

Filter #	Test Flow Rate (gpm)	Run Time per Cycle (min)	Volume Treated per Cycle (gallons)
1	1.0	10	10
2	0.5	5	2.5
3	1.0	5	5
4	0.5	20	10
5	0.5	10.5	5.25
6	0.5	10	5
7	0.5	10	5
8	0.5	20	10

3.1.5 DETERMINATION OF ACTIVATED CARBON WEIGHT AND VOLUME

After completion of filter performance testing, each used filter cartridge was removed and completely disassembled. In addition, unused spare cartridges for Filters #2 and #4 were also disassembled. The GAC portion of the cartridges was emptied into previously weighed, aluminum pie pans. The PAC blocks were cut away from their plastic endcaps and the inner plastic cores were removed. The PAC blocks were placed into previously weighed, aluminum pie pans. Each pan of activated carbon was weighed, then oven dried at 170 °C for 3-4 days. The pans of activated carbon were cooled in a vacuum dessicator, and weighed again. All weights were determined using a Sartorius Model 1364 MP scale. The PAC/fiber block material from Filter #8 started to burn while it was drying at 170 °C. The pans were immediately removed, the PAC/fiber blocks were wetted down with distilled water, then placed in a vacuum dessicator. After cooling, the PAC/fiber blocks were placed in a 95 °C

oven, dried for 4 days, cooled in a vacuum dessicator, and weighed again. The net dry weight was reported for each sample. The carbon weight for each unused cartridge agreed to within 3 percent of the used cartridge carbon weight. Used cartridge dry carbon weights were reported in Table 10 . The combined dry weight of cartridge #1 PAC/fiber block and cartridge #2 PAC/fiber block endpiece was reported for Filter #8 in Table 10.

To measure volume, dried GAC was poured through a funnel into a graduated cylinder. The cylinder was tapped to level and the volume noted. PAC block volumes were calculated from measurements of block inside and outside diameter, and length.

3.2   SAMPLE COLLECTION AND PREPARATION

3.2.1   FILTER SAMPLES

All challenge water and filter effluent samples were collected in 1-liter Nalgene bottles (Nalgene Co., Rochester, NY). Witt (1992) conducted a preservation study which showed that plasticizers did not leach into samples collected and stored in these bottles.

Prior to use, the bottles and plastic screw caps were cleaned according to the following procedure:

1.   washed with Micro-Shine" laboratory detergent and hot tap water;

2.   rinsed with cool tap water, emptied;

3.   rinsed with methanol, emptied;

4.   rinsed twice with reagent water, emptied; and

5.   capped and stored at room temperature until ready to use.

During sampling, a bottle was first rinsed with the sample to be collected, capped, shaken, emptied, and then used to collect a sample.

The sample bottles were filled completely, tightly capped, labeled, and stored in a refrigerator at 4 °C. The portions of these samples that were analyzed for pH, alkalinity, and chlorine residual were routinely processed immediately after sampling. The portions that were used for atrazine and TOC analysis were routinely processed within one week.

3.2.2 SAMPLES FOR ATRAZINE ANALYSIS

Qorpak" 4-oz. amber glass bottles with TFE-lined screw caps were used to store samples that later would be extracted for atrazine analysis. Prior to use, the bottles and caps were cleaned according to the following procedure:

1. rinsed with hot tap water, emptied;

2. rinsed with 10 mL of methanol, emptied;

3. rinsed twice with reagent water, emptied; and

4. capped and stored at room temperature until ready to use.

During sample preparation, the bottles were first rinsed with a portion of the sample to be placed in them, capped, shaken, emptied, then filled to within 1/2 inch of the top. The bottles were labeled, tightly capped, and stored in a refrigerator at 4 °C until further processing.

3.2.3 SAMPLES FOR TOTAL ORGANIC CARBON (TOC) ANALYSIS

Falcon Blue Max" 15-mL graduated, conical-bottom, polypropylene centrifuge tubes, with plastic screw caps, were used to store samples that were analyzed for TOC. Prior to use, the tubes and caps were

cleaned according to the following procedure:

1.   washed with Micro-Shine" laboratory detergent and hot tap water;

2.   rinsed with cool tap water, emptied;

3.   rinsed three times with reagent water, emptied;

4.   capped tightly and stored at room temperature until use.

During sample preparation, the tubes were first rinsed with a portion of the sample to be placed in them, capped, shaken, emptied, then filled to the 10-mL mark with sample. Two drops of concentrated phosphoric acid were added to acidify the sample below pH 2. The tube was capped tightly, then inverted several times to mix. Each tube was labeled with a sample identification code and placed in a tube rack. The racks of tubes were stored in the refrigerator at 4 °C until analyzed.

3.3   ATRAZINE ANALYSIS

3.3.1   PREPARATION OF SAMPLES

Prior to extracting samples, the sample set to be processed was allowed to come to room temperature. The pH of each sample was measured using a Fisher Accumet pH meter (Model 230) equipped with a Corning general-purpose combination electrode. The pH was then adjusted to 7.0 ± 0.1 using either dilute hydrochloric acid or dilute sodium hydroxide, as needed. Between samples, the electrode was thoroughly rinsed with reagent water, then lightly shaken to remove excess moisture. Because the reagent water, used to make standards and blanks, was so pure that it barely conducted an electrical current, actual pH meter readings were not meaningful for these samples.

Standards and blanks were assumed to be at pH 7.   Samples, standards, and blanks were all handled in the same manner.

3.3.2 STANDARDS AND REAGENTS

Atrazine standards were purchased from Supelco (Bellfonte, PA). Hydroxyatrazine, deethylatrazine, deisopropylatrazine, hydroxydeethylatrazine, and hydroxydeisopropylatrazine were provided at no charge by Ciba-Geigy Corp. (Greensboro, NC). The metribuzin, used as an internal standard, was an EPA reference standard. For procedures on preparation of standards, refer to Adams (1991). The metribuzin internal standard and all the atrazine/atrazine metabolite standard dilutions were prepared with reagent water produced by a Milli-Q® Reagent Water System (Millipore Corp.; Bedford, MA) fed with distilled water. Dilute standard concentrations of atrazine and metabolites in reagent water were handled in the same manner as filter samples for atrazine analysis. This included pH measurement, extraction, concentration, transfer into microvials, and refrigeration at 4 °C.

HPLC-grade methanol (Fisher Scientific; Springfield, NJ) was used throughout the sample preparation and analytical work in this study. Pesticide-grade ethyl acetate (Fisher Scientific; Springfield, NJ) was used to condition the Sep-Pak® solid phase extraction (SPE) cartridges. Reagent water was used to prepare standard dilutions and HPLC mobile-phase solvents, to condition SPE cartridges, and for rinsing (where indicated).

3.3.3 SOLID PHASE EXTRACTION (SPE) OF SAMPLES

All samples, standards, and blanks were manually prepared for high performance liquid chromatography (HPLC) analysis using a Supelco

(Division of Rohm and Haas; Bellefonte, PA) Visiprep™ solid phase extraction vacuum manifold (cat. no. 5-7030). Waters (Division of Millipore Corp.; Bedford, MA) Sep-Pak® Plus C_{18} Environmental solid phase extraction cartridges (part no. 23635) were used to concentrate the s-triazines present in 75-mL sample volumes. The samples were funneled into the SPE cartridges using Supelco 60-mL reservoirs (cat. no. 5-7022). When completely filled, these reservoirs contained exactly 75-mL. Pump dispenser pipettes were used to accurately deliver preset volumes of methanol, ethyl acetate, and reagent water when conditioning the SPE cartridges and eluting the sample extracts. A 15-20 inch Hg vacuum was applied when conditioning the cartridges and extracting the samples. Sample extracts were eluted into 16x100 mm Fisherbrand™ disposable glass culture tubes. Extracted samples were spiked with 50 µL of a metribuzin internal standard using a Sybron/Brinkman Eppendorf automatic pipette. Concentrated samples were transferred into 6 x 39 mm conical insert microvials (Kimble Division of Owens-Illinois, part no. 60840) placed on metal springs within glass holding vials, then capped with PTFE septa (Waters Division of Millipore, part no. 73005) and open top, plastic screw caps. The extraction procedure was as follows:

1. Attach a maximum of six SPE cartridges to the vacuum manifold.

2. Attach reservoirs to the SPE cartridges and close the valves connecting the cartridges to the vacuum manifold.

3. Apply a vacuum (15-20 inch Hg) to the manifold.

4. Condition the SPE cartridges by adding 2 mL methanol to each reservoir, open the valve under each cartridge and allow the solvent to flow through, then close the valve

quickly to retain a set volume of solvent (the tip of the reservoir) above the cartridge; repeat the same procedure with 6 mL of ethyl acetate, then 2 mL additional methanol, then 4 mL reagent water.

5. Add 75 mL of sample to each reservoir, open the valves under the SPE cartridges, and allow the samples to completely pass through the cartridges.

6. Purge for 5 minutes by allowing air to pass through the cartridges while maintaining a vacuum, then leave the valves open and turn off the vacuum.

7. Vent the manifold, then carefully remove the top portion, with attached cartridges and reservoirs intact, and place it on a clean paper towel.

8. Label the glass culture tubes with indelible marker to identify each sample, place these tubes in a collection rack, then put tubes and rack into the vacuum manifold. Replace the top portion of the manifold, taking care to align the glass tubes under the appropriate cartridges.

9. With the vacuum off and the valves under the cartridges open, add 3 mL of methanol to each reservoir. Apply a momentary vacuum to start the flow of eluent into the glass tubes, then turn off the vacuum and allow the remaining methanol to elute under gravity.

10. Finish the extraction by applying a momentary vacuum to recover any methanol held up in the SPE cartridges.

11. Remove the top portion of the vacuum manifold and take out the rack of glass tubes containing the extracted samples.

12.   Spike each extracted sample with 50 µL of 0.015 µg/mL metribuzin (in reagent water) internal standard, then mix using a vortex mixer.

13.   Place sample tubes in a 58 °C water bath and insert air manifold plastic tube ends into the glass sample tubes. Open the main valve on the compressed air cylinder and adjust the regulator to provide a light, steady air stream into sample tubes.

14.   Concentrate the spiked samples to a final volume of approximately 200 µL, turn off the air, then remove the air manifold.

15.   Remove the glass sample tubes from the water bath and place into a styrofoam tube holder.

16.   Transfer the concentrated sample eluents into labeled microvials. Cap each microvial with a new PTFE septum and open-top screw cap, then place in a styrofoam tube holder.

17.   Refrigerate the prepared microvials at 4 °C, until ready to analyze by high performance liquid chromatography (HPLC).

Refer to Figure 4 for details concerning the SPE equipment arrangement.

Figure 4.   Solid Phase Extraction Equipment Arrangement
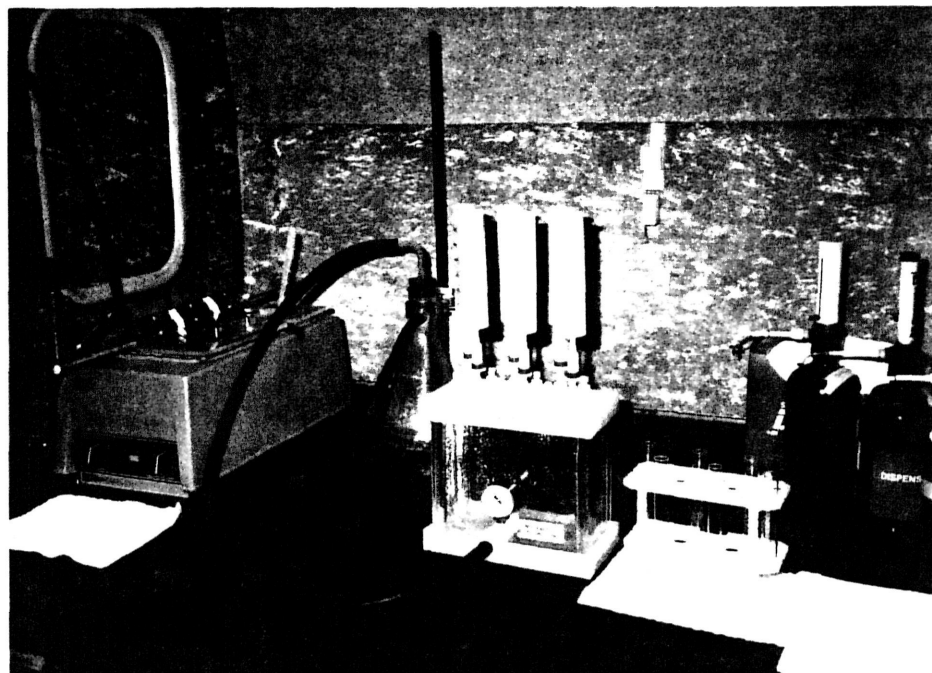
3.3.4   HIGH PERFORMANCE LIQUID CHROMOTOGRAPHY (HPLC) ANALYSIS OF
ATRAZINE, HYDROXYATRAZINE, AND DEETHYLATRAZINE

A Waters (Division of Millipore Corp.; Bedford, MA) HPLC system consisting of the following equipment was used to analyze samples for the s-triazines of interest:

1.   Type 600E System Controller/Powerline® Multi-solvent Delivery System;

2.   Type 490E Programmable Multi-wavelength Detector;

3.   Type 700 Satellite WISP® (Waters Intelligent Sample Processor);

4.   NEC Powermate® SX Plus Computer Workstation with Waters 815 Baseline® Software;

5.   NEC Pinwriter® P5200 Printer;

6.   Nova-Pak® C₈ Guard-Pak™ Pre-column Insert; and

7.   Nova-Pak® C₈, 3.9 x 150 mm Column.

Prior to sample injection, the Nova-Pak® C$_8$ column was equilibrated with a binary mobile phase (methanol/water, 10:90 v/v) solution, buffered with 50 millimolar (mM) ammonium acetate and adjusted to pH 7.2. After the WISP® injected a 50 μL sample volume, the 600E System Controller ramped the binary mobile phase from 10:90 (v/v) methanol/water (solution A) to 70:30 (v/v) methanol/water (solution B), then back to 10:90 (v/v) methanol/water (solution A). The mobile phase flow rate was 1 mL/min. The run time for each sample was 30 minutes.

During a typical sample run, the system operating pressure ranged from 1850 to 2300 psi. The Guard-Pak™ insert was replaced after every 20 to 30 sample injections. This was done to maintain sharp peaks, appropriate retention times, and reasonable system operating pressures. Ultraviolet (UV) detection at 230 nanometers (nm) was used to quantify the s-triazine compounds against the metribuzin internal standard.

After a set of samples was analyzed, the Nova-Pak® C$_8$ column was cleaned at 1.0 mL/min with an unbuffered 10:90 (v/v) methanol/water rinse (solution D). A flow rate of 0.1 mL/min of solution D was maintained on the column after the shutdown procedure was completed. Prior to running the next set of samples, the column was routinely cleaned for 15 minutes at 1 mL/min with an unbuffered 90:10 (v/v) methanol/water rinse (solution C). Prior to use, solutions A, B, C,

and D were degassed daily by vacuum filtration.

The chromatograph for a 6-component standard mixture of hydroxydeisopropylatrazine (OEAT), hydroxydeethylatrazine (OIAT), deisopropylatrazine (CEAT), deethylatrazine (CIAT), hydroxyatrazine (OIET), and atrazine (CIET), each at 15 µg/L concentration, is presented in Figure 5. The baseline curvature is due to ramping of the methanol/water binary mobile phase solvent during the sample run. The HPLC equipment layout is shown in Figure 6.

Figure 5.   HPLC Chromatograph of a Six Component Standard Mixture
           (The components shown, from left to right, are CEAT, OIAT,
           CEAT, CIAT, OIET, Metribuzin, and CIET.
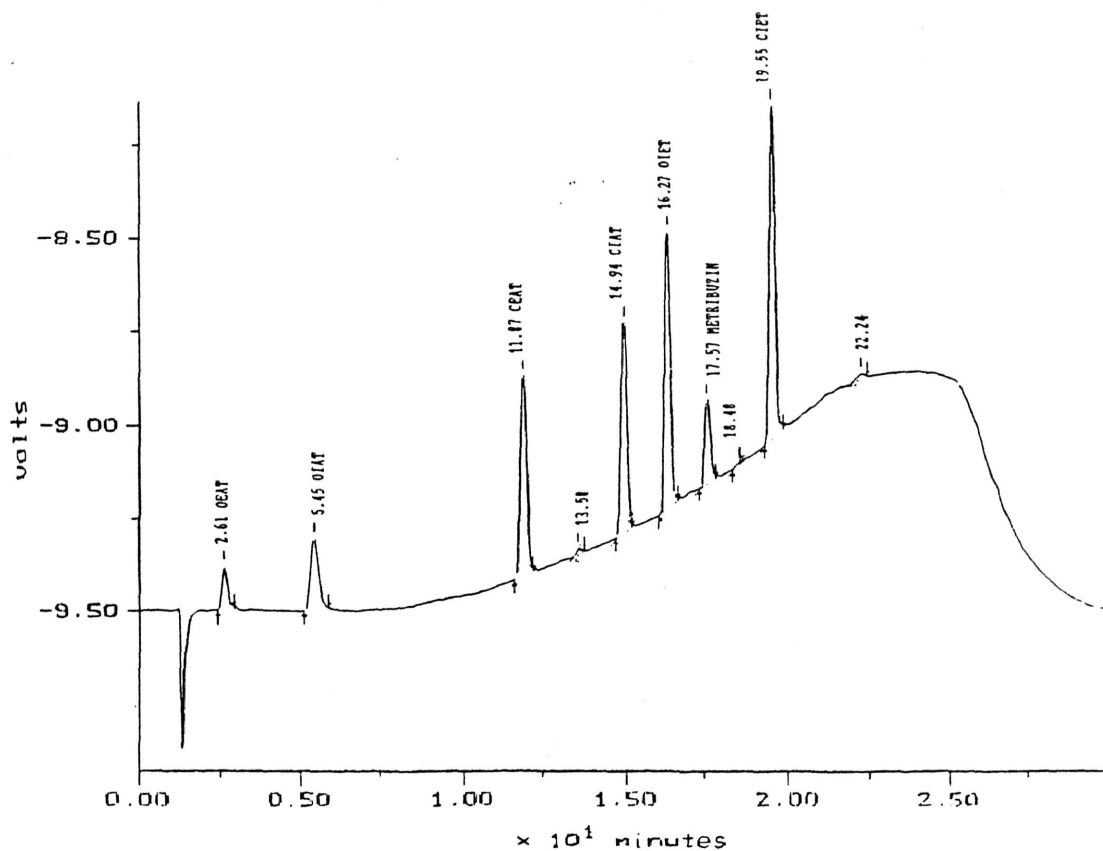
Figure 6.   HPLC Equipment Layout
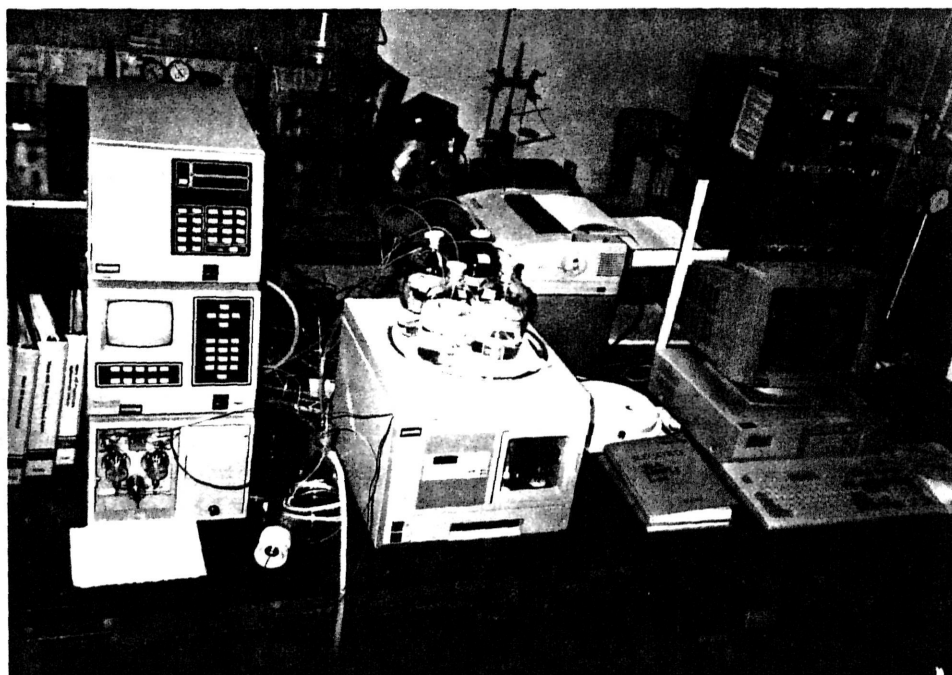
3.4   TOTAL ORGANIC CARBON (TOC) ANALYSIS

3.4.1   PREPARATION OF SAMPLES AND STANDARDS

Prior to analysis, acidified samples and several tubes of acidified 10 mg/L carbon standard solution were brought to room temperature. Two by two, the samples were sparged for 5 minutes with 100 mL/min streams of pure nitrogen to remove inorganic carbon. The sparging was accomplished by inserting stainless steel sparging needles into the sample tubes. Reagent water was used to rinse the needles between samples.

3.4.2   SAMPLE ANALYSIS

A Dohrmann Total Organic Carbon Analyzer (Model DC-80) was used to determine TOC concentrations in prepared samples.   The procedure followed was similar to Standard Method 5310 C. (APHA, 1989).   The acidified persulfate reagent was made by adding 60 grams of $K_2S_2O_8$ to approximately 1.5 L of reagent water, dissolving it, acidifying with 4 mL of concentrated phosphoric acid, then diluting to a final volume of 2 L with additional reagent water.   The sparge gas was pure oxygen. The instrument calibration range was set for 0 to 10 mg/L, and the sample injection volume was 1.00 mL.   Each sample was injected at least twice.   For a given sample, the detected TOC concentrations had to agree within 2 percent to be considered acceptable.   Averaged values were reported.   The TOC analyzer is shown in Figure 7.

Figure 7.   Dohrmann DC-80 TOC Analyzer and Associated Equipment
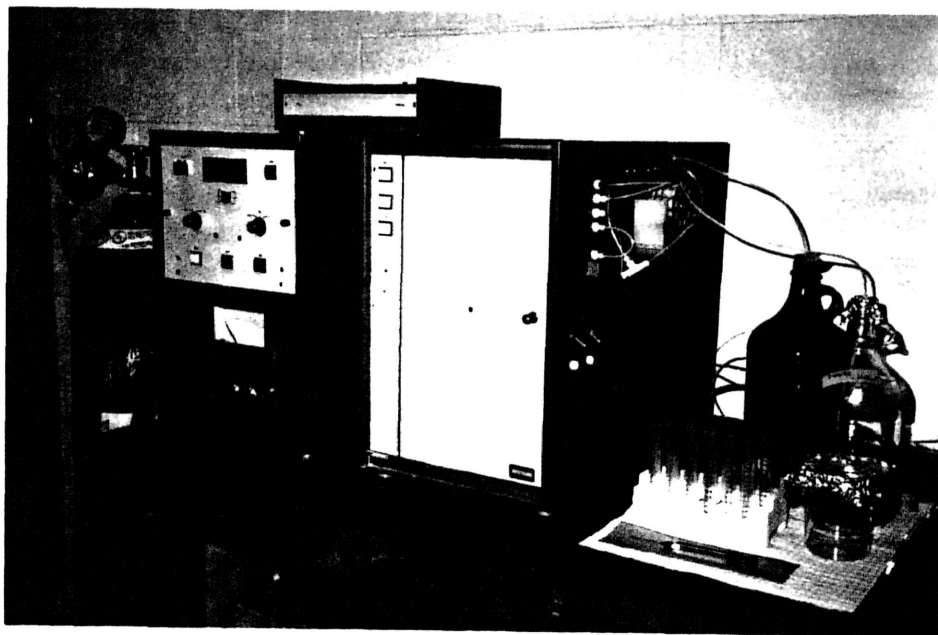
3.5 TOTAL CHLORINE RESIDUAL (TCR) ANALYSIS

Filter effluent samples and challenge water samples were routinely analyzed to determine total chlorine residual following Standard Method 4500-Cl (F. DPD Ferrous Titrimetric Method; APHA, 1989). For these tests, 100-mL sample volumes were used.

3.6 ALKALINITY ANALYSIS

Challenge water samples were routinely analyzed to determine alkalinity concentration following Standard Method 2320 (B. Titration Method; APHA, 1989). For these tests, 100-mL sample volumes were used. Samples were titrated to a final pH of 4.5. Initially, alkalinity measurements were also done for filter effluent samples. However, as little or no difference in alkalinity was noted between the challenge water and the filtered water, testing of filter effluent samples for alkalinity was discontinued.

3.7 pH MEASUREMENT

Either a Corning M105 pH meter or a Fisher Accumet Model 230 pH meter was used to determine sample pH. Each meter was equipped with a Corning general-purpose combination electrode. Prior to use, after conditioning or changing the electrode, each pH meter was standardized using pH 4, 7, and 10 standard buffer solutions. Prior to normal daily use, the meters were standardized using the pH 4 and 7 buffer solutions and recalibrated if necessary.

CHAPTER 4

EXPERIMENTAL ERRORS

4.1   SOURCES OF ERROR DURING FILTER PERFORMANCE TESTING

4.1.1   DELIVERY OF CHALLENGE WATER

Possible sources of error during filter performance testing included fluctuations in filter influent flow rate, variations in filter run time, and improper measurement of actual volume throughput. To minimize error, flow rates were measured with large rotameters that were accurate to within $\pm$ 0.025 gallons per minute, time was measured to within $\pm$ 5 seconds, and volume throughput was measured to within $\pm$ 0.066 gallons (0.25 liters) with calibrated 5 gallon (20 liter) plastic jugs.

It was important to collect filter samples without disturbing the filter flow rates. While samples were collected, the four on-line filters were allowed to run until sample collection was completed for all of them. This was done to minimize the effect of small pressure surges in the system that occurred when the influent valves were closed against a flow. Samples were collected during the last half of a cycle in order to assure stable conditions.

4.1.2   ACTIVATED CARBON WEIGHT AND VOLUME DETERMINATIONS

Since carbon weights were determined after the filters were used, a major possible source of error was inadequate sample drying. Adsorbed inorganics and bacterial growth could also significantly add to the measured weight of the carbon and contribute to sample weight errors.

To assure that the carbon samples were thoroughly dried, two

samples (Filters #2 and #4) were dried for 2 days, cooled and weighed, then dried for another 2 days, cooled and reweighed. The difference in net carbon weight between 2 days and 4 days of oven drying (170 °C) was 0.13 percent for both. The remaining samples were then dried for 3-4 days.

To determined if there was a significant weight difference between used and unused carbon, unused spare cartridges for Filters #2 and #4 were also dried, cooled, and weighed. The difference between Filter #2 used and unused dried carbon samples was 2.2 percent. For Filter #4, the difference was 1.6 percent. Used cartridge, dry carbon weights were reported for all the filters.

Volumes were measured with graduated cylinders. Filters that contained only a small volume of GAC were measured with a 250-mL (± 2.5 mL) graduated cylinder. Larger samples were measured with a 1000-mL (± 10 mL) graduated cylinder, sometimes in combination with a 500-mL (± 5 mL) graduated cylinder. Since the volume of carbon block-type filters could not be determined in this manner, measurements of inside and outside block diameter and block length were used to calculate volume. These measurements were accurate to within ± 0.0625 inches (± 0.16 cm).

4.2   SOURCES OF ERROR DURING ATRAZINE ANALYSIS

4.2.1   SAMPLE PREPARATION

There was an extensive number of steps required to prepare and analyze samples for atrazine and atrazine metabolite concentrations. Proper sample handling during the solid-phase extraction and metribuzin spiking procedures was especially critical in obtaining accurate results. To minimize variations in extraction efficiency, the pH of

each sample was adjusted to 7.0 ± 0.1 pH units. The extraction
procedure was closely followed, and standards and blanks were routinely
analyzed. The metribuzin internal standard was added to each extracted
sample using an automatic pipette calibrated at 50 µL to within 0.5
percent. Disposable pipette tips, transfer pipettes, glass culture
tubes, and microvials precluded contamination from one sample to
another.

4.2.2   METHOD DETECTION LIMIT

For the method used, Adams (1991) determined that the detection
and quantitation limits for the atrazine metabolites 2-amino-4-hydroxy-
6-isopropylamino-s-triazine (OIAT) and 2-amino-4-ethylamino-6-hydroxy-
s-triazine (OEAT) were:

"ND" = "Not Detected" (or less than 0.3 µg/L); and

"T" = "Trace" (and $0.3 \leq T \leq 0.5$ µg/L)

For the less soluble metabolites, hydroxyatrazine (OIET),
deethylatrazine (CIAT), deisopropylatrazine (CEAT), and for atrazine
(CIET), the detection and quantitation limits were:

"ND" = "Not Detected" (or less than 0.1 µg/L); and

"T" = "Trace" (and $0.1 \leq T \leq 0.2$ µg/L)

The coefficient of variation for the method was reported to be 4
percent.

4.2.3   ERROR INTRODUCED BY THE METRIBUZIN INTERNAL STANDARD

A new batch of metribuzin internal standard (0.015 µg/µL in
reagent water) was used for the later half of the test samples. Since
the old standard curve was based on the old metribuzin internal
standard, a new standard curve was generated using the new metribuzin.

A check was made to determine if this introduced error in the test results. Six 75-mL aliquots of a 10 μg/L six-component standard mix were extracted following the normal procedures. Three extracted samples were spiked with the old metribuzin, and three with the new metribuzin. Each was analyzed for OIAT, CEAT, CIAT, OIET, and CIET, as if it were an unknown sample. Each was quantified using the appropriate standard curve. The old standard curve did not include OEAT, the new standard curve did. Table 12 summarizes the results of this test.

Table 12. Effect of Metribuzin Internal Standard on Analysis Results

	USING "OLD" METRIBUZIN				USING "NEW" METRIBUZIN			
	#1	#2	#3	AVERAGE	#1	#2	#3	AVERAGE
OEAT (μg/L)	--	--	--	--	10.06	9.87	12.33	10.75
OIAT (μg/L)	8.39	9.03	9.28	8.90	10.12	9.75	11.52	10.46
CEAT (μg/L)	8.89	8.80	8.78	8.82	10.02	9.89	10.31	10.07
CIAT (μg/L)	8.65	8.51	8.67	8.61	9.77	9.66	10.04	9.82
OIET (μg/L)	9.00	9.45	9.54	9.33	9.88	8.94	10.40	9.74
CIET (μg/L)	10.24	10.08	10.01	10.11	10.03	9.94	10.00	9.99

For this research project, the components of interest were, deethylatrazine (CIAT), hydroxyatrazine (OIET), and atrazine (CIET). Atrazine, the most insoluble component in the mixture, was accurately analyzed using either the "old" or "new" metribuzin. The other components showed variable results. The CIAT average values agreed to within 14 percent. The OIET average values agreed to within 4 percent. This may have been due to small variations in extraction efficiency or sample preparation.

4.2.4 PRECISION OF THE METHOD AT HIGH AND LOW CONCENTRATIONS

An effort was made to determine the precision of the method at both high and low concentrations. To represent the high concentration, six 75-mL aliquots of a 15 µg/L six-component standard mix were extracted following normal procedures, then spiked with "new" metribuzin. Each was analyzed as if it were an unknown sample. The results are summarized in Table 13.

Table 13. Precision of Method at High Concentration

	SAMPLE NO.							
	#1	#2	#3	#4	#5	#6	MEAN	SD
OEAT (µg/L)	15.86	14.78	15.44	16.41	15.56	14.65	15.4	± 0.7
OIAT (µg/L)	15.14	14.17	15.65	15.17	14.78	14.73	14.9	± 0.5
CEAT (µg/L)	14.89	15.35	15.32	14.89	14.92	15.56	15.2	± 0.3
CIAT (µg/L)	14.34	14.42	14.86	14.66	14.70	14.97	14.7	± 0.2
OIET (µg/L)	13.18	13.75	14.16	13.74	13.68	13.88	13.7	± 0.3
CIET (µg/L)	14.79	14.72	15.46	15.14	15.29	15.32	15.1	± 0.3

At high concentrations, the method was accurate and precise for all the components analyzed, except for OIET, OIAT, and OEAT. The amount of OIET determined in these sample was consistently low. The more soluble components, OEAT and OIAT, had a broader range of results. This was possibly due to variations in sample extraction efficiency.

Seven 75-mL aliquots of a 0.2 µg/L six-component standard mix were extracted, spiked, and analyzed in the same manner as the high concentration samples. The results are summarized in Table 14.

Table 14.   Precision of Method at Low Concentration

	SAMPLE NO.								
	#1	#2	#3	#4	#5	#6	#7	MEAN	SD
OEAT (μg/L)	--	--	0.14	0.29	0.47	--	--	--	± --
OIAT (μg/L)	--	--	--	0.38	0.08	0.18	0.23	--	± --
CEAT (μg/L)	0.05	0.08	0.04	0.06	0.04	0.08	0.06	0.06	± 0.02
CIAT (μg/L)	0.05	0.08	0.07	0.08	0.10	0.10	0.04	0.07	± 0.02
OIET (μg/L)	0.08	0.12	0.07	0.08	0.11	0.12	0.09	0.10	± 0.02
CIET (μg/L)	0.03	0.05	0.05	0.05	0.04	0.05	0.07	0.05	± 0.01

The results for the low level samples agreed with the quantifiable and method detection limits reported by Adams (1991). At very low concentrations, the accuracy was inadequate for quantifying the components. It should be noted that there was a consistent, detectable signal at the low concentration level for CEAT, CIAT, OIET, and CIET. For these components, levels detected below 0.2 μg/L were reported as "Trace" concentrations.

4.3   SOURCES OF ERROR IN TOTAL ORGANIC CARBON (TOC) ANALYSIS

To minimize error during TOC analysis, multiple injections of a standard carbon solution (10 mg/L as C), were made prior to the analysis of a sample set. The measured TOC concentrations had to agree within 2 percent of one another, and within 1 percent of the value 10 mg/L. Challenge water and filter samples were injected at least twice. Results had to agree within 2 percent, or another injection was made. Averaged results were reported. The 10 mg/L standard was reinjected after every 8 to 10 samples had been analyzed, and at the end of the sample set. This was done to minimize baseline drift and confirm the accuracy of the intermediate results.

Pure methanol was used to make the atrazine stock solution. Every 225 gallon (852 L) batch of challenge water received 1-mL of this stock solution. Since the density of pure methanol is 0.7917 g/mL at 20 °C, this added a maximum of 0.93 mg/L of CH_3OH (equivalent to 0.35 mg/L of carbon) to the challenge water. Because methanol is very soluble in water, it was neither adsorbed by the activated carbon nor volatilized from the dilute aqueous solution. Therefore, the challenge water had a known fractional portion of TOC that could not be removed. This did have the effect of decreasing the percent TOC removal calculated for each filter. The effect was less pronounced as the filter effluent TOC concentrations increased above 1.0 mg/L.

4.4   SOURCES OF ERROR IN TOTAL CHLORINE RESIDUAL (TCR) ANALYSIS

Each batch of challenge water was normally delivered over a period of 2 to 3 days. During this time, the temperature of challenge water in the mix tank approached room temperature (75 °F). Plowman and Rademacher (1958) reported an apparent critical temperature range (60-75 °F) where high losses of combined chlorine residuals occurred. They noted extreme losses with only a 3-5 °F rise in water temperature above 65 °F. Little or no loss of combined chlorine residual occurred when water temperatures were below 65 °F. Loss of TCR in the challenge water during filter testing was attributed to temperature. Figure 8 illustrates the magnitude of these losses for several different batches of challenge water.

Obviously, if challenge water TCR concentrations were very low, the filter effluent TCR concentrations would be also. To reduce the effect of storage losses on filter performance evaluations, only the test runs where the challenge water TCR was ≥ 1.0 mg/L, were used to

determine percent TCR removal.   Sets of samples that could not be
analyzed immediately for TCR were refrigerated at 4 °C, then analyzed
within 24 hours.   The minimum detectable residual concentration was
0.05 mg/L (Δ 0.05 ml buret reading).

Figure 8.   Storage Loss of Influent TCR
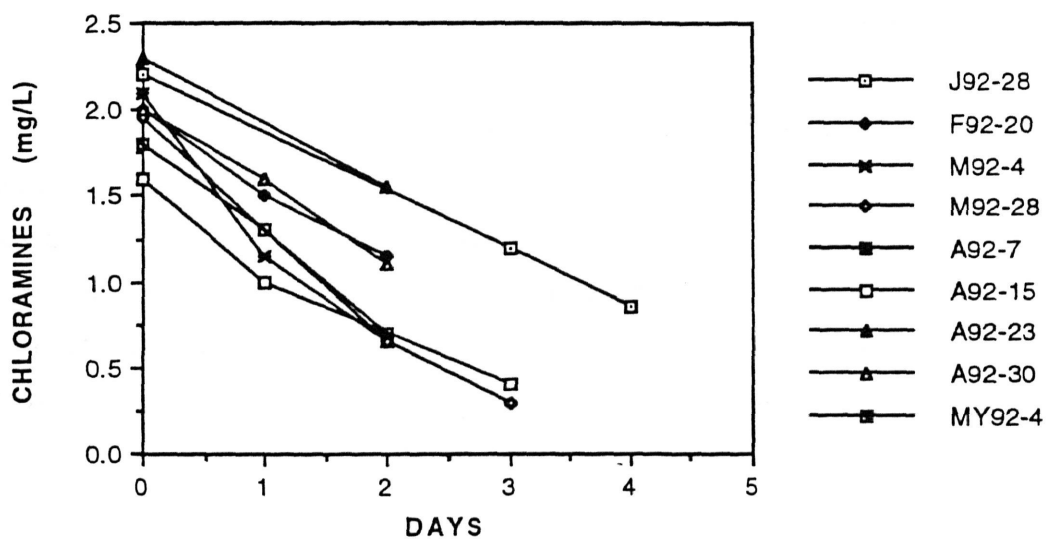
CHAPTER 5

RESULTS

The following sections present the results obtained from analyses of the challenge water and filter effluents for atrazine, total organic carbon, and combined chlorine residual. The raw data are presented in Appendix B.

5.1 CHALLENGE WATER CHARACTERISTICS

A summary of the challenge water characteristics is presented in Table 15. Note that low levels of atrazine (CIET), hydroxyatrazine (OIET), and deethlyatrazine (CIAT) were detected in the unspiked tap water throughout the study. Addition of the AAtrex Nine-O atrazine spike solution did not alter the concentrations of either OIET or CIAT.

Table 15.   Summary of Challenge Water Characteristics

Date of study: January 2 – May 4, 1992
Water source: Lawrence, Kansas – city water
                (Kaw River and Clinton Lake)

Characteristics of unspiked tap water:

	Mean value	Std. deviation
Temperature	16 °C	1.3 °C
pH	8.3	0.2
Alkalinity	65 mg/L as $CaCO_3$	17 mg/L
Combined Chlorine	1.95 mg/L as Cl_2	0.24 mg/L
TOC (nonpurgeable)	2.65 mg/L as C	0.58 mg/L
Atrazine (CIET)	0.53 µg/L	0.12 µg/L
Hydroxyatrazine (OIET)	0.59 µg/L	0.08 µg/L
Deethylatrazine (CIAT)	0.32 µg/L	0.10 µg/L

Characteristics of challenge water used in filter tests:

	Mean value	Std. deviation
Temperature	20 °C	1.8 °C
pH	8.3	0.2
Alkalinity	65 mg/L as $CaCO_3$	17 mg/L
Combined Chlorine	0.99 mg/L as Cl_2	0.45 mg/L
TOC (nonpurgeable)	2.99 mg/L as C	0.50 mg/L
Atrazine (CIET)	12.31 µg/L	0.92 µg/L
Hydroxyatrazine (OIET)	0.57 µg/L	0.08 µg/L
Deethylatrazine (CIAT)	0.38 µg/L	0.12 µg/L

5.2   INDIVIDUAL FILTER PERFORMANCE EVALUATIONS

Performance summaries for each filter are presented in Tables 16-23.   Cumulative   volume   throughput   is   simply   referred   to   as "throughput".   Percent rated capacity is based on the manufacturer's rated capacity for volume throughput at 100 percent.   The abbreviations used for identifying the components removed by the filters are:

CIET = Atrazine

OIET = Hydroxyatrazine

CIAT = Deethylatrazine

TOC = Total Organic Carbon (Nonpurgeable)

TCR = Total Combined Chlorine (Chloramine) Residual

Graphical representations of these data are presented in Figures 9-16. The   atrazine   metabolites,   OIET   and   CIAT,   were   present   at   very   low concentrations   in   the   influent   water.   Because   of   this,   an   accurate assessment of their removal could not be made.   If trace concentrations of these metabolites were detected in the filter effluent, removal was reported   as   less   than   100   percent.   If   more   than   a   "trace" concentration   was   detected,   a   percent   removal   was   calculated   and reported.   Note that the quantities detected were near the quantitative limit of the method.

Table 16. Performance Summary for Filter #1

Model: Instapure IF-10   Rated Capacity: 1800 gallons
Test Flowrate: 1.0 gpm   Run Time per Cycle: 10 min.
Cycles per Day: 2 minimum, 4 maximum

Throughput (gallons)	% Rated Capacity	% Removed				
		CIET	OIET	CIAT	TOC	TCR
41.9	2.3	84	<100	100	40	80
123.2	6.8				30	75
164.3	9.1	83	<100	100	31	81
184.8	10.3				26	
205.1	11.4				21	75
287.3	16.0	83	<100	<100	25	
327.8	18.2				25	
408.5	22.7				22	69
528.7	29.4	76	71	<100	23	61
650.7	36.2	75	<100	<100	19	
771.6	42.9	73	<100	100	14	
892.6	49.6	66	<100	<100	17	62
1013.2	56.3	64	59	<100	13	
1154.3	64.1	62	<100	100	10	60
1296.2	72.0	62	49	<100	16	
1397.3	77.6	58	57	100	19	61
1539.1	85.5	57	46	<100	18	55
1619.7	90.0	57	55	<100	14	

Table 17. **Performance Summary for Filter #2**

Model: Instapure F-2C   Rated Capacity: 200 gallons
Test Flowrate: 0.5 gpm   Run Time per Cycle: 5 min.
Cycles per Day: 2 minimum, 4 maximum

Throughput	% Rated	% Removed				
(gallons)	Capacity	CIET	OIET	CIAT	TOC	TCR
12.9	6.5	69	<100	<100	19	50
29.6	14.8					44
34.9	17.4	59	<100	<100	13	43
40.2	20.1	60	58	100	16	41
45.2	22.6	57	55	<100	16	38
50.2	25.1				13	
55.6	27.8					33
75.4	37.7	57	57	<100	7	
85.3	42.7				14	
95.1	47.6	49	56	<100	11	
105.1	52.6				7	31
135.5	67.8	44	43	<100	12	22
155.5	77.7				9	
165.4	82.7	45	40	44	8	
194.8	97.4	43	43	100	5	
204.5	102.2				6	
214.2	107.1				8	27
224.1	112.0	32	34	9	8	23
252.9	126.5	29	42	<100	8	
287.4	143.7	29	31	<100	5	40
322.1	161.0	33	34	29	11	
347.1	173.5	26	30	49	12	26
381.5	190.7	27	27	7	11	14
401.3	200.6	24	20	32	6	

Table 18.   Performance Summary for Filter #3

Model: Amway WTS III   Rated Capacity: 750 gallons
Test Flowrate: 1.0 gpm   Run Time per Cycle: 5 min.
Cycles per Day: 2 minimum, 4 maximum

Throughput (gallons)	% Rated Capacity	% Removed				
		CIET	OIET	CIAT	TOC	TCR
21.1	2.8	100	100	100	76	100
60.9	8.1				77	100
81.5	10.9	100	100	100	82	100
101.8	13.6				80	100
147.1	19.6				76	
167.4	22.3				74	
208.3	27.8				65	100
268.8	35.8	100	100	100	58	91
329.2	43.9				52	100
389.9	52.0				43	
450.2	60.0	100	100	100	42	92
510.4	68.0				37	
580.6	77.4	100	100	100	34	90
650.9	86.8				43	
701.1	93.5				37	94
771.4	102.8				37	91
811.6	108.2	100	100	100	30	

Table 19. Performance Summary for Filter #4

Model: Ametek CCF-201   Rated Capacity: 1500 gallons
Test Flowrate: 0.5 gpm   Run Time per Cycle: 20 min.
Cycles per Day: 2 minimum, 4 maximum

Throughput	% Rated	% Removed				
(gallons)	Capacity	CIET	OIET	CIAT	TOC	TCR
40.8	2.7	100	100	100	63	100
120.9	8.0				52	100
160.9	10.7	100	100	100	44	100
200.8	13.4				42	92
276.3	18.4				39	
316.2	21.1				36	
396.6	26.4				30	92
517.1	34.5	100	100	100	30	91
637.6	42.5				26	
758.0	50.5	100	100	100	22	
878.8	58.6	100	100	100	25	92
939.0	62.6	<100	100	100	19	83
999.2	66.6	<100	100	100	22	
1139.9	76.0	<100	100	100	18	95
1280.4	85.4	98	100	100	22	
1380.8	92.1	97	100	100	20	94
1521.4	101.4	97	100	100	24	91
1601.7	106.8	95	100	100	17	

Table 20.   Performance Summary for Filter #5

Model: Culligan SG-2   Rated Capacity: 1000 gallons
Test Flowrate: 0.5 gpm   Run Time per Cycle: 10.5 min.
Cycles per Day: 2 minimum, 4 maximum

Throughput	% Rated	% Removed				
(gallons)	Capacity	CIET	OIET	CIAT	TOC	TCR
20.1	2.0	<100	100	100	80	96
35.7	3.6	<100	100	100	75	
55.6	5.6	<100	100	100	75	
97.4	9.7	<100	100	100	69	92
160.5	16.0	98	100	100	69	91
223.6	22.4				64	
287.0	28.7	98	100	100	60	
350.4	35.0	96	100	100	60	92
413.8	41.4	97	100	100	53	
487.7	48.8	96	100	100	46	90
561.6	56.2	96	100	100	56	
614.6	61.5	96	100	100	55	87
688.6	68.8	96	100	100	54	91
730.8	73.1	95	100	100	58	

Table 21. Performance Summary for Filter #6

Model: Multi-Pure 500B   Rated Capacity: 500 gallons
Test Flowrate: 0.5 gpm   Run Time per Cycle: 10 min.
Cycles per Day: 2 minimum, 4 maximum

Throughput	% Rated	% Removed				
(gallons)	Capacity	CIET	OIET	CIAT	TOC	TCR
20.2	4.0	100	100	100	82	100
60.1	12.0				81	100
80.2	16.0	100	100	100	79	100
100.2	20.0				81	100
140.5	28.1	100	100	100	83	
160.9	32.2				83	
201.2	40.2				81	100
261.4	52.3	100	100	100	79	100
321.6	64.3				72	
381.9	76.4				67	
442.1	88.4	100	100	100	68	100
502.3	100.5				61	
572.6	114.5	100	100	100	55	100
642.9	128.6				62	
693.1	138.6				59	100
763.32	152.7				49	100
803.48	160.7	100	100	100	49	

Table 22. Performance Summary for Filter #7

Model: PureWater "Pup"   Rated Capacity: 1500 gallons
Test Flowrate: 0.5 gpm   Run Time per Cycle: 10 min.
Cycles per Day: 2 minimum, 4 maximum

| Throughput | % Rated | % Removed | | | | |
(gallons)	Capacity	CIET	OIET	CIAT	TOC	TCR
20.2	1.3	<100	100	100	43	90
60.1	4.0				29	68
80.3	5.4	97	100	100	26	69
100.4	6.7				24	67
140.5	9.4	92	<100	100	19	
160.8	10.7				21	
201.0	13.4	85	<100	100	16	62
261.3	17.4	84	<100	<100	18	52
321.5	21.4	82	100	100	16	
381.7	25.4	78	<100	100	12	
442.0	29.5	64	<100	<100	14	50
502.2	33.5	63	65	<100	11	
572.5	38.2	59	52	65	12	60
642.7	42.8	56	<100	100	11	
692.9	46.2	52	56	<100	10	55
763.2	50.9	54	47	61	15	45
803.4	53.6	49	<100	<100	11	

Table 23. Performance Summary for Filter #8

Model: Ecowater Water Master   Rated Capacity: 1500 gal.
Test Flowrate: 0.5 gpm   Run Time per Cycle: 20 min.
Cycles per Day: 2 minimum, 4 maximum

Throughput (gallons)	% Rated Capacity	% Removed				
		CIET	OIET	CIAT	TOC	TCR
40.7	2.7	100	100	100	77	100
120.9	8.0				57	96
161.0	10.7	100	100	100	53	96
201.0	13.4				47	92
277.0	18.5	100	100	100	41	
317.1	21.1				39	
397.6	26.5				33	92
518.0	34.5	100	100	100	32	91
638.5	42.6				28	
759.0	50.6				22	
879.7	58.6	100	100	100	24	92
1000.2	66.7	100	100	100	22	
1141.0	76.1	100	100	100	20	90
1281.5	85.4				25	
1381.9	92.1				18	94
1522.4	101.5	100	100	100	20	91
1602.7	106.8	100	100	100	16	

Figure 9.   Graph of Filter #1 Performance
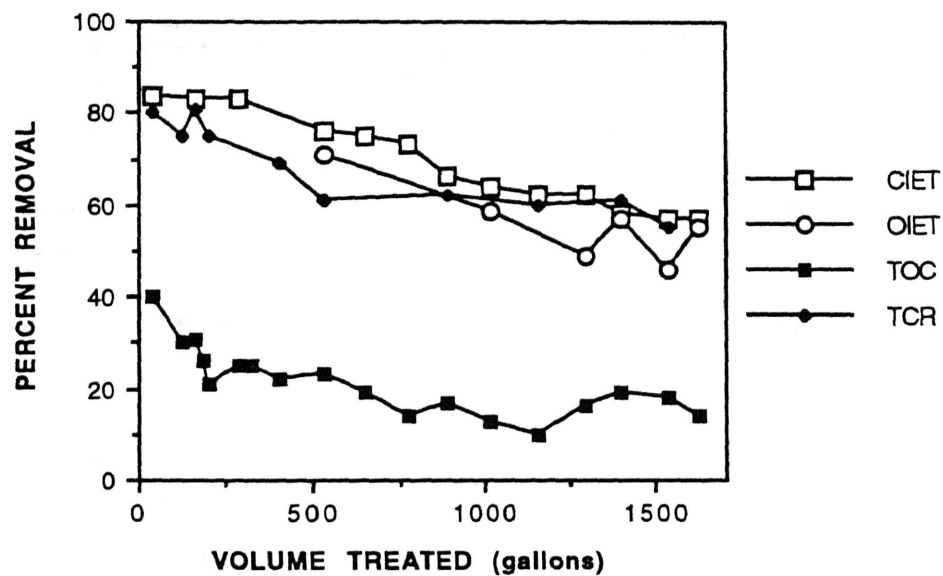
Figure 10.   Graph of Filter #2 Performance
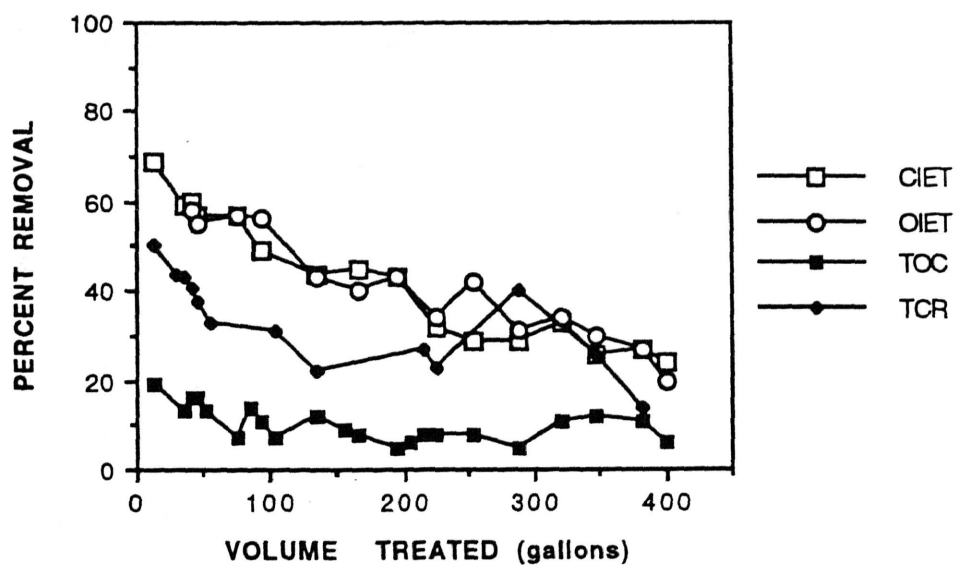
Figure 11.   Graph of Filter #3 Performance
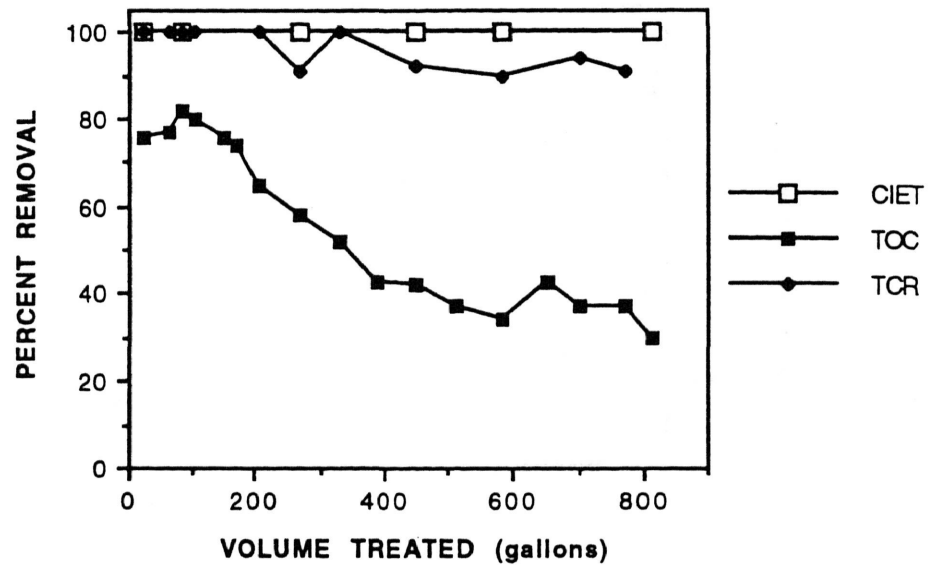
Figure 12.   Graph of Filter #4 Performance
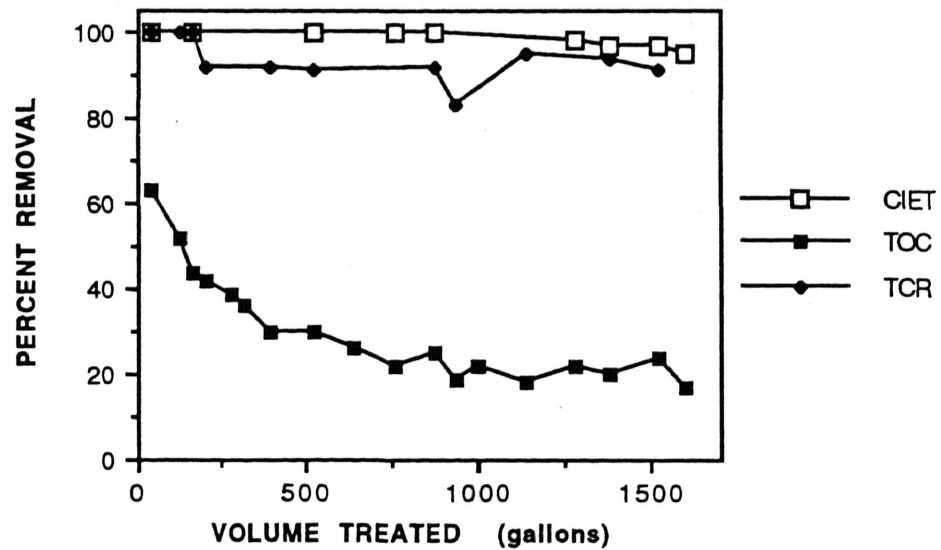
Figure 13.   Graph of Filter #5 Performance
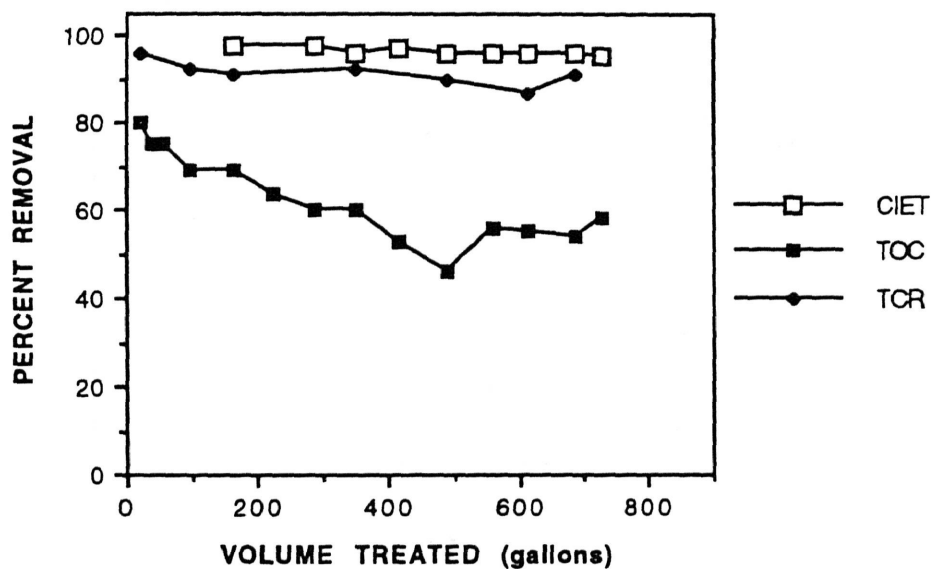
Figure 14.   Graph of Filter #6 Performance
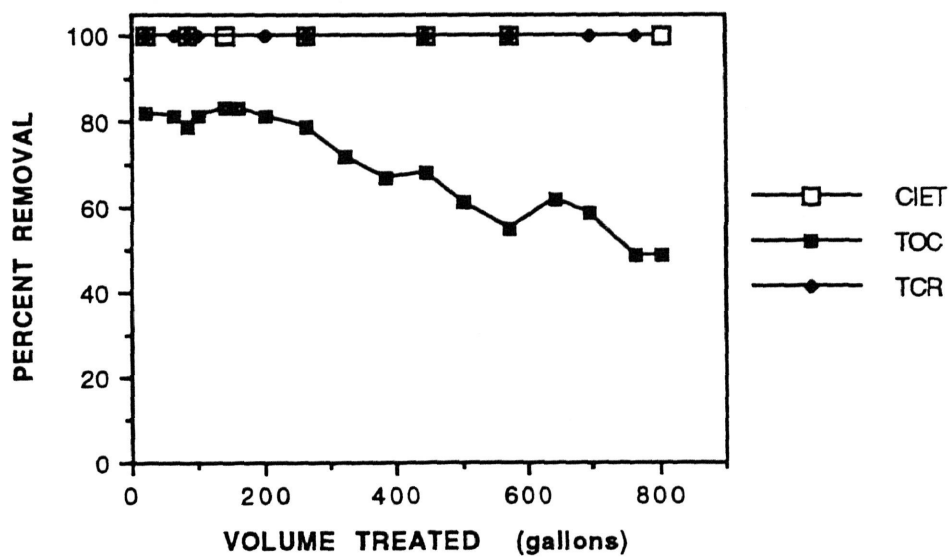
Figure 15. Graph of Filter #7 Performance
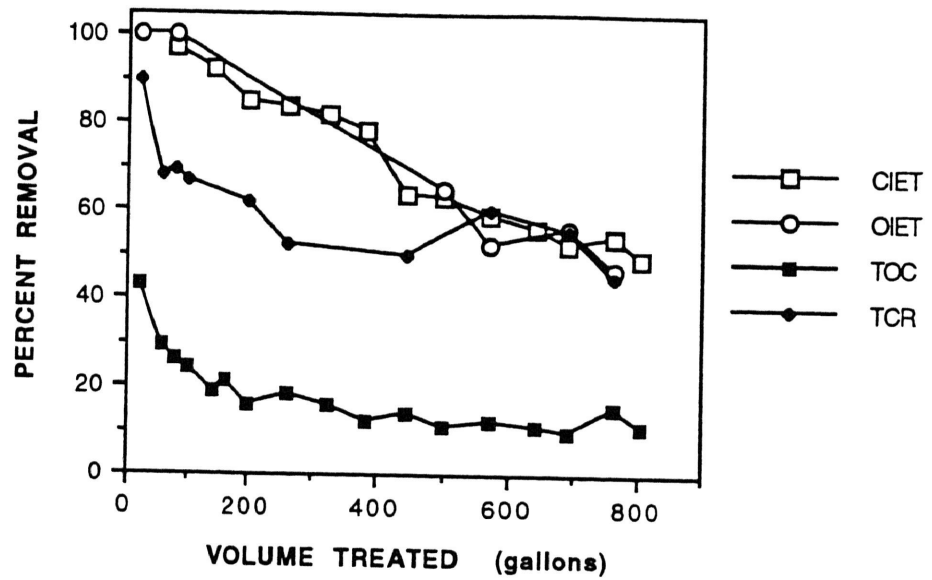
Figure 16. Graph of Filter #8 Performance
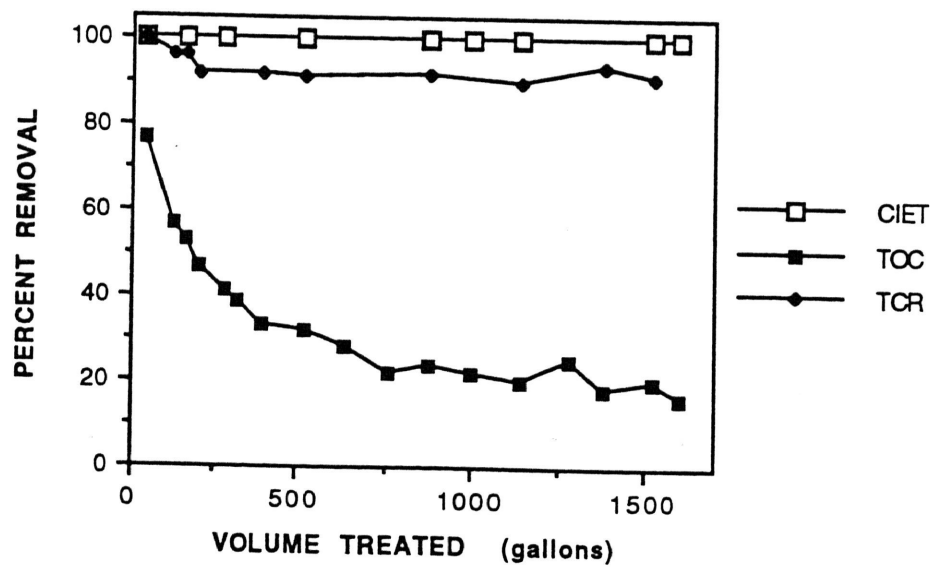
5.3 COLLECTIVE FILTER PERFORMANCE EVALUATIONS

To determine how the filters performed relative to one another, percent removals of atrazine, TOC, and TCR versus percent rated capacity were plotted for each filter. These graphs are presented in Figures 17-19.

Rated capacity is a somewhat arbitrary number. Most filter manufacturers recommend that the filter cartridges be changed out at least once per year. For some filter units, the rated capacity is based on the anticipated number of gallons to be processed annually. For other units, the rated capacity is based on the anticipated number of gallons to be processed prior to breakthrough of chlorine or some other compound. Usually, the basis for the manufacturer's rated capacity is not stated.

A filter capacity rating given by one manufacturer may not be based on the same criteria as a rating given by another manufacturer. Because of this, effluent and influent concentration ratios for atrazine, TOC, and TCR versus bed volumes treated were also plotted. The number of bed volumes is a particularly useful parameter because the data from filter cartridges of different sizes and with different flow rates are normalized. These graphs are presented in Figures 20-22. Evaluation of filter performance on the basis of bed volumes treated allowed for objective comparisons to be made.

Figure 17.   Atrazine Removal vs. Rated Filter Capacity
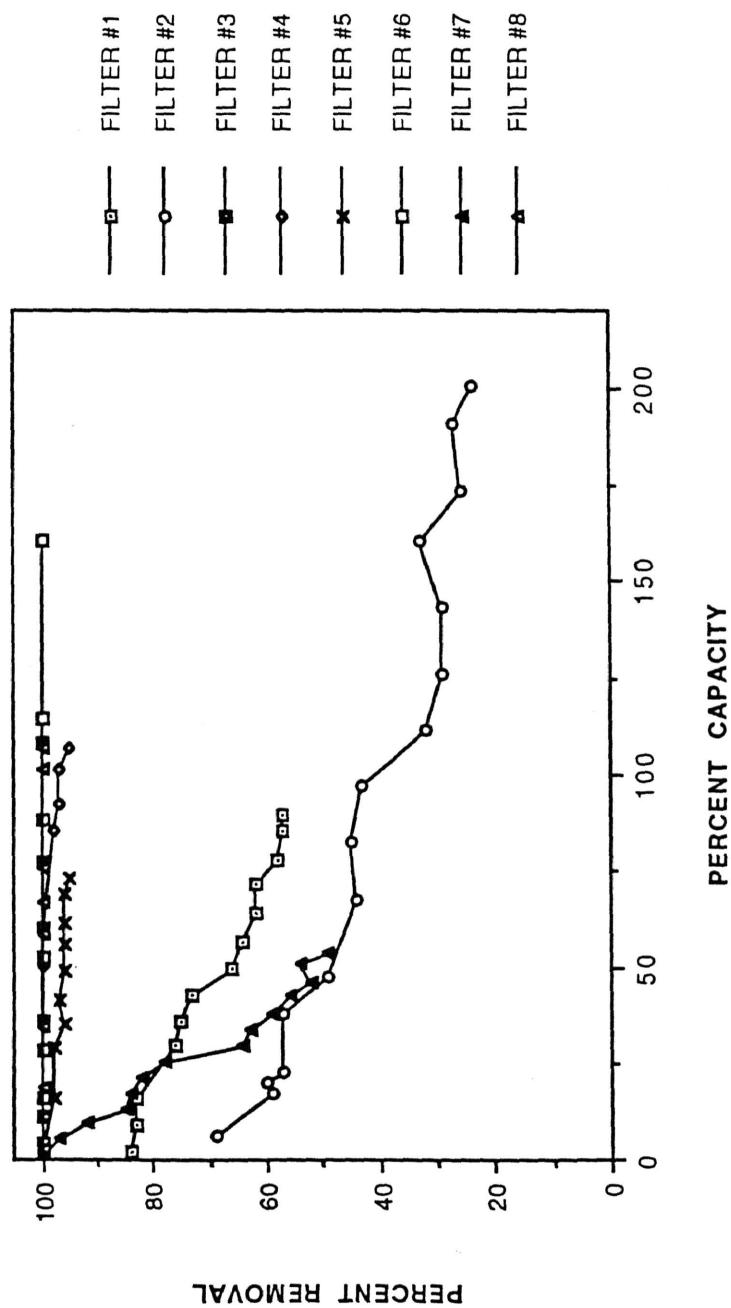
Figure 18.   TOC Removal vs. Rated Filter Capacity

Figure 19.   TCR Removal vs. Rated Filter Capacity

Figure 20.   Atrazine Breakthrough Profiles

Figure 21. TOC Breakthrough Profiles

Figure 22.   TCR Breakthrough Profiles

FILTER #1
FILTER #2
FILTER #3
FILTER #4
FILTER #5
FILTER #6
FILTER #7
FILTER #8
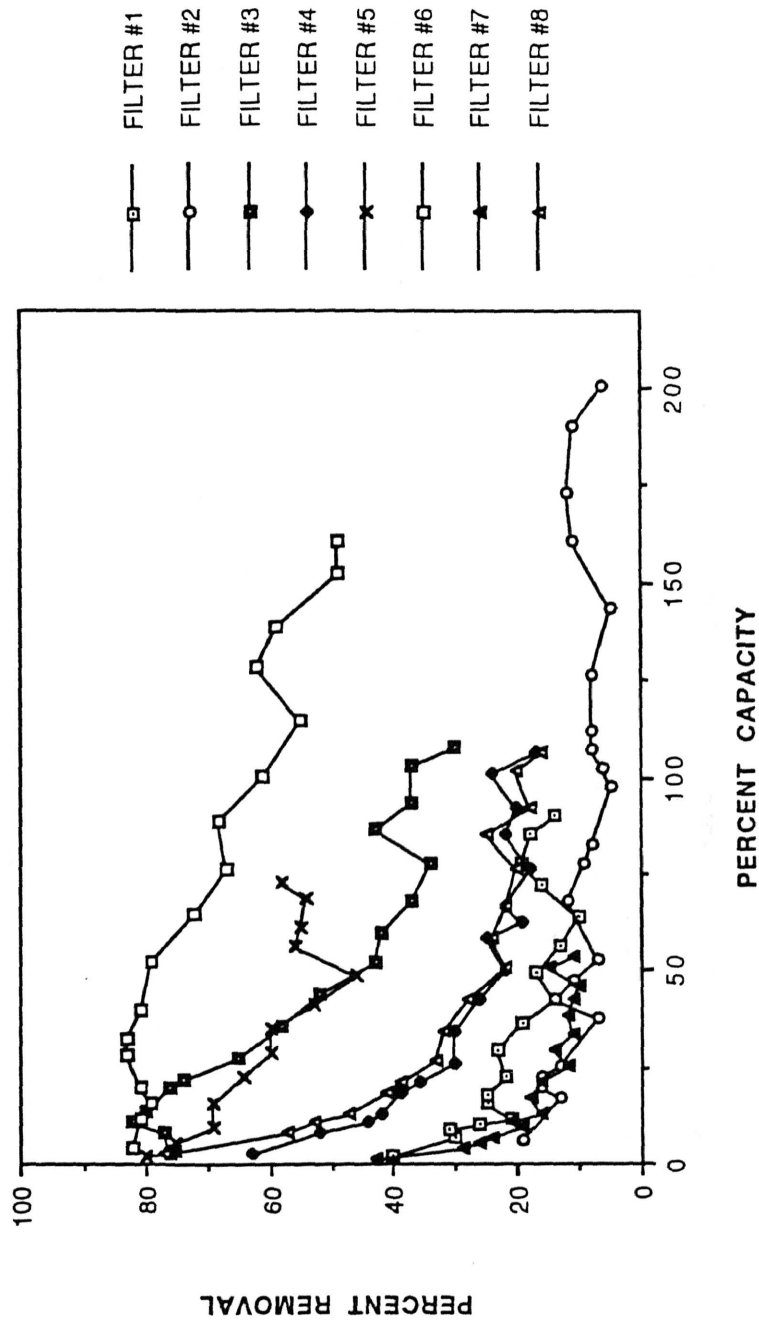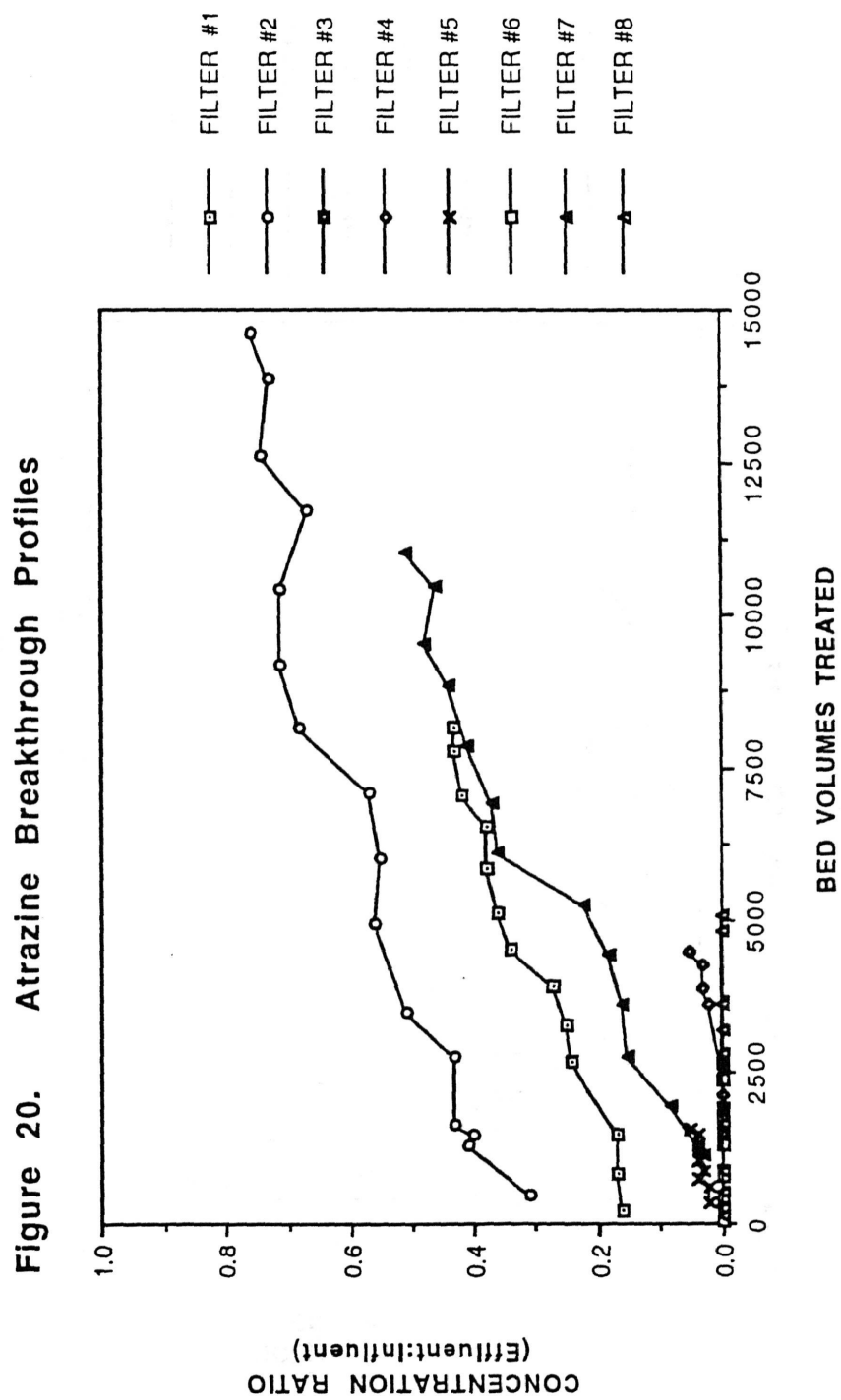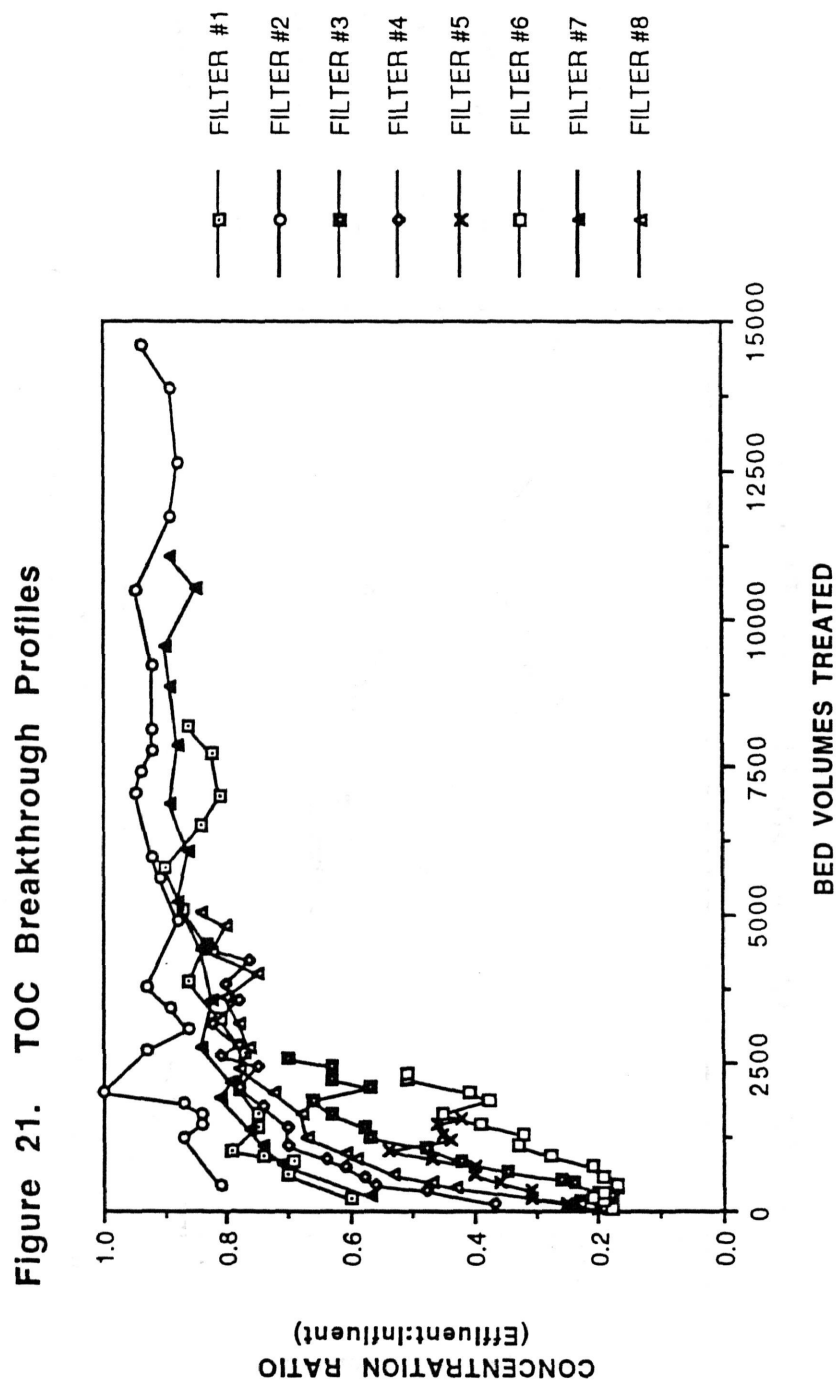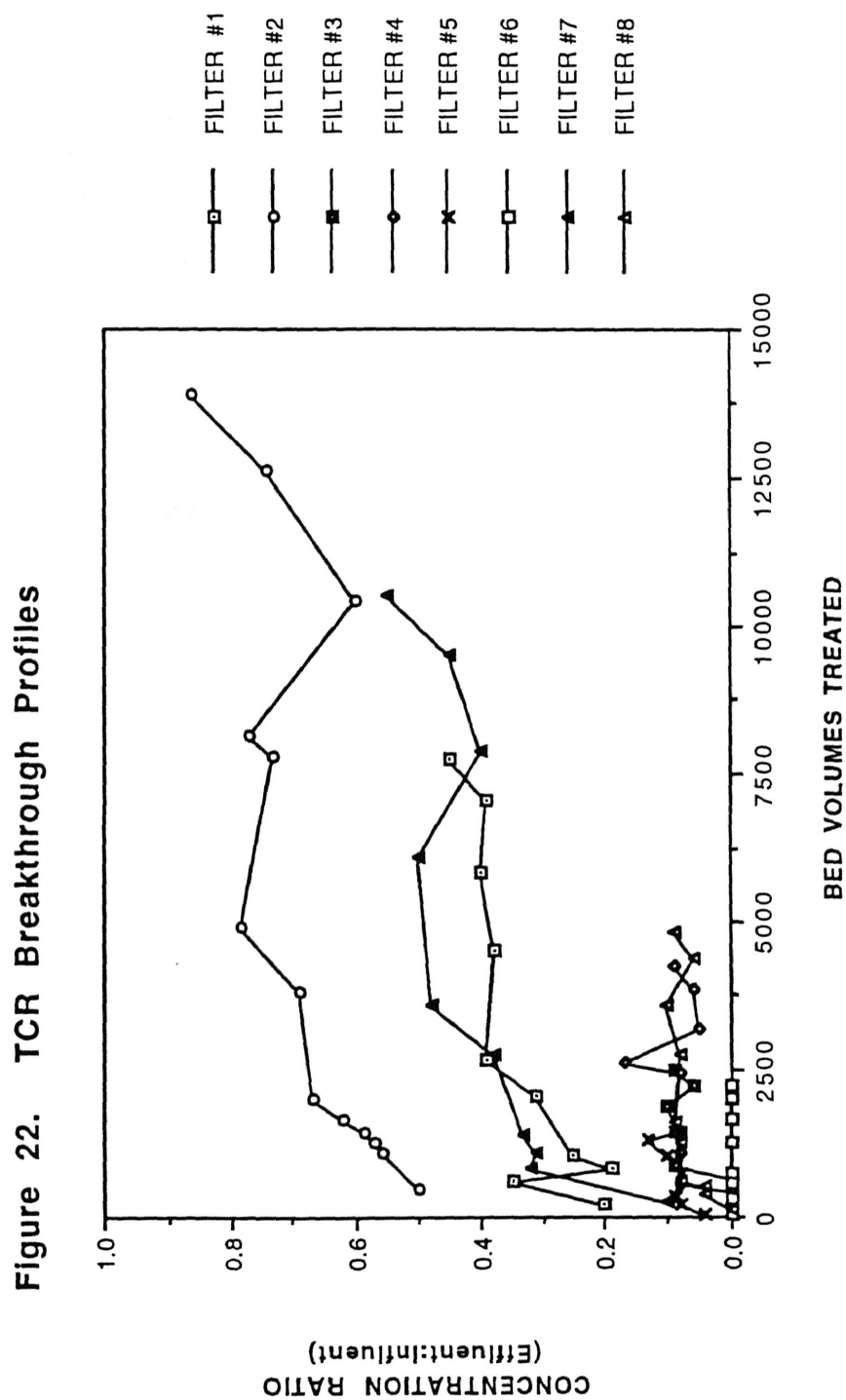
5.4 ACTIVATED CARBON UTILIZATION

To evaluate filter performance with respect to activated carbon utilization, the filter effluent atrazine concentrations were plotted against the net cumulative atrazine loads (mg atrazine adsorbed/g carbon) for each filter. Influent concentrations were included to provide a point of reference. These graphs are presented in Figures 23 -27. Tables of calculations are presented in Appendix C. There were three filters that did not have any detectable effluent concentration of atrazine for the full duration of testing. The cumulative atrazine loads for these filters were:

Filter #3: 0.066 mg Atrazine/g Carbon

Filter #6: 0.065 mg Atrazine/g Carbon

Filter #8: 0.15 mg Atrazine/g Carbon

Figure 23.   Atrazine Adsorptive Capacity of Filter #1
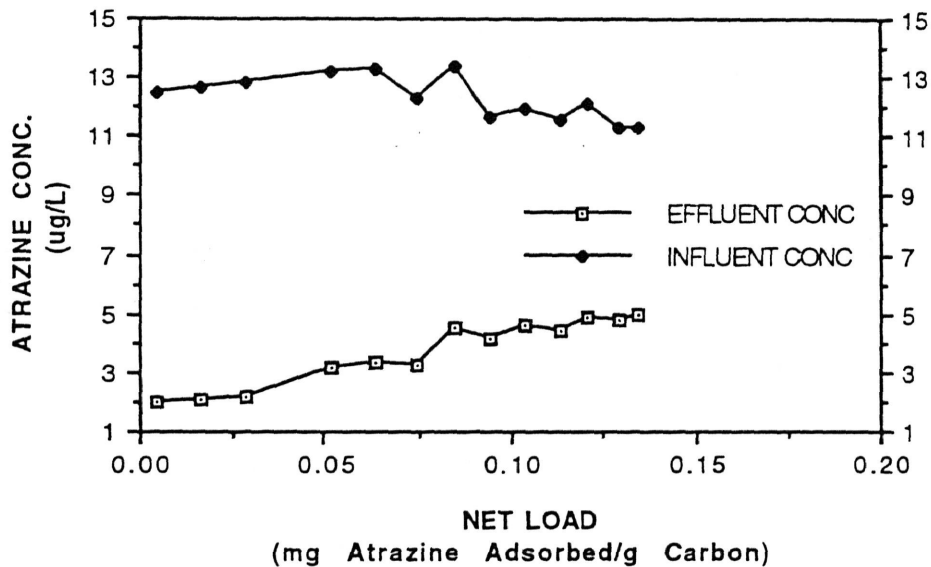
Figure 24.   Atrazine Adsorptive Capacity of Filter #2
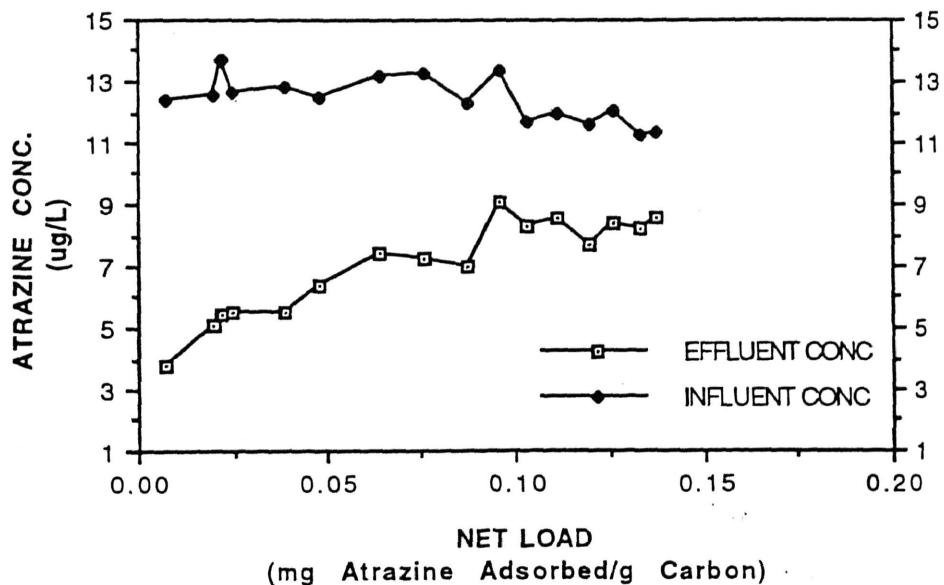
Figure 25.   Atrazine Adsorptive Capacity of Filter #4
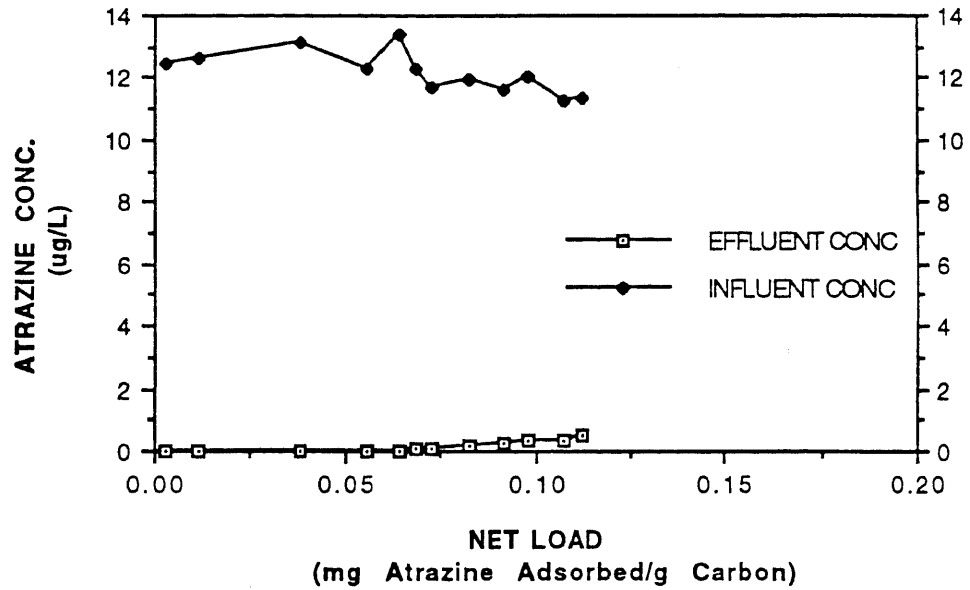
Figure 26.   Atrazine Adsorptive Capacity of Filter #5
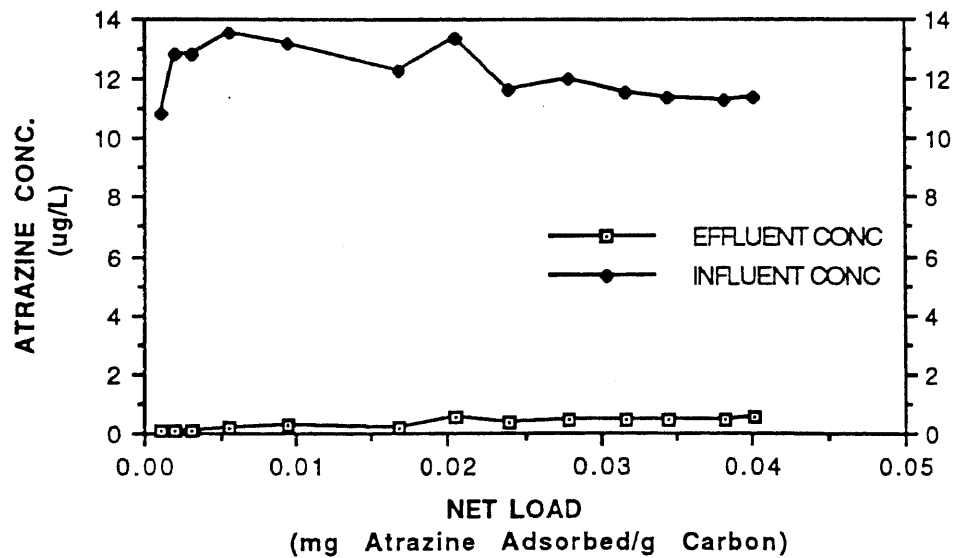
Figure 27.   Atrazine Adsorptive Capacity of Filter #7
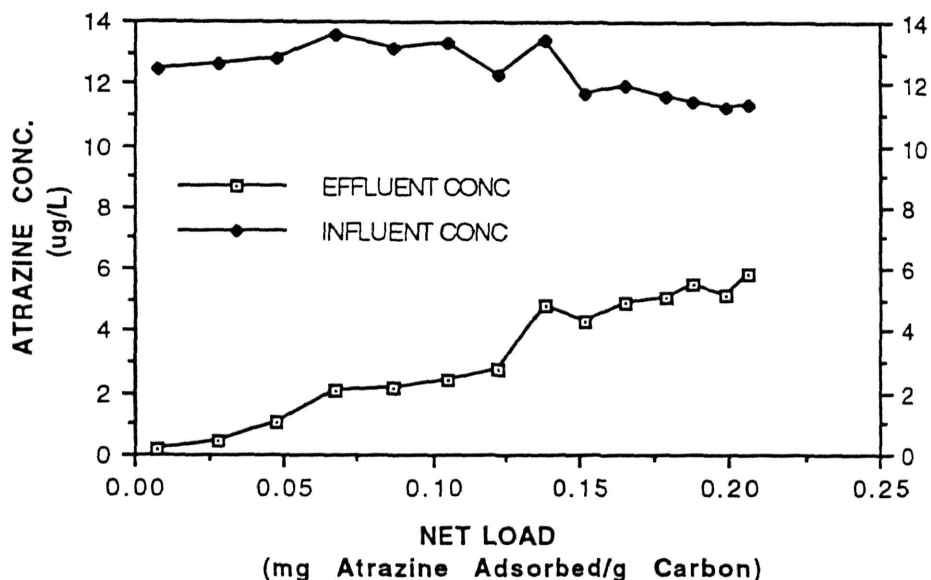
5.5   STATISTICAL CORRELATIONS

Linear regression analysis was used to statistically characterize the relationships between atrazine removal, TOC removal, and TCR removal.   Two plots were made for each set of filter data.   One plot correlated percent TOC removal with percent atrazine removal, the other correlated percent TCR removal with percent atrazine removal.   Only Filters #1, #2, and #7 had sufficient data over a large enough range for this technique to be used.   The correlation coefficients, slopes, and y-intercepts for these plots are summarized in Table 24.   The scatter plots obtained from the data are presented in Figures 28-33.

Table 24.   Statistical Correlations

Parameter	Filter #1	Filter #2	Filter #7
TOC vs. Atrazine:			
Slope	0.64	0.18	0.23
y-Intercept	22.67	2.73	- 0.74
Correlation Coefficient, r	0.80	0.61	0.85
No. of Points	8	14	9
Significance Level of Correlation	>95 %	>95 %	>99 %
TCR vs. Atrazine			
Slope	0.79	0.55	0.30
y-Intercept	10.74	8.50	34.73
Correlation Coefficient, r	0.88	0.76	0.66
No. of Points	7	9	7
Significance Level of Correlation	>99 %	>95 %	*

* Correlation between the variables is not significantly different from zero.   Refer to Rohlf and Sokal (1981) for a listing of critical values for correlation coefficients.

Figure 28.   Correlation Between TOC and Atrazine Removal for Filter #1
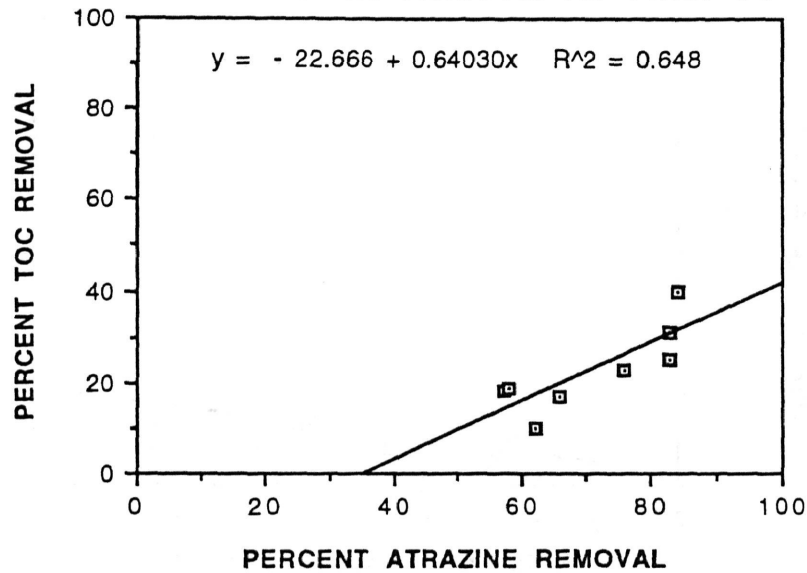
Figure 29.   Correlation Between TCR and Atrazine Removal for Filter #1
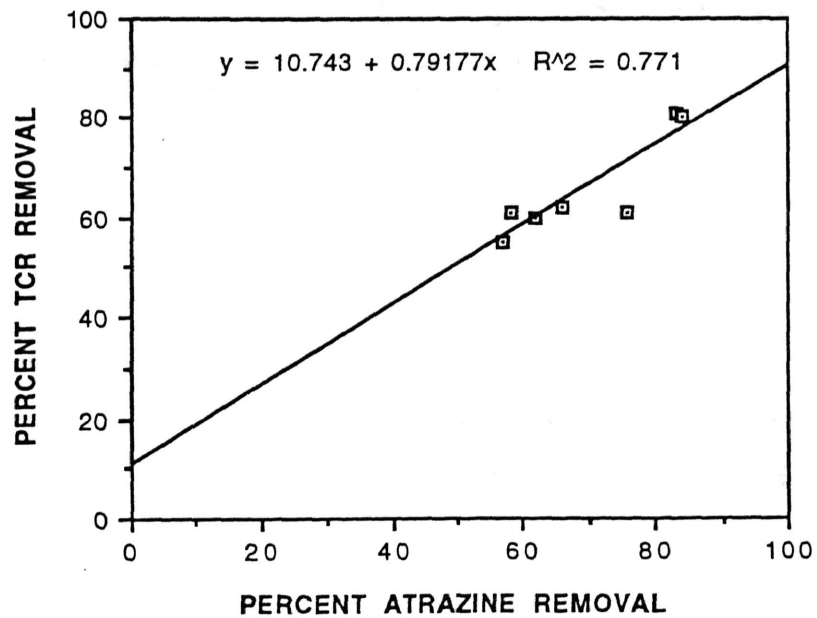
Figure 30. Correlation Between TOC and Atrazine Removal for Filter #2

y = 2.7306 + 0.18015x   R^2 = 0.370

PERCENT TOC REMOVAL vs PERCENT ATRAZINE REMOVAL
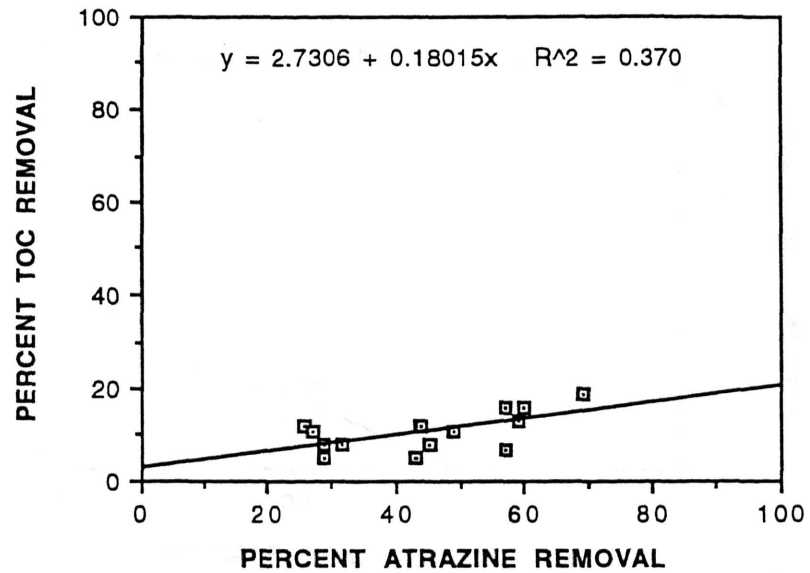
Figure 31. Correlation Between TCR and Atrazine Removal for Filter #2

y = 8.4986 + 0.54718x   R^2 = 0.582

PERCENT TCR REMOVAL vs PERCENT ATRAZINE REMOVAL
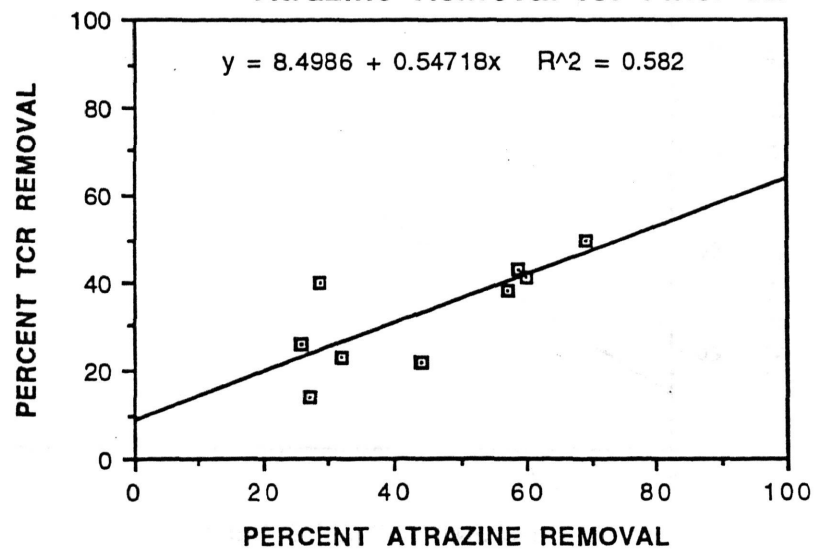
Figure 32.   Correlation Between TOC and Atrazine Removal for Filter #7

$y = -0.73989 + 0.22819x$ $R^2 = 0.720$

PERCENT TOC REMOVAL (y-axis)

PERCENT ATRAZINE REMOVAL (x-axis)
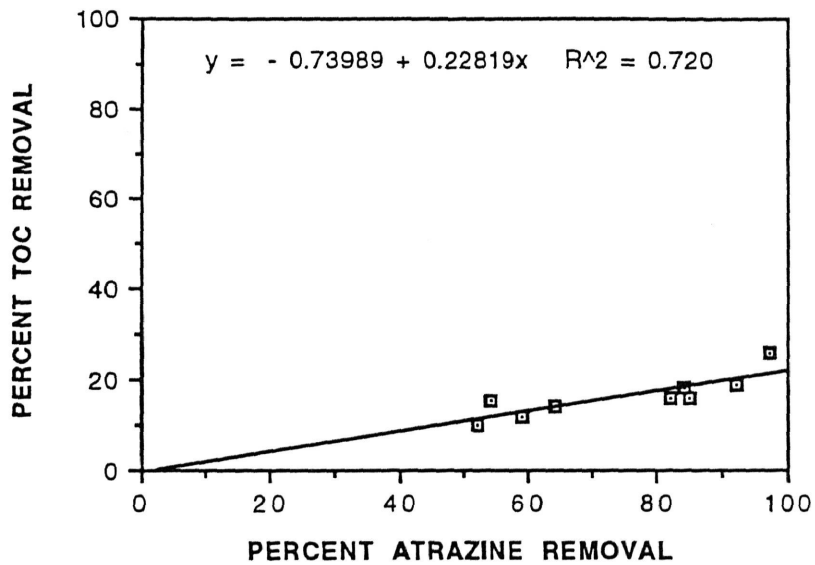
Figure 33.   Correlation Between TCR and Atrazine Removal for Filter #7

$y = 34.731 + 0.30279x$ $R^2 = 0.437$

PERCENT TCR REMOVAL (y-axis)

PERCENT ATRAZINE REMOVAL (x-axis)
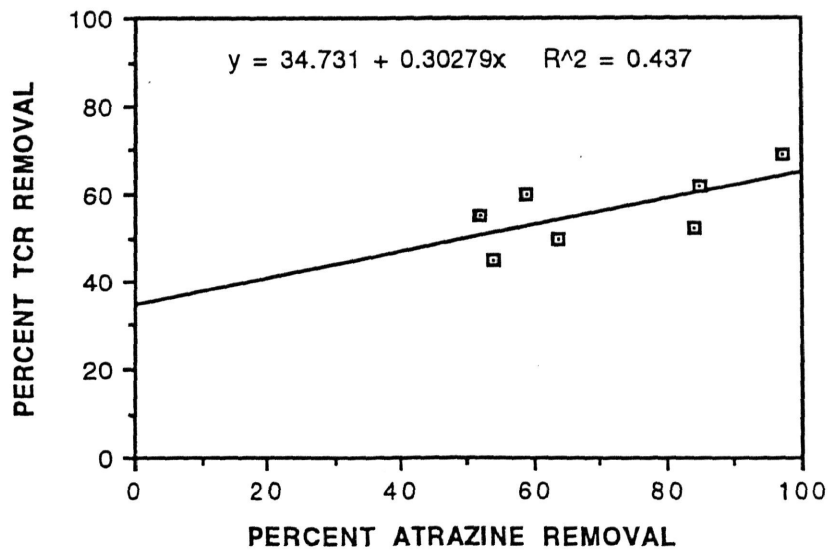
5.6 RESULTS OF PHYSICAL INSPECTION OF FILTER CARTRIDGES

Each filter cartridge was disassembled and physically inspected after use. No visible evidence of bacterial slimes or deposits was found on the activated carbon. Fabric sediment prefilters were brown colored, presumably from iron sediments. None of the seals or gaskets was found to be leaking or damaged.

CHAPTER 6

DISCUSSION

The adsorption process is controlled by both equilibrium and kinetic effects. Because of this, the performance of activated carbon filters will change as breakthrough criteria and water compositions change. All of the results in this study were obtained under specific test conditions. These results are not claimed to be definitive for each filter under all conditions.

6.1 OVERALL FILTER PERFORMANCE

All of the filters tested removed atrazine (CIET), hydroxyatrazine (OIET), and deethylatrazine (CIAT), as well as, or better than, total organic carbon (TOC) or total chlorine residual (TCR). Although TCR was less completely removed than atrazine, TCR reduction closely paralleled atrazine reduction over the life of the filter cartridges. Generally, TOC removal was poor.

6.1.1 REMOVAL OF ATRAZINE, HYDROXYATRAZINE, AND DEETHYLATRAZINE

Low concentrations ($\leq$ 0.7 µg/L) of OIET and CIAT were present in the tap water used to make challenge water. The mean concentration of atrazine in the challenge water was 12.3 µg/L. Tables 18, 19, 20, 21, and 23 show that Filters #3, #4, #5, #6, and #8 consistently removed more than 90 percent of the atrazine and 100 percent of the CIAT and OIET. All of these filters contained more than 500 grams of activated carbon. Tables 16, 17, and 22 indicate that Filters #1, #2, and #7 removed less than 90 percent of the influent atrazine and less than

100 percent of the influent OIET and CIAT. All of these filters contained less than 500 grams of activated carbon.

Figures 9, 10, and 15 suggest that removal of OIET was proportionally the same as atrazine removal. This indicates that OIET and CIET molecules were transported at about the same rate to the available adsorption sites. The lack of a sigmoidal breakthrough curve or adsorption "front" indicates that both compounds were readily adsorbable, but that insufficient contact time resulted in only fractional removal. Note that the influent CIET concentration was much greater than the influent OIET concentration. The fact that these two compounds were consistently removed in the same proportion indicates that there was little or no competition between them. There were insufficient data to further evaluate CIAT removal.

The atrazine breakthrough profiles presented in Figure 20 indicate that atrazine was readily adsorbed by all of the filters tested. Breakthroughs were gradual and linear. Significant initial atrazine breakthrough occurred for Filters #1 and #2 because the length of the mass transfer zone (MTZ) was greater than the available column length (i.e., there was insufficient carbon contact time). Filter #7 also had significant atrazine breakthrough early in the test period for the same reason.

Pseudomonas bacteria are known to colonize in activated carbon filters used to treat drinking water (Sandberg, 1977; Geldreich et al., 1985). Pseudomonas bacteria are also capable of utilizing atrazine as a carbon source (Behki and Khan, 1986). For Filters #1, #2, and #7, the effluent to influent atrazine concentration ratio continued to increase with the number of bed volumes treated rather than level off at a constant value. This indicated that atrazine removal by

biodegradation was not significant during these tests. Though the low concentration of methanol in the challenge water might have enhanced biological activity, this did not enhance atrazine removal. However, possible biological removal of a portion of the TOC was noted, even though there was a combined chlorine residual in the influent challenge water (this is discussed in Section 6.1.2). No evidence of bacterial slimes or deposits was found when the filters were opened and inspected.

6.1.2 TOTAL ORGANIC CARBON REMOVAL

Removal of total organic carbon (TOC) was generally poor. Figures 13 and 14 indicate that the exceptions were Filters #5 and #6, which maintained more than 45 percent reduction of TOC up to the last day of testing. This is attributed to a combination of the amount of carbon and the amount of contact time provided by these two filters, as well as design factors (discussed below in Section 6.2). Filter #5 provided the greatest amount of carbon (815 g) and the longest EBCT (56.4 sec) of all the filters tested.   Filter #6 provided 574 g of carbon and 41.1 sec of EBCT, placing it third in both categories among the filters tested. Several investigators (Perry et al., 1981; Cairo et al., 1980) have reported increased TOC removal when longer contact times are used. Theoretically, one would expect EBCT to be an important factor for TOC removal, since a substantial portion of TOC is presumed to be composed of large molecules (i.e., humic substances) that diffuse rather slowly.

Another factor may have been the type of carbon used in Filters #5 and #6. Badorek et al. (1980) reported distinct differences in TOC removal between various types of activated carbon. They found that activated carbon optimized for trihalomethane (THM) removal displayed

much lower TOC removal than other types of activated carbon. They suggested this was due to insufficient numbers of pores in the larger size range. Because of this, the larger TOC molecules were excluded from the majority of available adsorption sites.

The shapes of the breakthrough profiles, shown in Figure 21, give more insight on the adsorption behavior of TOC. Snoeyink (1990) interpreted similar curves. Comparing these curves to his example, there is evidence of a nonadsorbable fraction of TOC present in the challenge water (20 percent). There is also evidence of a biodegradable fraction (10-15 percent) represented by the steady-state removal reached after about 2500 bed volumes. The biodegradable fraction was probably the methanol (~12 percent of the challenge water TOC) added with the atrazine stock solution. The steep slopes of the breakthrough curves, close to the origin, indicate that the length of the mass transfer zone (MTZ) was much longer than the filter column lengths.

Cairo et al. (1980) reported that TOC removal was affected primarily by adsorption onto activated carbon in the initial weeks, and jointly by adsorption and biological activity after approximately four weeks. Biological activity was said to play the dominant role in sustaining long-term removal characteristics.

6.1.3 TOTAL CHLORINE RESIDUAL REMOVAL

The City of Lawrence, Kansas adds ammonia to all chlorinated, treated water to form a combined chlorine residual prior to distribution. The average pH of the challenge water was 8.3, indicating that most of the chlorine residual was in the form of monochloramine. This was confirmed by analysis.

Removal of total chlorine residual (TCR) was excellent ($\geq$ 90 percent) for Filters #3, #4, #5, #6, and #8. Filters #1 and #7 maintained more than 40 percent TCR reduction up to the conclusion of testing. Filter #2 was not very effective in removing TCR.

As shown in Figure 22, after the initial decline in performance, the level of TCR in the effluents of Filters #1, #2, #3, #4, #5, #7, and #8 fluctuated about certain values. One possible explanation for this behavior is that the reaction between the monochloramine and the activated carbon reached a steady state. Another possible explanation is that insufficient contact time was available for the reaction to proceed to completion for all the monochloramine present.

Suidan et al. (1980) observed that the reaction of monochloramine with activated carbon reached a steady state. They concluded that this steady state condition arose from the fact that monochloramine could undergo reduction through one of two mechanisms: 1. the conversion of monochloramine to ammonia conjunctive with oxidation of the carbon surface; and 2. the monochloramine reacting with surface oxides to produce nitrogen gas and thus regenerate the carbon. They also found that higher temperatures (35 °C versus 4.5 °C) significantly improved the removal of monochloramine by activated carbon.

J. M. Montgomery Consulting Engineers, Inc. (1985) reported that monochloramine (NH_2Cl) reacted with activated carbon more slowly than free chlorine ($HOCl$). To allow sufficient time for monochloramine to be removed, a greater amount of carbon is required.

6.2 FILTER DESIGN FACTORS

The filters that provided the most effective removal of atrazine,

TOC, and TCR had four things in common:

1. more than 500 grams of activated carbon;

2. an empty bed contact time in excess of 18 seconds;

3. good distribution of influent flow; and

4. a rated capacity of fewer than 5000 bed volumes.

The most complete removal of atrazine, TOC, and TCR was achieved by Filter #6. This filter used a PAC block-type cartridge, with radial flow towards the center of the block. At 160 percent of rated capacity (803 gallons throughput), the cumulative atrazine load for Filter #6 was 0.065 mg atrazine/g carbon.

The next best performer was Filter #3, also served by a PAC block-type cartridge, with radial flow toward the center. At 108 percent of rated capacity (811 gallons throughput), the cumulative atrazine load for Filter #3 was 0.066 mg atrazine/g carbon. It should be noted that Filter #3 was tested at a 1 gpm flow rate, twice that of Filter #6, and both had approximately the same size PAC carbon block.

Next came Filter #8 and Filter #4. These two filters were very similar in design. Both had two cartridges in series. Both had the same size (20 x 50 mesh) GAC. Both were rated for 1500 gallons. Filter #8 effluent had no detectable levels of atrazine, but Filter #4 effluent did. The one significant difference between the two was that Filter #8 had a PAC/fiber molded-block cartridge, followed by a GAC cartridge that ended with an additional short length of PAC/fiber block. Filter #4 had two GAC cartridges. Filter #8 was the most efficient carbon user of all the filters tested, accumulating 0.15 mg atrazine/g carbon without releasing any detectable concentration of atrazine.

Filter #4 was equipped with a flow totalizer and automatic shutoff valve. The unit was designed to turn off automatically after processing a set number of gallons. At the beginning of testing, the adjustment was set at 1500 gallons, the rated capacity of the filter. The unit actually turned off after processing only 960 gallons. The adjustment was reset and testing continued. Had the filter cartridges been replaced at this point, only one effluent sample would have had a detectable atrazine concentration.

Filter #8 was equipped with a flow totalizer and an indicator light. The unit displayed a green light when the filter was operated until a preset number of gallons was processed, then switched to red. The adjustment was set at 1500 gallons, the rated capacity. The indicator light changed from green to red after processing only 840 gallons. To get the green light to come back on, the batteries in the electronic control box had to be changed. Testing was then continued.

Filter #5 contained 815 g of activated carbon, more than any of the other filters. It had a single-stage, upflow cartridge. Table 20 reveals that trace concentrations of atrazine were found in the initial samples of filter effluent. Effluent concentrations gradually increased to about the 0.50 µg/L level, then stabilized. This behavior may have been due to channeling between the inside cylinder wall and the GAC or to leakage associated with the GAC mesh size (12 x 40) used.

Prior to attaining rated capacity, the effluent from Filters #1, #2, and #7 exceeded the 3 µg/L MCL for atrazine. Filter #7 was remarkable in that, with only 135 g of activated carbon, it outperformed Filter #1, which had 401 g of activated carbon. With an EBCT of only 8.7 seconds, Filter #7 reached a net cumulative atrazine load of 0.125 mg atrazine/g carbon before exceeding the MCL. Over

5000 bed volumes were treated by this small demo unit prior to exceeding 3.0 μg/L atrazine in the filter effluent. It appears that either the type of GAC used or the first stage KDF-55 cartridge enhanced the performance of the second stage GAC cartridge.

The main purpose of the KDF-55 cartridge is to remove chlorine and certain metal ions ahead of the GAC cartridge. Zinc or copper ions are exchanged in the process and the KDF-55 catalyst granules are gradually consumed. Figure 19 indicates that TCR was poorly removed by Filter #7 after only a few bed volumes. However, Figure 20 indicates more than a 90 percent reduction of atrazine concentration by Filter #7 after 2000 bed volumes; thus it is evident that atrazine removal was not significantly affected by TCR removal. Some other compound removed (or possibly added) by the KDF-55 granules may have enhanced atrazine removal.

Filter #7's rated capacity of 1500 gallons was based on removal of free chlorine. It is a prime example of how misleading the term "rated capacity" can be. Faust et al. (1990) reported that no correlation was observed between POU-filter rated capacity and removal performance for seven volatile organic compounds (VOCs). Unless the compound being tested has the same adsorptive and/or reactive characteristics as the compound originally used to determine the rated capacity, a correlation would be very unlikely.

Figure 20 clearly indicates that Filters #1 and #2 contained insufficient carbon to contain the length of mass transfer zone required for atrazine removal. Figures 23 and 24 show how the 3 μg/L MCL was exceeded with a net cumulative atrazine load of less than 0.05 mg atrazine/g carbon. Filters such as these do not use activated carbon in an effective and efficient manner.

6.3   STATISTICAL CORRELATION OF FILTER PERFORMANCE DATA

Only Filters #1, #2, and #7 yielded sufficient performance data for evaluating statistical correlations between atrazine removal and TOC removal, and between atrazine removal and TCR removal. Statistical analysis of the data (presented in Table 24) indicates a significant correlation between atrazine removal and TCR removal for Filters #1 and #2, but not for Filter #7. A significant correlation between TOC removal and atrazine removal was found for all three filters.

The t-test was used to determine the significance of the correlation coefficients. If the observed correlation coefficient is greater than a certain "critical" value, then it is assumed that a correlation between the variables is significantly greater than zero (Rohlf and Sokal, 1981). The higher the level of significance (i.e., 99% compared to 95%), the greater the critical value for the correlation coefficient.

The scatter plots presented in Figures 28-33 help illustrate the correlations determined from the data sets. The best correlations were obtained between TCR and atrazine removal for Filter #1 and between TOC and atrazine removal for Filter #7. Such correlations may prove useful for predicting atrazine removal based on measurement of TCR or TOC removal.

For all of the filters studied, virtually all of the data points lie below a line having a 1:1 slope (equal removal); hence, removal of TOC or TCR provides a conservative estimate of atrazine removal. The slopes (Table 24) were closer to unity for TCR vs. atrazine than for TOC vs. atrazine; hence, TCR removal appears to be better than TOC removal as a predictor of atrazine removal.

6.4   ENGINEERING SIGNIFICANCE

The data collected and presented in this thesis permit objective evaluation of the limitations and applicability of POU activated carbon filters in treating atrazine contaminated drinking water. Also, important design features are examined and qualified.

This information is immediately useful to POU filter manufacturers in their efforts to produce high quality products. For private and small community water supplies, this information provides a guide in selecting an effective and economical POU filter.

The limitations of POU activated carbon filters must be recognized in order to properly apply this water treatment alternative. The data presented here clearly indicate that timely replacement of filter cartridges is essential for good performance.

POU activated carbon filters do not use carbon efficiently. Single-stage units are particularly inefficient, since they must be completely replaced at the time the mass transfer zone (MTZ) begins to exit the filter. At this point, there may still be a great deal of capacity left in the carbon. The data indicate that when the MTZ for atrazine removal cannot be contained in the bed of activated carbon, little or no water of acceptable quality is produced. Because of this, treatment of an entire water supply should be done when truly hazardous contamination exists.

For private systems, or as an interim measure in small communities, POU systems for removing atrazine (and other SOCs) should be designed to provide a large amount of carbon, a long contact time, and a flow pattern that avoids short-circuiting.

CHAPTER 7

CONCLUSIONS

1. Consistent removal of atrazine challenge concentrations from 12.3 µg/L to nondetectable levels was achieved using PAC block-type or dual-cartridge POU filters.

2. Limited data suggest that hydroxyatrazine was removed as readily as atrazine.

3. Insufficient data were available to quantify removal of deethylatrazine. Low concentrations (≤ 0.5 µg/L) were removed to nondetectable levels by most of the POU filters tested.

4. Total organic carbon (TOC) levels of 3.0 mg/L were poorly reduced (less than 50 percent removal) by POU activated carbon filters.

5. Total chlorine residual (TCR) levels of 1 to 2 mg/L were reduced by 90 percent or more by sufficiently sized POU activated carbon filters.

6. The POU filters that provided the most effective removal of atrazine, TOC, and TCR had four things in common:
   * more than 500 grams of activated carbon;
   * empty bed contact time (EBCT) in excess of 18 seconds;
   * good distribution of influent flow; and
   * a rated capacity corresponding to fewer than 5000 bed volumes.

7.   Upflow granular activated carbon (GAC) filter cartridges are
      susceptible to flow channeling along the inside cylinder wall
      and/or within the GAC bed.

8.   To contain the mass transfer zone (MTZ) and maintain filter
      capacity for contaminant removal, there must be a sufficient
      amount of activated carbon present relative to the flow rate at
      which the system operates.

9.   Filter #7 achieved an unusually high loading of atrazine, perhaps
      due to the action of the proprietary KDF-55 copper/zinc compound
      or to use of a superior grade of GAC.

10.   For compliance with federal drinking water standards, POU
      activated carbon filters should be considered as interim measures
      of treatment.

11.   Ultimately, public water suppliers should be responsible for
      supplying properly treated, potable water to their consumers.

CHAPTER 8

FUTURE STUDIES

1. There is a need for adsorption isotherm data for the most commonly encountered atrazine metabolites: deethylatrazine, deisopropylatrazine, and hydroxyatrazine. Studies of dynamic equilibrium and order of elution (chromatographic behavior) for these compounds, in activated carbon columns, are also needed.

2. The effect of various periods of non-use, followed by periods of moderate to heavy use of POU filters, should be investigated.

3. The effect of high influent concentrations of atrazine, followed by low concentrations, should be determined.

4. Suitable surrogate parameters for atrazine, possibly chloramines, should be examined. A surrogate compound would serve to indicate when a POU filter cartridge requires replacement. Testing for chloramines is simple and inexpensive. Effluent chloramine levels may prove to be useful in predicting when cartridge replacement is needed to maintain atrazine removal performance.

5. Studies using higher levels of influent TOC and several different concentrations of atrazine would be useful for determining if atrazine may be complexed by poorly adsorbed TOC. Tests for this effect at different pH levels are also needed.

REFERENCES

1.   Adams, C. D., Randtke, S. J., Thurman, E. M., and Hulsey, R. A. (1990), "Occurrence and Treatment of Atrazine and its Degradation Products in Drinking Water", Proc. of the AWWA 1990 Annual Conf., June 1990, Cincinnati, OH.

2.   Adams, C. D. (1991), "Ozonation of Atrazine: A Kinetic Model and Byproduct Formation in Natural Waters", Doctoral Dissertation, Dept. of Civil Engg., Univ. of Kansas, Lawrence, Kansas.

3.   Adams, J. Q., Clark, R. M., and Miltner, R. J. (1989), "Controlling Organics With GAC: A Cost and Performance Analysis", *J. Amer. Water Works Assoc.*, **81:4**, pp. 132-140.

4.   Alben, K., Mathvet, L., Kaczmarczyk, J., Shpirt, E., Notthakun, S., Hand, D., and Crittenden, J. C. (1990), "Effect of Temperature on GAC Adsorption in Batch Systems and Predictions for Pilot-Scale Systems", Proc. of the AWWA 1990 Annual Conf., June 1990, Cincinnati, OH.

5.   Amer. Public Health Assoc. (APHA), Amer. Water Works Assoc., and Water Pollut. Control Fed. (1989), *Standard Methods for the Examination of Water and Wastewater, 17th Ed.*, American Public Health Association, Washington, D. C.

6.   Badorek, D. L., Thiem, L. T., and O'Connor, J. T. (1980), "Removal of Trihalomethanes and Total Organic Carbon from Drinking Water by Adsorption onto Several Granular Activated Carbons", Chap. 3 in *Activated Carbon Adsorption of Organics from the Aqueous Phase, Vol. 2*, edited by M. J. McGuire and I. H. Suffet, Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, pp. 71-84.

7.   Behki, R. M., and Khan, S. U. (1986), "Degradation of Atrazine by Pseudomonas: N-Dealkylation and Dehalogenation of Atrazine and its Metabolites", *J. Agric. Food Chem.*, **34**, pp. 746-749.

8.   Bell Jr., F. A., Perry, D. L., Smith, J. K., and Lynch, S. C. (1984), "Studies on Home Water Treatment Systems", *J. Amer. Water Works Assoc.*, 76:4, pp. 126-130.

9.   Cairo, P. R., Radziul, J. V., Coyle, J. T., Santo, J. P., Suffet, I. H., and McGuire, M. J. (1980), "The Application of Bench-scale and Pilot-scale Studies for Control of Chemical Contaminants in Drinking Water", Chap. 1 in *Activated Carbon Adsorption of Organics from the Aqueous Phase, Vol. 2*, edited by M. J. McGuire and I. H. Suffet, Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, pp. 3-26.

10.   Carney, E., Butler, M. K., and Hays, E. (1991), *"Atrazine in Kansas", 2nd Ed.*, Kansas Dept. of Health and Environment, Topeka, Kansas.

11.   Chiou, C. T. (1989), "Partition and Adsorption on Soil and Mobility of Organic Pollutants and Pesticides", Chap. 7 in *Toxic Organic Chemicals in Porous Media*, Ecology Studies Vol. 73, edited by Z. Gerstl, Y. Chen, U. Mingelgrin, and B. Yaron, Springer-Verlag, Berlin Heidelberg New York, pp. 163-175.

12.   Ciba-Geigy (1989), "Material Safety Data Sheet: Atrazine Technical", Ciba-Geigy Corp., Greensboro, North Carolina.

13.   Consumer Reports (1990), "Evaluation of Home Water Treatment Systems", **55:1**, pp. 33-42.

14.   Cook, A. M., and Hütter, R. (1981), "s-Triazines as Nitrogen Sources for Bacteria", *J. Agric. Food Chem.*, **29**, pp. 1135-1143.

15.   Cotruvo, J. A., and Vogt, C. D. (1990), "Rationale for Water Quality Standards and Goals", Chap. 1 in *Water Quality and Treatment: A Handbook of Community Water Supplies, 4th Ed.,* Amer. Water Works Assoc., edited by F. W. Pontius, McGraw-Hill, Inc., New York, pp. 1-62.

16.   Cowles, L. (1991), "Fourth Quarter Results, Pesticides in Drinking Water Study", *Nov. 5, 1991 Memorandum to Ralph Langemeier,* U.S. EPA, Region VII, Kansas City, Kansas.

17.   Crittenden, J. C., Hand, D. W., Arora, H., and Lykins Jr., B. W. (1987), "Design Considerations for GAC Treatment of Organic Chemicals", *J. Amer. Water Works Assoc.,* **79:1**, pp. 74-82.

18.   Crop Protection Chemicals Reference (1991), *7th Ed., Chemical and Pharmaceutical Press,* John Wiley & Sons, New York.

19.   DeWaters, J. E., and DiGiano, F. A. (1990), "The Influence of Ozonated Natural Organic Matter on the Biodegradation of a Micropollutant in a GAC Bed", *J. Amer. Water Works Assoc.,* **82:8**, pp. 69-75.

20.   Faust, S. D., Jen, A., Sanders, P. F., Mueller, R., Cotton, T., and Oxenford, J. (1990), "Evaluation of the Effectiveness of Ten Point-of-Use Domestic Activated Carbon Filtration Devices for the Removal of Seven Volatile Organic Contaminants From Drinking Water", Proc. from Nov. 1990 Water Quality Tech. Conf., San Diego, CA.

21.   Fornwalt, H. J., and Hutchins, R. A. (1966a), "Purifying Liquids with Activated Carbon", *Chemical Engineering,* April 11, 1966, pp. 179-184.

22.   Fornwalt, H. J., and Hutchins, R. A. (1966b), "Purifying Liquids
       with Activated Carbon", *Chemical Engineering*, May 9, 1966, pp.
       155-160.

23.   Geldreich, E. E., Taylor, R. H., Blannon, J. C., and Reasoner, D.
       J. (1985), "Bacterial Colonization of Point-of-Use Water
       Treatment Devices", *J. Amer. Water Works Assoc.*, **77:2**, pp. 72-80.

24.   Gianessi, L. P., and Puffer, C. (1991), "Herbicide Use in the
       United States", from a report by the Quality of the Environment
       Div. of Resources for the Future, Washington, D.C.

25.   Goolsby, D. A., Coupe, R. C., and Markovchick, D. J. (1991a),
       "Distribution of Selected Herbicides and Nitrate in the
       Mississippi River and its Major Tributaries, April Through June
       1991", U.S. Geological Survey Water-Resources Investigations
       Report 91-4163, Denver, CO.

26.   Goolsby, D. A., Thurman, E. M., and Kolpin, D. W. (1991b),
       "Herbicides in Streams: Midwestern United States", Proc. of July
       1991 Conf. Irrig. and Drainage Div. of ASCE, Honolulu, HI, pp.17-
       23.

27.   Horstmeier, G. (1993), "New Ink for Atrazine", *Farm Journal*, Jan.
       1993, pp. B-4 and B-5.

28.   James M. Montgomery Consulting Engineers, Inc. (1985), *Water
       Treatment Principles and Design*, John Wiley & Sons, New York.

29.   Kuennen, R. W., Van Dyke, K., Crittenden, J. C., and Hand, D. W.
       (1989), "Predicting the Multicomponent Removal of Surrogate
       Compounds by a Fixed-Bed Adsorber", *J. of Amer. Water Works
       Assoc.*, **81:12**, pp. 46-58.

30.   Lee, M. C., Snoeyink, V. L., and Crittenden, J. C. (1981),
      "Activated Carbon Adsorption of Humic Substances", *J. of Amer.
      Water Works Assoc.*, **73:8**, pp. 440-446.

31.   Lykins Jr., B. W., Clark, R. M., and Goodrich, J. A. (1992),
      Point-of-use/Point-of-entry for Drinking Water Treatment, Lewis
      Publishers, Inc., Chelsea, Michigan.

32.   McCreary, J. J., and Snoeyink, V. L. (1977), "Granular Activated
      Carbon in Water Treatment", *J. of Amer. Water Works Assoc.*, **69:8**,
      pp. 437-443.

33.   Miltner, R. J., Baker, D. B., Speth, T. F., and Fronk, C. A.
      (1989), "Treatment of Seasonal Pesticides in Surface Waters", *J.
      of Amer. Water Works Assoc.*, **81:1**, pp. 43-52.

34.   Najm, I. S., Snoeyink, V. L., and Richard, Y. (1991), "Effect of
      Initial Concentration of a SOC in Natural Water on its Adsorption
      by Activated Carbon", *J. of Amer. Water Works Assoc.*, **83:8**, pp.
      57-63.

35.   National Sanitation Foundation (1990), *Standard 53-1990: Drinking
      Water Treatment Units - Health Effects*, NSF International, Ann
      Arbor, Michigan.

36.   Pereira, W. E., and Rostad, C. E. (1990), "Occurrence,
      Distributions, and Transport of Herbicides and Their Degradation
      Products in the Lower Mississippi River and its Tributaries",
      Environ. Sci. Technol., **24:9**, pp. 1400-1406.

37.   Perry, D. L., Smith, J. K., and Lynch, S. C. (1981), "Development
      of Basic Data and Knowledge Regarding Organic Removal
      Capabilities of Commercially Available Home Water Treatment Units
      Utilizing Activated Carbon: Phase 3/Final Report, Phase
      3/Addendum, Phase 3/Supplemental Data", report to USEPA by Gulf

South Research Institute, New Orleans, LA, NTIS: PB82-159633, PB82-159641, PB82-159658.

38.   Perry, D. L., Smith, J. K., and Lynch, S. C. (1980), "Development of Basic Data and Knowledge Regarding Organic Removal Capabilities of Commercially Available Home Water Treatment Units Utilizing Activated Carbon: Phase 2/Interim Report, Phase 2/Supplemental Data", report to USEPA by Gulf South Research Institute, New Orleans, LA, NTIS: PB82-159617, PB82-159625.

39.   Plowman Jr., H. L., and Rademacher, J. M. (1958), "Persistence of Combined Available Chlorine Residual in Gary-Hobart Distribution System", *J. of Amer. Water Works Assoc.*, **50:9**, pp. 1250-1258.

40.   Pontius, F. W. (1990), "Complying With the New Drinking Water Quality Regulations", *J. of Amer. Water Works Assoc.*, **82:2**, pp. 32-52.

41.   Randtke, S. J., and Snoeyink, V. L. (1983), "Evaluating GAC Adsorptive Capacity", *J. of Amer. Water Works Assoc.*, **75:8**, pp. 406-413.

42.   Reasoner, D. J., Blannon, J. C., and Geldreich, E. E. (1987), "Microbiological Characteristics of Third-Faucet Point-of-Use Devices", *J. of Amer. Water Works Assoc.*, **79:10**, pp. 60-66.

43.   Regehr, D. L., Peterson, D. E., and Hickman, J. S. (1992), "Questions & Answers About Atrazine", Kansas State University Cooperative Extension Service Bulletin, KSU, Manhattan, Kansas.

44.   Regunathan, P., Beauman, W. H., and Kreusch, E. G. (1983), "Efficiency of Point-of-Use Treatment Devices", *J. of Amer. Water Works Assoc.*, **75:1**, pp. 42-50.

45. Roberts, P. V., and Summers, R. S. (1982), "Performance of Granular Activated Carbon for Total Organic Carbon Removal", *J. of Amer. Water Works Assoc.*, **74:2**, pp. 113-118.

46. Rohlf, F. J., Sokal, R. R. (1981), *Statistical Tables, 2nd Ed.*, W. H. Freeman and Co., San Francisco, pp. 166-168.

47. Sandberg, N. (1977), "Bacteriological Evaluation of Home Activated Carbon Filter", M. S. thesis, Dept. of Civil Engg., University of Kansas, Lawrence, Kansas.

48. Senesi, N., Chen, Y. (1989), "Interactions of Toxic Organic Chemicals with Humic Substances", Chap. 3 in *Toxic Organic Chemicals in Porous Media*, Ecology Studies Vol. 73, edited by Z. Gerstl, Y. Chen, U. Mingelgrin, and B. Yaron, Springer-Verlag, Berlin Heidelberg New York, pp. 37-90.

49. Sigworth, E. A., and Smith, S. B. (1972), "Adsorption of Inorganic Compounds by Activated Carbon", *J. of Amer. Water Works Assoc.*, **64:6**, pp. 386-391.

50. Smith, J. K., Lynch, S. C., Gebhart, J., and Monteith, C. S. (1979), "Development of Basic Data and Knowledge Regarding Organic Removal Capabilities of Commercially Available Home Water Treatment Units Utilizing Activated Carbon: Phase 1/Preliminary Report, Phase 1/Supplemental Data", report to USEPA by Gulf South Research Institute, New Orleans, LA, NTIS: PB82-159591, PB82-159609.

51. Snoeyink, V. L. (1990), "Adsorption of Organic Compounds", Chap. 13 in *Water Quality and Treatment: A Handbook of Community Water Supplies, 4th Ed.*, Amer. Water Works Assoc., edited by F. W. Pontius, McGraw-Hill, Inc., New York, pp. 781-875.

52.   Speitel Jr., G. E., Turahia, M. H., and Lu, C. (1989),
      "Initiation of Micropollutant Biodegradation in Virgin GAC
      Columns", *J. of Amer. Water Works Assoc.*, **81:4**, pp. 168-176.

53.   Speth, T. F., and Miltner, R. J. (1990), "Technical Note:
      Adsorption Capacity of GAC for Synthetic Organics", *J. of Amer.
      Water Works Assoc.*, **82:2**, pp. 72-75.

54.   Speth, T. F. (1990), "The Removal of Glyphosate from Drinking
      Water", Proc. of the AWWA 1990 Annual Conf., June 1990,
      Cincinnati, OH.

55.   Squillace, P. J., and Thurman, E. M. (1992), "Herbicide Transport
      in Rivers: Importance of Hydrology and Geochemistry in Nonpoint-
      Source Contamination", *Environ. Sci. Technol.*, **26:3**, pp. 538-545.

56.   Stacha, J. H., and Pontius, F. W. (1984), "An Overview of Water
      Treatment Practices in the United States", *J. of Amer. Water
      Works Assoc.*, **76:10**, pp. 73-85.

57.   Suidan, M. T., Kim, B. R., and Snoeyink, V. L. (1980), "Reduction
      of Free and Combined Chlorine with Granular Activated Carbon",
      Chap. 19 in *Activated Carbon Adsorption of Organics from the
      Aqueous Phase, Vol. 1*, edited by M. J. McGuire and I. H. Suffet,
      Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, pp. 397-
      423.

58.   Taylor, R. H., Allen, M. J., and Geldreich, E. E. (1979),
      "Testing of Home Use Carbon Filters", *J. Amer. Water Works
      Assoc.*, **71:10**, pp. 577-579.

59.   Thurman, E. M., Goolsby, D. A., Meyer, M. T., and Kolpin, D. W.
      (1991), "Herbicides in Surface Waters of the Midwestern United
      States: The Effect of Spring Flush", *Environ. Sci. Technol.*,
      25:10, pp. 1794-1796.

60.   Tucker, G. J. (1978), "Evaluation of Chloroform Removal from Drinking Water by Home Activated Carbon Filters", M. S. thesis, Dept. of Civil Engg., University of Kansas, Lawrence, Kansas.

61.   USEPA Office of Drinking Water Health Advisories, *Drinking Water Health Advisory: Pesticides (1989)*, Lewis Publishers, Inc., Chelsea, Michigan.

62.   Van Dyke, K., and Kuennen, R. W. (1987), "Performance and Applications of Granular Activated Carbon Point-of-Use Systems", published in EPA Conference Proceedings, EPA/600/9-88/012, June 1988.

63.   Wang, Z., Gamble, D. S., and Cooper, H. L. (1992), "Interaction of Atrazine with Laurentian Soil", *Environ. Sci. Technol.*, **26:3**, pp. 560-565.

64.   Weber Jr., W. J. (1972), *Physicochemical Processes for Water Quality Control*, John Wiley & Sons, New York.

65.   Witt, A. A. (1992), "The Occurrence and Fate of Atrazine and Atrazine Degradation Products in Drinking Water", M. S. thesis, Dept. of Civil Engg., University of Kansas, Lawrence, Kansas.

66.   Wulfkuhle, B. (1992), telephone conversation with farmer Bret Wulfkuhle, regarding field application of atrazine.

67.   Yohe, T. L., Suffet, I. H., and Cairo, P. R. (1981), "Specific Organic Removals by Granular Activated Carbon Pilot Contactors", *J. of Amer. Water Works Assoc.*, **73:8**, pp. 402-410.

APPENDIX A

CALCULATION OF MAXIMUM CONTAMINANT LEVEL

FOR ATRAZINE

CALCULATION OF MAXIMUM CONTAMINANT LEVEL

FOR ATRAZINE

The following calculation procedure was adapted from *Drinking Water Health Advisory: Pesticides* (USEPA, 1989):

Step 1:   The No Observed Adverse Effect Level (NOAEL), in the most sensitive species tested, is used to calculate the reference dose, RfD. For atrazine, the NOAEL of 0.48 mg/kg/day that was determined for a 1-year dog study using Atrazine Technical, reported in 1987 by Ciba-Geigy (97% active ingredient), is used by EPA. An uncertainty factor of 100 is used to calculate the Rfd, since good chronic toxicity data identifying a NOAEL are available for more than one species, but not for humans.

$$Rfd = (NOAEL)/100$$

$$Rfd = 0.48 \text{ mg/kg/day} \div 100$$

$$Rfd = 0.0048 \text{ mg/kg/day}$$

Step 2:   The RfD is adjusted for an adult, with an assumed body weight of 70 kg, consuming 2 liters of water per day to produce the Drinking Water Equivalent Level (DWEL).

$$DWEL = (RfD \times 70 \text{ kg}) + (2 \text{ L/day})$$

$$DWEL = (0.0048 \times 70) \div 2$$

$$DWEL = 0.168 \text{ mg/L}$$

The DWEL represents the concentration of a substance in drinking water that is not expected to cause any adverse noncarcinogenic health effects in humans over a lifetime of exposure. The DWEL is calculated assuming that all exposure to the chemical comes from drinking water.

Step 3:   The lifetime health advisory (HA) or maximum contaminant level goal (MCLG) is calculated by reducing the DWEL, in proportion to the amount of exposure from drinking water, relative to other sources (e.g. food, air). In the absence of actual exposure data, this relative source contribution (RSC) is generally assumed to be 20 percent.

A study submitted by Ciba-Geigy in 1986, indicated that atrazine induced an increase in mammary tumors in female Sprague-Dawley rats. Applying the EPA criteria for assessment of carcinogenic risk, atrazine may be classified in Group C: possible human carcinogen. For chemicals classified in Group C, EPA applies an additional 10-fold uncertainty factor when deriving a lifetime HA.

Lifetime HA or MCLG = DWEL x RSC + 10

MCLG = 0.168 mg/L x 0.20 ÷ 10

MCLG = 0.0034 mg/L

Step 4:   The value calculated for the MCLG is then presented in µg/L and is generally rounded to one significant figure.

MCLG = 0.0034 mg/L x 1000 µg/mg = 3 µg/L

The 1986 Amendments to the Safe Drinking Water Act (SDWA) require the EPA to set MCLGs for many contaminants found in drinking water. These MCLGs must provide adequate safety margins to prevent adverse effects on human health. For each contaminant the EPA sets a MCLG; it also must establish a maximum contaminant level (MCL) that is as close to the MCLG as is feasible with the use of best available technology (BAT) (Lykins et al., 1992). Whereas HAs and MCLGs are recommendations, not enforceable standards, MCLs are enforceable standards. For atrazine, the MCL of 3 µg/L became the enforceable standard in July, 1992.

APPENDIX B

DATA COLLECTED DURING

FILTER PERFORMANCE TESTING

ANALYSIS OF TANK FILL

DATE	BATCH #	TCR (mg/L)	TOC (mg/L)	CIET (ppb)	OIET (ppb)	CIAT (ppb)	TEMP. (°C)
1/28/92	J92-28	2.20	3.14	0.50	0.68	T	
2/16/92	F92-16		2.95	0.52	0.64	0.25	
2/20/92	F92-20	2.00	2.95	0.70	0.68	0.22	
3/4/92	M92-4	2.10	2.74	0.69	0.51	0.40	
3/28/92	M92-28	1.95	2.15	0.56	0.53	0.23	14.0
4/4/92	A92-4		2.13	0.42	0.48	0.48	15.0
4/7/92	A92-7	1.60	2.01	0.33	0.50	0.34	
4/15/92	A92-15	1.60	2.03	0.45	0.55	0.32	16.5
4/23/92	A92-23	2.30	3.57	0.56	0.70	0.30	15.0
4/30/92	A92-30	2.00	2.15	0.44	0.53	0.47	16.0
5/4/92	MY92-4	1.80	3.38	0.63	0.67	0.21	17.5

ANALYSIS OF TANK DISCHARGE

DATE	BATCH #	TCR (mg/L)	TOC (mg/L)	TOTAL ALKALINITY (mg/L)	pH	TEMP. (°C)	CIET (ppb)	OIET (ppb)	CIAT (ppb)
1/4/92	J92-2	1.00	3.41	80.0	8.25		12.43	0.56	T
1/7/92	J92-5	1.35	3.73		8.20	19.0	13.20	0.64	T
1/11/92	J92-9	1.80	3.43	81.0	8.20	20.0	13.69	0.55	T
1/12/92	J92-9	1.40	3.37	82.5	8.20	20.0	12.53	0.49	T
1/15/92	J92-13	1.60	3.54	77.0	8.35	20.0	13.73	0.67	0.23
1/16/92	J92-13	1.30	3.64		8.30	21.0	12.64	0.68	T
1/19/92	J92-17	1.60	3.47	77.0	8.25	19.0	12.78	0.49	T
1/20/92	J92-17	1.20	3.49	77.0	8.20	20.0	12.34	0.51	0.40
1/25/92	J92-23	0.80	3.39	74.0	8.40	18.0	11.48	0.66	0.35
1/27/92	J92-23	0.50	3.45	74.0	8.32	20.0	10.44	0.81	0.56
1/31/92	J92-28	1.20	3.53	76.0	8.33	21.0	10.87	0.68	0.25
2/1/92	J92-28	0.85	3.43			22.0	12.81	0.66	0.20
2/5/92	F92-4	1.10	3.50	75.0	8.36	19.0	13.02	0.58	0.22
2/7/92	F92-4	0.55	3.48	75.0	8.30	21.0	12.84	0.52	0.29
2/10/92	F92-8		3.18	74.0	8.36	19.0	13.15	0.51	0.36
2/13/92	F92-8	0.20	3.14			22.0	12.52	0.55	0.29
2/15/92	F92-14	1.70	3.18	71.0	8.57	15.0	13.63	0.65	T
2/16/92	F92-14	1.30	3.22	72.0	8.53	19.0	13.56	0.63	0.21
2/17/92	F92-16		3.20	69.0	8.42	16.0	13.18	0.54	0.24
2/18/92	F92-16	0.35	3.30	67.0		18.0	13.23	0.55	0.25
2/19/92	F92-18	1.35	3.37	70.0	8.44	16.0	13.03		
2/20/92	F92-18	0.80	3.33			19.0	13.03	0.58	0.26
2/21/92	F92-20	1.50	3.43	72.0	8.39	16.0	13.31	0.70	0.21
2/22/92	F92-20	1.15	3.51	72.0	8.39	19.0	13.18	0.71	0.34
2/29/92	F92-27		3.15	61.0	7.93	21.0	13.05	0.57	0.57
3/1/92	F92-27		3.10			22.0	12.88	0.59	0.51
3/3/92	M92-2	0.65	3.05	58.0	8.18	21.0	13.37	0.55	0.56
3/4/92	M92-2	0.30	3.07			24.0	12.96	0.45	0.49
3/5/92	M92-4	1.15	3.18	62.0	8.27	20.0	13.66	0.54	0.34
3/6/92	M92-4	0.65	3.16	62.0	8.25	22.0	13.28	0.53	0.55
3/9/92	M92-7		3.39		8.40	24.0	12.68		
3/10/92	M92-7		3.37			23.0	12.68	0.58	0.33
3/11/92	M92-10		3.37		8.31	19.0	12.72		
3/12/92	M92-10		3.42			20.0	12.72	0.63	0.35
3/16/92	M92-14	0.80	3.47	75.0	8.31	20.0	10.55	0.51	0.38
3/17/92	M92-14	0.45	3.43	74.0	8.32	22.0	12.30	0.57	0.21
3/19/92	M92-18		2.87		8.20	19.0	13.20		
3/20/92	M92-18		2.80		8.30	23.0	13.20	0.54	0.48
3/21/92	M92-20		2.86		8.42	19.0	13.36		
3/22/92	M92-20	1.10	2.85	72.0	8.06	20.0	13.36	0.62	0.26
3/23/92	M92-22	1.80	2.82		8.70	17.0	13.52	0.59	0.34

ANALYSIS OF TANK DISCHARGE

DATE	BATCH #	TCR (mg/L)	TOC (mg/L)	TOTAL ALKALINITY (mg/L)	pH	TEMP. (°C)	CIET (ppb)	OIET (ppb)	CIAT (ppb)
3/24/92	M92-22	1.30	2.85	66.0	8.28	19.0	13.36	0.63	0.36
3/25/92	M92-24		3.07		8.33	18.0	10.81		
3/26/92	M92-24	0.70	2.96	64.0	7.92	19.0	10.81	0.54	0.33
3/27/92	M92-26	1.50	2.74		8.35	17.0	12.29	0.47	0.30
3/28/92	M92-26	1.00	2.74	54.5	8.08	19.0	12.15	0.62	0.34
3/30/92	M92-28	0.65	2.61		8.07	19.0	11.71	0.58	0.39
3/31/92	M92-28	0.30	2.59	42.0	8.00	20.0	11.68	0.62	0.40
4/1/92	M92-31		2.69		8.02	18.0	11.36		
4/2/92	M92-31		2.60	53.0	7.95	20.0	11.36	0.53	0.34
4/3/92	A92-2		2.23			18.0	11.50		
4/4/92	A92-2		2.25	46.0	8.11	21.0	11.50	0.54	0.54
4/6/92	A92-4		2.64			21.0	12.13		
4/7/92	A92-4		2.73	56.0	8.20	23.0	12.13	0.52	0.34
4/8/92	A92-7	1.00	2.31	36.0	7.94	19.0	11.97	0.43	0.60
4/9/92	A92-7		2.34	35.5	7.85	21.0	11.64	0.43	0.58
4/10/92	A92-9	1.20	2.28			21.0	11.13		
4/11/92	A92-9	0.60	2.24	37.0	8.00	22.0	11.13	0.48	0.60
4/12/92	A92-11		2.21	45.5	8.43	18.0	11.96		
4/13/92	A92-11		2.04	44.0	8.18	20.0	11.96	0.48	0.35
4/16/92	A92-15	1.00	2.25	39.0	8.13	20.0	11.33	0.49	0.67
4/18/92	A92-15	0.40	2.28	39.0	8.06	22.0	11.58	0.46	0.44
4/20/92	A92-18		2.25		8.38	22.0	10.71		
4/21/92	A92-18	0.20	2.28	35.5	8.10	21.0	10.71	0.59	0.31
4/22/92	A92-21		3.74			19.0	11.61		
4/23/92	A92-21	0.70	3.83	95.5	8.24	20.0	11.61	0.64	0.28
4/25/92	A92-23	1.55	3.81	99.0	8.25	20.0	11.42	0.70	0.42
4/25/92	A92-23		3.83	98.0	8.18	20.5	12.07	0.67	0.39
4/26/92	A92-25		2.37		8.20	18.0	11.56		
4/27/92	A92-25		2.31	37.0	8.00	20.0	11.56	0.49	0.22
4/28/92	A92-27		2.25			20.0	11.01		
4/29/92	A92-27	0.50	2.23	42.5	8.23	21.0	11.01	0.40	0.41
5/1/92	A92-30	1.60	2.37	69.0	8.92	21.0	11.13	0.51	0.35
5/2/92	A92-30	1.10	2.42	68.5	8.87	23.0	11.28	0.49	0.52
5/3/92	MY92-2		2.53			19.0	11.39		
5/4/92	MY92-2	0.60	2.53	68.0	8.56	21.0	11.39	0.68	0.46
5/5/92	MY92-4	1.30	3.21	77.0	8.38	21.0	11.93	0.60	0.38
5/6/92	MY92-4	0.70	3.23	77.0	8.32	21.0	11.34	0.54	0.34

TCR = TOTAL COMBINED CHLORINE RESIDUAL; TOC = TOTAL ORGANIC CARBON
CIET = ATRAZINE; OIET = HYDROXYATRAZINE; CIAT = DEETHYLATRAZINE
ND = "NOT DETECTED" = LESS THAN 0.1 PPB; T = "TRACE" = LESS THAN 0.2 PPB

EFFLUENT ANALYSIS FOR FILTER #1
(INSTAPURE IF-10 UNDERSINK MODEL)

DATE	TOTAL VOLUME TREATED (gallons)	TOTAL ATRAZINE LOAD (mg)	TCR (mg/L)	TCR OUT:IN	TOC (mg/L)	TOC OUT:IN	CIET (ppb)	CIET OUT:IN	OIET (ppb)	OIET OUT:IN	CIAT (ppb)	CIAT OUT:IN
1/4/92	41.9	1.97	0.20	0.20	2.04	0.60	1.95	0.16	T		ND	0.00
1/7/92	82.6	4.00										
1/11/92	102.6	5.04										
1/12/92	123.2	6.02	0.35	0.25	2.36	0.70						
1/15/92	143.8	7.09										
1/16/92	164.3	8.07	0.25	0.19	2.50	0.69	2.10	0.17	T		ND	0.00
1/19/92	184.8	9.06			2.58	0.74						
1/20/92	205.1	10.01	0.30	0.25	2.77	0.79						
1/25/92	225.5	10.90										
1/27/92	245.8	11.70										
1/31/92	266.3	12.54										
2/1/92	287.3	13.56	0.25	0.29	2.56	0.75	2.21	0.17	T		T	
2/5/92	307.2	14.54										
2/7/92	327.8	15.55	0.15	0.27	2.62	0.75						
2/10/92	348.2	16.56										
2/13/92	368.4	17.52										
2/15/92	388.6	18.56										
2/16/92	408.5	19.58	0.40	0.31	2.52	0.78						
2/17/92	428.6	20.58										
2/18/92	448.7	21.59										
2/19/92	468.8	22.58										
2/20/92	489.0	23.58										
2/21/92	508.9	24.58										
2/22/92	528.7	25.57	0.45	0.39	2.72	0.77	3.20	0.24	0.21	0.29	T	
2/29/92	548.9	26.57										
3/1/92	570.1	27.60										
3/3/92	590.2	28.62										
3/4/92	610.2	29.60										
3/5/92	630.3	30.64										
3/6/92	650.7	31.66	0.25	0.38	2.57	0.81	3.35	0.25	T		T	
3/9/92	670.9	32.63										
3/10/92	690.8	33.59										
3/11/92	710.9	34.55										
3/12/92	731.2	35.53										
3/16/92	751.6	36.35										
3/17/92	771.6	37.28	0.20	0.44	2.93	0.86	3.27	0.27	T		ND	0.00
3/19/92	792.0	38.30										
3/20/92	812.2	39.31										
3/21/92	832.3	40.32										
3/22/92	852.5	41.35										
3/23/92	872.6	42.37										

EFFLUENT ANALYSIS FOR FILTER #1
(INSTAPURE IF-10 UNDERSINK MODEL)

DATE	TOTAL VOLUME TREATED (gallons)	TOTAL ATRAZINE LOAD (mg)	TCR (mg/L)	TCR OUT:IN	TOC (mg/L)	TOC OUT:IN	CIET (ppb)	CIET OUT:IN	OIET (ppb)	OIET OUT:IN	CIAT (ppb)	CIAT OUT:IN
3/24/92	892.6	43.39	0.50	0.38	2.37	0.83	4.52	0.34	T		T	
3/25/92	912.7	44.21										
3/26/92	932.8	45.03										
3/27/92	952.9	45.96										
3/28/92	972.9	46.89										
3/30/92	993.0	47.78										
3/31/92	1,013.2	48.67	0.25	0.83	2.24	0.87	4.16	0.36	0.25	0.41	T	
4/1/92	1,033.6	49.55										
4/2/92	1,053.7	50.41										
4/3/92	1,073.9	51.29										
4/4/92	1,094.1	52.17										
4/6/92	1,114.1	53.09										
4/7/92	1,134.2	54.01										
4/8/92	1,154.3	54.92	0.40	0.40	2.08	0.90	4.58	0.38	T		ND	0.00
4/9/92	1,174.8	55.83										
4/10/92	1,194.8	56.67										
4/11/92	1,215.1	57.52										
4/12/92	1,235.3	58.44										
4/13/92	1,255.7	59.36										
4/16/92	1,276.0	60.23										
4/18/92	1,296.2	61.12	0.20	0.50	1.91	0.84	4.42	0.38	0.24	0.51	T	
4/20/92	1,316.4	61.94										
4/21/92	1,336.7	62.76										
4/22/92	1,356.9	63.65										
4/23/92	1,377.3	64.54										
4/25/92	1,397.3	65.41	0.60	0.39	3.09	0.81	4.85	0.42	0.30	0.43	ND	0.00
4/25/92	1,417.8	66.35										
4/26/92	1,437.9	67.22										
4/27/92	1,458.0	68.10										
4/28/92	1,478.2	68.94										
4/29/92	1,498.4	69.79										
5/1/92	1,518.6	70.64										
5/2/92	1,539.1	71.51	0.50	0.45	1.98	0.82	4.81	0.43	0.27	0.54	T	
5/3/92	1,559.1	72.38										
5/4/92	1,579.3	73.25										
5/5/92	1,599.4	74.15										
5/6/92	1,619.7	75.03	0.40	0.57	2.78	0.86	4.93	0.43	0.24	0.45	T	

TCR = TOTAL COMBINED CHLORINE RESIDUAL; TOC = TOTAL ORGANIC CARBON
CIET = ATRAZINE; OIET = HYDROXYATRAZINE; CIAT = DEETHYLATRAZINE
ND = "NOT DETECTED" = LESS THAN 0.1 PPB; T = "TRACE" = LESS THAN 0.2 PPB

EFFLUENT ANALYSIS FOR FILTER #2
(INSTAPURE F-2C FAUCET-MOUNT)

DATE	TOTAL VOLUME TREATED (gallons)	TOTAL ATRAZINE LOAD (mg)	TCR (mg/L)	TCR OUT:IN	TOC (mg/L)	TOC OUT:IN	CIET (ppb)	CIET OUT:IN	OIET (ppb)	OIET OUT:IN	CIAT (ppb)	CIAT OUT:IN
1/4/92	12.9	0.61	0.50	0.50	2.77	0.81	3.82	0.31	T		T	
1/7/92	24.2	1.17										
1/11/92	29.6	1.45	1.00	0.56								
1/12/92	34.9	1.70	0.80	0.57	2.93	0.87	5.10	0.41	T		T	
1/15/92	40.2	1.98	0.95	0.59	2.99	0.84	5.46	0.40	0.28	0.42	ND	0.00
1/16/92	45.2	2.22	0.80	0.62	3.05	0.84	5.49	0.43	0.30	0.45	T	
1/19/92	50.2	2.46			3.02	0.87						
1/20/92	55.6	2.71	0.80	0.67	3.51	1.00						
1/25/92	60.4	2.92										
1/27/92	65.4	3.12										
1/31/92	70.4	3.32										
2/1/92	75.4	3.57	0.50	0.59	3.18	0.93	5.49	0.43	0.28	0.43	T	
2/5/92	80.6	3.82										
2/7/92	85.3	4.05	0.40	0.73	2.98	0.86						
2/10/92	90.3	4.30										
2/13/92	95.1	4.53			2.80	0.89	6.43	0.51	0.24	0.44	T	
2/15/92	100.0	4.78										
2/16/92	105.1	5.04	0.90	0.69	3.00	0.93						
2/17/92	110.3	5.30										
2/18/92	115.4	5.56										
2/19/92	120.5	5.81										
2/20/92	125.6	6.06										
2/21/92	130.5	6.31										
2/22/92	135.5	6.56	0.90	0.78	3.07	0.88	7.40	0.56	0.41	0.57	T	
2/29/92	140.4	6.80										
3/1/92	145.4	7.04										
3/3/92	150.4	7.30										
3/4/92	155.5	7.54	0.20	0.67	2.79	0.91						
3/5/92	160.5	7.80										
3/6/92	165.4	8.05	0.55	0.85	2.91	0.92	7.25	0.55	0.32	0.60	0.31	0.56
3/9/92	170.1	8.28										
3/10/92	175.1	8.52										
3/11/92	180.0	8.75										
3/12/92	184.9	8.99										
3/16/92	189.8	9.18										
3/17/92	194.8	9.42	0.35	0.78	3.24	0.95	6.99	0.57	0.32	0.57	ND	0.00
3/19/92	199.7	9.66										
3/20/92	204.5	9.90			2.64	0.94						
3/21/92	209.4	10.15										
3/22/92	214.2	10.39	0.80	0.73	2.61	0.92						
3/23/92	219.1	10.64										

EFFLUENT ANALYSIS FOR FILTER #2
(INSTAPURE F-2C FAUCET-MOUNT)

DATE	TOTAL VOLUME TREATED (gallons)	TOTAL ATRAZINE LOAD (mg)	TCR (mg/L)	TCR OUT:IN	TOC (mg/L)	TOC OUT:IN	CIET (ppb)	CIET OUT:IN	OIET (ppb)	OIET OUT:IN	CIAT (ppb)	CIAT OUT:IN
3/24/92	224.1	10.89	1.00	0.77	2.63	0.92	9.12	0.68	0.41	0.66	0.33	0.91
3/25/92	228.8	11.09										
3/26/92	233.7	11.29										
3/27/92	238.5	11.51										
3/28/92	243.3	11.73										
3/30/92	248.2	11.95										
3/31/92	252.9	12.16	0.30	1.00	2.39	0.92	8.34	0.71	0.36	0.58	T	
4/1/92	258.0	12.37										
4/2/92	262.9	12.58										
4/3/92	267.9	12.80										
4/4/92	272.8	13.02										
4/6/92	277.5	13.23										
4/7/92	282.5	13.47										
4/8/92	287.4	13.69	0.60	0.60	2.18	0.95	8.53	0.71	0.29	0.69	T	
4/9/92	292.4	13.91										
4/10/92	297.4	14.12										
4/11/92	302.3	14.32										
4/12/92	307.3	14.55										
4/13/92	312.2	14.77										
4/16/92	317.1	14.98										
4/18/92	322.1	15.20	0.35	0.88	2.03	0.89	7.70	0.67	0.31	0.66	0.31	0.71
4/20/92	327.0	15.40										
4/21/92	332.1	15.60										
4/22/92	337.1	15.82										
4/23/92	342.0	16.04										
4/25/92	347.1	16.26	1.15	0.74	3.36	0.88	8.41	0.74	0.48	0.70	0.22	0.51
4/25/92	351.9	16.48										
4/26/92	356.8	16.70										
4/27/92	361.8	16.92										
4/28/92	366.7	17.12										
4/29/92	371.6	17.32										
5/1/92	376.6	17.53										
5/2/92	381.5	17.74	0.95	0.86	2.15	0.89	8.19	0.73	0.36	0.73	0.48	0.93
5/3/92	386.4	17.95										
5/4/92	391.4	18.17										
5/5/92	396.4	18.39										
5/6/92	401.3	18.60	0.60	0.86	3.04	0.94	8.57	0.76	0.44	0.80	0.23	0.68

TCR = TOTAL COMBINED CHLORINE RESIDUAL;   TOC = TOTAL ORGANIC CARBON
CIET = ATRAZINE;   OIET = HYDROXYATRAZINE;   CIAT = DEETHYLATRAZINE
ND = "NOT DETECTED" = LESS THAN 0.1 PPB;   T = "TRACE" = LESS THAN 0.2 PPB

EFFLUENT ANALYSIS FOR FILTER #3
(AMWAY WTS III)

DATE	TOTAL VOLUME TREATED (gallons)	TOTAL ATRAZINE LOAD (mg)	TCR (mg/L)	TCR OUT:IN	TOC (mg/L)	TOC OUT:IN	CIET (ppb)	CIET OUT:IN	OIET (ppb)	OIET OUT:IN	CIAT (ppb)	CIAT OUT:IN
1/4/92	21.1	0.99	0.00	0.00	0.82	0.24	ND	0.00	ND	0.00	ND	0.00
1/7/92	40.7	1.97										
1/11/92	50.9	2.50										
1/12/92	60.9	2.97	0.00	0.00	0.79	0.23						
1/15/92	71.2	3.51										
1/16/92	81.5	4.00	0.00	0.00	0.67	0.18	ND	0.00	ND	0.00	ND	0.00
1/19/92	91.8	4.50										
1/20/92	101.8	4.97	0.00	0.00	0.68	0.20						
1/25/92	111.9	5.41										
1/27/92	121.9	5.80										
1/31/92	132.0	6.22										
2/1/92	147.1	6.95	0.00	0.00	0.82	0.24						
2/5/92	157.2	7.45										
2/7/92	167.4	7.94	0.00	0.00	0.90	0.26						
2/10/92	177.7	8.45										
2/13/92	187.7	8.93										
2/15/92	197.9	9.46										
2/16/92	208.3	9.99	0.00	0.00	1.12	0.35						
2/17/92	218.3	10.49										
2/18/92	228.5	11.00										
2/19/92	238.5	11.50										
2/20/92	248.6	11.99										
2/21/92	258.6	12.50										
2/22/92	268.8	13.00	0.10	0.09	1.48	0.42	ND	0.00	ND	0.00	ND	0.00
2/29/92	278.8	13.50										
3/1/92	289.0	14.00										
3/3/92	299.0	14.50										
3/4/92	309.1	15.00										
3/5/92	319.1	15.52										
3/6/92	329.2	16.02	0.00	0.00	1.52	0.48						
3/9/92	339.2	16.50										
3/10/92	349.5	17.00										
3/11/92	359.5	17.48										
3/12/92	369.6	17.96										
3/16/92	379.6	18.36										
3/17/92	389.9	18.84	0.00	0.00	1.96	0.57						
3/19/92	400.0	19.35										
3/20/92	410.0	19.85										
3/21/92	420.0	20.36										
3/22/92	430.1	20.86										
3/23/92	440.1	21.38										

EFFLUENT ANALYSIS FOR FILTER #3
(AMWAY WTS III)

DATE	TOTAL VOLUME TREATED (gallons)	TOTAL ATRAZINE LOAD (mg)	TCR (mg/L)	TCR OUT:IN	TOC (mg/L)	TOC OUT:IN	CIET (ppb)	CIET OUT:IN	OIET (ppb)	OIET OUT:IN	CIAT (ppb)	CIAT OUT:IN
3/24/92	450.1	21.88	0.10	0.08	1.64	0.58	ND	0.00	ND	0.00	ND	0.00
3/25/92	460.2	22.30										
3/26/92	470.2	22.71										
3/27/92	480.3	23.17										
3/28/92	490.3	23.63										
3/30/92	500.3	24.08										
3/31/92	510.4	24.52	0.00	0.00	1.64	0.63						
4/1/92	520.4	24.95										
4/2/92	530.5	25.39										
4/3/92	540.5	25.82										
4/4/92	550.5	26.26										
4/6/92	560.6	26.72										
4/7/92	570.6	27.18										
4/8/92	580.7	27.64	0.10	0.10	1.51	0.66	ND	0.00	ND	0.00	ND	0.00
4/9/92	590.7	28.08										
4/10/92	600.7	28.50										
4/11/92	610.8	28.93										
4/12/92	620.8	29.38										
4/13/92	630.8	29.84										
4/16/92	640.9	30.27										
4/18/92	650.9	30.71	0.00	0.00	1.30	0.57						
4/20/92	661.0	31.11										
4/21/92	671.0	31.52										
4/22/92	681.0	31.96										
4/23/92	691.1	32.40										
4/25/92	701.1	32.84	0.10	0.06	2.40	0.63						
4/25/92	711.2	33.29										
4/26/92	721.2	33.73										
4/27/92	731.2	34.17										
4/28/92	741.3	34.59										
4/29/92	751.3	35.01										
5/1/92	761.3	35.43										
5/2/92	771.4	35.86	0.10	0.09	1.52	0.63						
5/3/92	781.5	36.30										
5/4/92	791.5	36.73										
5/5/92	801.6	37.18										
5/6/92	811.6	37.61	0.10	0.14	2.25	0.70	ND	0.00	ND	0.00	ND	0.00

TCR = TOTAL COMBINED CHLORINE RESIDUAL;   TOC = TOTAL ORGANIC CARBON
CIET = ATRAZINE;   OIET = HYDROXYATRAZINE;   CIAT = DEETHYLATRAZINE
ND = "NOT DETECTED" = LESS THAN 0.1 PPB;   T = "TRACE" = LESS THAN 0.2 PPB

EFFLUENT ANALYSIS FOR FILTER #4
(AMETEK CCF-201)

DATE	TOTAL VOLUME TREATED (gallons)	TOTAL ATRAZINE LOAD (mg)	TCR (mg/L)	TCR OUT:IN	TOC (mg/L)	TOC OUT:IN	CIET (ppb)	CIET OUT:IN	OIET (ppb)	OIET OUT:IN	CIAT (ppb)	CIAT OUT:IN
1/4/92	40.8	1.92	0.00	0.00	1.25	0.37	ND	0.00	ND	0.00	ND	0.00
1/7/92	81.0	3.93										
1/11/92	101.0	4.97										
1/12/92	120.9	5.91	0.00	0.00	1.63	0.48						
1/15/92	140.9	6.95										
1/16/92	160.9	7.91	0.00	0.00	2.03	0.56	ND	0.00	ND	0.00	ND	0.00
1/19/92	180.7	8.86										
1/20/92	200.8	9.80	0.10	0.08	2.04	0.58						
1/25/92	220.8	10.68										
1/27/92	240.9	11.47										
1/31/92	260.7	12.28										
2/1/92	276.3	13.04	0.00	0.00	2.08	0.61						
2/5/92	296.1	14.02										
2/7/92	316.2	14.99	0.00	0.00	2.21	0.64						
2/10/92	336.3	15.99										
2/13/92	356.4	16.94										
2/15/92	376.4	17.98										
2/16/92	396.7	19.02	0.10	0.08	2.26	0.70						
2/17/92	416.7	20.02										
2/18/92	436.8	21.02										
2/19/92	456.9	22.01										
2/20/92	477.0	23.00										
2/21/92	497.0	24.01										
2/22/92	517.1	25.02	0.10	0.09	2.44	0.70	ND	0.00	ND	0.00	ND	0.00
2/29/92	537.2	26.01										
3/1/92	557.3	26.99										
3/3/92	577.3	28.00										
3/4/92	597.4	28.99										
3/5/92	617.5	30.03										
3/6/92	637.6	31.04	0.00	0.00	2.35	0.74						
3/9/92	657.7	32.00										
3/10/92	677.7	32.96										
3/11/92	697.8	33.93										
3/12/92	717.9	34.90										
3/16/92	738.0	35.70										
3/17/92	758.0	36.63	0.10	0.22	2.69	0.78	ND	0.00	ND	0.00	ND	0.00
3/19/92	778.4	37.65										
3/20/92	798.5	38.65										
3/21/92	818.5	39.67										
3/22/92	838.6	40.68										
3/23/92	858.7	41.71										

EFFLUENT ANALYSIS FOR FILTER #4
(AMETEK CCF-201)

DATE	TOTAL VOLUME TREATED (gallons)	TOTAL ATRAZINE LOAD (mg)	TCR (mg/L)	TCR OUT:IN	TOC (mg/L)	TOC OUT:IN	CIET (ppb)	CIET OUT:IN	OIET (ppb)	OIET OUT:IN	CIAT (ppb)	CIAT OUT:IN
3/24/92	878.8	42.73	0.10	0.08	2.13	0.75	ND	0.00	ND	0.00	ND	0.00
3/25/92	898.8	43.55										
3/26/92	918.9	44.37										
3/27/92	939.0	45.30	0.25	0.17	2.23	0.81	T		ND	0.00	ND	0.00
3/28/92	959.1	46.23										
3/30/92	979.2	47.12										
3/31/92	999.2	48.00	0.00	0.00	2.01	0.78	T		ND	0.00	ND	0.00
4/1/92	1,019.3	48.87										
4/2/92	1,039.4	49.73										
4/3/92	1,059.5	50.60										
4/4/92	1,079.7	51.48										
4/6/92	1,099.7	52.41										
4/7/92	1,119.8	53.33										
4/8/92	1,139.9	54.24	0.05	0.05	1.90	0.82	T		ND	0.00	ND	0.00
4/9/92	1,160.0	55.12										
4/10/92	1,180.1	55.97										
4/11/92	1,200.1	56.81										
4/12/92	1,220.2	57.72										
4/13/92	1,240.3	58.63										
4/16/92	1,260.4	59.49										
4/18/92	1,280.4	60.37	0.05	0.13	1.77	0.78	0.25	0.02	ND	0.00	ND	0.00
4/20/92	1,300.5	61.19										
4/21/92	1,320.6	62.00										
4/22/92	1,340.7	62.88										
4/23/92	1,360.7	63.77										
4/25/92	1,380.8	64.63	0.10	0.06	3.06	0.80	0.37	0.03	ND	0.00	ND	0.00
4/25/92	1,400.9	65.55										
4/26/92	1,421.0	66.43										
4/27/92	1,441.1	67.31										
4/28/92	1,461.1	68.14										
4/29/92	1,481.2	68.98										
5/1/92	1,501.3	69.83										
5/2/92	1,521.4	70.68	0.10	0.09	1.84	0.76	0.34	0.03	ND	0.00	ND	0.00
5/3/92	1,541.4	71.55										
5/4/92	1,561.5	72.42										
5/5/92	1,581.6	73.32										
5/6/92	1,601.7	74.18	0.10	0.14	2.69	0.83	0.55	0.05	ND	0.00	ND	0.00

TCR = TOTAL COMBINED CHLORINE RESIDUAL;   TOC = TOTAL ORGANIC CARBON
CIET = ATRAZINE;   OIET = HYDROXYATRAZINE;   CIAT = DEETHYLATRAZINE
ND = "NOT DETECTED" = LESS THAN 0.1 PPB;   T = "TRACE" = LESS THAN 0.2 PPB

EFFLUENT ANALYSIS FOR FILTER #5-RO GAC
(CULLIGAN GAC PRETREAT FOR R.O.)

DATE	TOTAL VOLUME TREATED (gallons)	TOTAL ATRAZINE LOAD (mg)	TCR (mg/L)	TCR OUT:IN	TOC (mg/L)	TOC OUT:IN	CIET (ppb)	CIET OUT:IN	OIET (ppb)	OIET OUT:IN	CIAT (ppb)	CIAT OUT:IN
1/4/92	20.6	0.97	0.50	0.50	1.98	0.58	0.91	0.07	T		ND	0.00
1/7/92	39.9	1.93										
1/11/92	49.9	2.45										
1/12/92	60.0	2.93	0.70	0.50	2.22	0.66						
1/15/92	70.0	3.45										
1/16/92	80.0	3.93	0.60	0.46	2.33	0.64	1.20	0.09	T		ND	0.00
1/19/92	89.6	4.39					0.26	0.02	ND	0.00	ND	0.00
1/20/92	99.3	4.85	0.30	0.25	1.98	0.57						
1/25/92				EFFLUENT ANALYSIS FOR FILTER #5								
1/27/92				(CULLIGAN SG-2)								
1/31/92	20.1	0.83	0.05	0.04	0.72	0.20	T		ND	0.00	ND	0.00
2/1/92	35.7	1.58	0.00	0.00	0.84	0.25	T		ND	0.00	ND	0.00
2/5/92	45.6	2.07										
2/7/92	55.6	2.56	0.05	0.09	0.86	0.25	T		ND	0.00	ND	0.00
2/10/92	66.2	3.08										
2/13/92	76.7	3.58										
2/15/92	87.0	4.12										
2/16/92	97.3	4.64	0.10	0.08	0.99	0.31	T		ND	0.00	ND	0.00
2/17/92	107.9	5.17										
2/18/92	118.5	5.70										
2/19/92	129.0	6.22										
2/20/92	139.6	6.74										
2/21/92	150.2	7.28										
2/22/92	160.5	7.79	0.10	0.09	1.09	0.31	0.30	0.02	ND	0.00	ND	0.00
2/29/92	171.1	8.31										
3/1/92	181.6	8.83										
3/3/92	192.2	9.36										
3/4/92	202.8	9.88										
3/5/92	213.3	10.43										
3/6/92	223.6	10.94	0.00	0.00	1.15	0.36						
3/9/92	234.2	11.45										
3/10/92	244.8	11.96										
3/11/92	255.3	12.47										
3/12/92	265.9	12.98										
3/16/92	276.5	13.40										
3/17/92	287.0	13.89	0.00	0.00	1.36	0.40	0.22	0.02	ND	0.00	ND	0.00
3/19/92	297.6	14.42										
3/20/92	308.2	14.95										
3/21/92	318.7	15.48										
3/22/92	329.3	16.02										
3/23/92	339.9	16.56										

EFFLUENT ANALYSIS FOR FILTER #5
(CULLIGAN SG-2)

DATE	TOTAL VOLUME TREATED (gallons)	TOTAL ATRAZINE LOAD (mg)	TCR (mg/L)	TCR OUT:IN	TOC (mg/L)	TOC OUT:IN	CIET (ppb)	CIET OUT:IN	OIET (ppb)	OIET OUT:IN	CIAT (ppb)	CIAT OUT:IN
3/24/92	350.4	17.09	0.10	0.08	1.14	0.40	0.53	0.04	ND	0.00	ND	0.00
3/25/92	361.0	17.52										
3/26/92	371.6	17.96										
3/27/92	382.1	18.45										
3/28/92	392.7	18.93										
3/30/92	403.3	19.40										
3/31/92	413.8	19.87	0.00	0.00	1.22	0.47	0.39	0.03	ND	0.00	ND	0.00
4/1/92	424.4	20.32										
4/2/92	435.0	20.78										
4/3/92	445.5	21.24										
4/4/92	456.1	21.70										
4/6/92	466.7	22.18										
4/7/92	477.2	22.67										
4/8/92	487.7	23.14	0.10	0.10	1.24	0.54	0.49	0.04	ND	0.00	ND	0.00
4/9/92	498.2	23.61										
4/10/92	508.8	24.05										
4/11/92	519.4	24.50										
4/12/92	529.9	24.98										
4/13/92	540.5	25.45										
4/16/92	551.1	25.91										
4/18/92	561.6	26.37	0.05	0.13	1.01	0.44	0.46	0.04	ND	0.00	ND	0.00
4/20/92	572.2	26.80										
4/21/92	582.8	27.23										
4/22/92	593.5	27.70										
4/23/92	604.0	28.16										
4/25/92	614.6	28.62	0.20	0.13	1.72	0.45	0.45	0.04	ND	0.00	ND	0.00
4/25/92	625.2	29.10										
4/26/92	635.7	29.56										
4/27/92	646.3	30.02										
4/28/92	656.9	30.47										
4/29/92	667.4	30.91										
5/1/92	678.0	31.35										
5/2/92	688.6	31.80	0.10	0.09	1.12	0.46	0.43	0.04	ND	0.00	ND	0.00
5/3/92	699.1	32.26										
5/4/92	709.7	32.71										
5/5/92	720.3	33.19										
5/6/92	730.8	33.64	0.10	0.14	1.36	0.42	0.52	0.05	ND	0.00	ND	0.00

TCR = TOTAL COMBINED CHLORINE RESIDUAL;   TOC = TOTAL ORGANIC CARBON
CIET = ATRAZINE;   OIET = HYDROXYATRAZINE;   CIAT = DEETHYLATRAZINE
ND = "NOT DETECTED" = LESS THAN 0.1 PPB;   T = "TRACE" = LESS THAN 0.2 PPB

EFFLUENT ANALYSIS FOR FILTER #6
(MULTI-PURE 500B)

DATE	TOTAL VOLUME TREATED (gallons)	TOTAL ATRAZINE LOAD (mg)	TCR (mg/L)	TCR OUT:IN	TOC (mg/L)	TOC OUT:IN	CIET (ppb)	CIET OUT:IN	OIET (ppb)	OIET OUT:IN	CIAT (ppb)	CIAT OUT:IN
1/4/92	20.21	0.95	0.00	0.00	0.63	0.18	ND	0.00	ND	0.00	ND	0.00
1/7/92	40.02	1.94										
1/11/92	50.06	2.46										
1/12/92	60.10	2.94	0.00	0.00	0.64	0.19						
1/15/92	70.14	3.46										
1/16/92	80.18	3.94	0.00	0.00	0.77	0.21	ND	0.00	ND	0.00	ND	0.00
1/19/92	90.21	4.43										
1/20/92	100.25	4.89	0.00	0.00	0.66	0.19						
1/25/92	110.29	5.33										
1/27/92	120.33	5.73										
1/31/92	130.50	6.15										
2/1/92	140.54	6.63	0.00	0.00	0.59	0.17	ND	0.00	ND	0.00	ND	0.00
2/5/92	150.58	7.13										
2/7/92	160.88	7.63	0.00	0.00	0.59	0.17						
2/10/92	170.92	8.13										
2/13/92	180.96	8.60										
2/15/92	191.13	9.13										
2/16/92	201.17	9.64	0.00	0.00	0.62	0.19						
2/17/92	211.21	10.14										
2/18/92	221.24	10.65										
2/19/92	231.28	11.14										
2/20/92	241.32	11.64										
2/21/92	251.36	12.14										
2/22/92	261.40	12.64	0.00	0.00	0.74	0.21	ND	0.00	ND	0.00	ND	0.00
2/29/92	271.44	13.14										
3/1/92	281.48	13.63										
3/3/92	291.51	14.14										
3/4/92	301.55	14.63										
3/5/92	311.59	15.15										
3/6/92	321.63	15.65	0.00	0.00	0.89	0.28						
3/9/92	331.67	16.14										
3/10/92	341.71	16.62										
3/11/92	351.75	17.10										
3/12/92	361.78	17.58										
3/16/92	371.82	17.98										
3/17/92	381.86	18.45	0.00	0.00	1.14	0.33						
3/19/92	391.90	18.95										
3/20/92	401.94	19.46										
3/21/92	411.98	19.96										
3/22/92	422.01	20.47										
3/23/92	432.05	20.98										

EFFLUENT ANALYSIS FOR FILTER #6
(MULTI-PURE 500B)

DATE	TOTAL VOLUME TREATED (gallons)	TOTAL ATRAZINE LOAD (mg)	TCR (mg/L)	TCR OUT:IN	TOC (mg/L)	TOC OUT:IN	CIET (ppb)	CIET OUT:IN	OIET (ppb)	OIET OUT:IN	CIAT (ppb)	CIAT OUT:IN
3/24/92	442.09	21.49	0.00	0.00	0.92	0.32	ND	0.00	ND	0.00	ND	0.00
3/25/92	452.13	21.90										
3/26/92	462.17	22.31										
3/27/92	472.21	22.78										
3/28/92	482.25	23.24										
3/30/92	492.28	23.69										
3/31/92	502.32	24.13	0.00	0.00	1.00	0.39						
4/1/92	512.36	24.56										
4/2/92	522.40	24.99										
4/3/92	532.44	25.43										
4/4/92	542.48	25.87										
4/6/92	552.52	26.33										
4/7/92	562.55	26.79										
4/8/92	572.59	27.25	0.00	0.00	1.05	0.45	ND	0.00	ND	0.00	ND	0.00
4/9/92	582.63	27.69										
4/10/92	592.67	28.11										
4/11/92	602.71	28.53										
4/12/92	612.75	28.99										
4/13/92	622.79	29.44										
4/16/92	632.82	29.87										
4/18/92	642.86	30.31	0.00	0.00	0.87	0.38						
4/20/92	652.90	30.72										
4/21/92	662.94	31.13										
4/22/92	672.98	31.57										
4/23/92	683.02	32.01										
4/25/92	693.06	32.44	0.00	0.00	1.56	0.41						
4/25/92	703.09	32.90										
4/26/92	713.13	33.34										
4/27/92	723.17	33.78										
4/28/92	733.21	34.20										
4/29/92	743.25	34.62										
5/1/92	753.29	35.04										
5/2/92	763.32	35.47	0.00	0.00	1.22	0.51						
5/3/92	773.36	35.90										
5/4/92	783.40	36.33										
5/5/92	793.44	36.79										
5/6/92	803.48	37.22	0.00	0.00	1.66	0.51	ND	0.00	ND	0.00	ND	0.00

TCR = TOTAL COMBINED CHLORINE RESIDUAL; TOC = TOTAL ORGANIC CARBON
CIET = ATRAZINE; OIET = HYDROXYATRAZINE; CIAT = DEETHYLATRAZINE
ND = "NOT DETECTED" = LESS THAN 0.1 PPB; T = "TRACE" = LESS THAN 0.2 PPB

EFFLUENT ANALYSIS FOR FILTER #7
(PUREWATER "PUP")

DATE	TOTAL VOLUME TREATED (gallons)	TOTAL ATRAZINE LOAD (mg)	TCR (mg/L)	TCR OUT:IN	TOC (mg/L)	TOC OUT:IN	CIET (ppb)	CIET OUT:IN	OIET (ppb)	OIET OUT:IN	CIAT (ppb)	CIAT OUT:IN
1/4/92	20.2	0.95	0.10	0.10	1.95	0.57	T		ND	0.00	ND	0.00
1/7/92	39.9	1.93										
1/11/92	49.9	2.45										
1/12/92	60.1	2.94	0.45	0.32	2.39	0.71						
1/15/92	70.1	3.46										
1/16/92	80.3	3.95	0.40	0.31	2.69	0.74	0.40	0.03	ND	0.00	ND	0.00
1/19/92	90.3	4.43										
1/20/92	100.4	4.90	0.40	0.33	2.66	0.76						
1/25/92	110.4	5.34										
1/27/92	120.5	5.73										
1/31/92	130.5	6.15										
2/1/92	140.5	6.63	0.25	0.29	2.79	0.81	1.04	0.08	T		ND	0.00
2/5/92	150.6	7.13										
2/7/92	160.7	7.62	0.20	0.36	2.76	0.79						
2/10/92	170.8	8.12										
2/13/92	180.8	8.60										
2/15/92	191.0	9.12										
2/16/92	201.0	9.64	0.50	0.38	2.70	0.84	2.05	0.15	T		ND	0.00
2/17/92	211.1	10.14										
2/18/92	221.1	10.64										
2/19/92	231.2	11.14										
2/20/92	241.2	11.63										
2/21/92	251.2	12.14										
2/22/92	261.3	12.64	0.55	0.48	2.86	0.82	2.16	0.16	T		T	
2/29/92	271.3	13.13										
3/1/92	281.3	13.62										
3/3/92	291.4	14.13										
3/4/92	301.4	14.62										
3/5/92	311.5	15.14										
3/6/92	321.5	15.65	0.30	0.46	2.65	0.84	2.42	0.18	ND	0.00	ND	0.00
3/9/92	331.5	16.13										
3/10/92	341.6	16.61										
3/11/92	351.6	17.09										
3/12/92	361.7	17.58										
3/16/92	371.7	17.98										
3/17/92	381.7	18.45	0.25	0.56	3.01	0.88	2.74	0.22	T		ND	0.00
3/19/92	391.8	18.95										
3/20/92	401.8	19.45										
3/21/92	411.8	19.96										
3/22/92	421.9	20.47										
3/23/92	431.9	20.98										

EFFLUENT ANALYSIS FOR FILTER #7
(PUREWATER "PUP")

DATE	TOTAL VOLUME TREATED (gallons)	TOTAL ATRAZINE LOAD (mg)	TCR (mg/L)	TCR OUT:IN	TOC (mg/L)	TOC OUT:IN	CIET (ppb)	CIET OUT:IN	OIET (ppb)	OIET OUT:IN	CIAT (ppb)	CIAT OUT:IN
3/24/92	442.0	21.49	0.65	0.50	2.46	0.86	4.81	0.36	T		T	
3/25/92	452.0	21.90										
3/26/92	462.0	22.31										
3/27/92	472.1	22.77										
3/28/92	482.1	23.24										
3/30/92	492.2	23.68										
3/31/92	502.2	24.12	0.20	0.67	2.31	0.89	4.33	0.37	0.21	0.35	T	
4/1/92	512.2	24.56										
4/2/92	522.3	24.99										
4/3/92	532.3	25.43										
4/4/92	542.3	25.86										
4/6/92	552.4	26.32										
4/7/92	562.4	26.78										
4/8/92	572.5	27.24	0.40	0.40	2.04	0.88	4.88	0.41	0.20	0.48	0.21	0.35
4/9/92	582.5	27.68										
4/10/92	592.5	28.10										
4/11/92	602.6	28.53										
4/12/92	612.6	28.98										
4/13/92	622.7	29.44										
4/16/92	632.7	29.87										
4/18/92	642.7	30.31	0.20	0.50	2.02	0.89	5.09	0.44	T		ND	0.00
4/20/92	652.8	30.71										
4/21/92	662.8	31.12										
4/22/92	672.8	31.56										
4/23/92	682.9	32.00										
4/25/92	692.9	32.44	0.70	0.45	3.43	0.90	5.53	0.48	0.31	0.44	T	
4/25/92	703.0	32.90										
4/26/92	713.0	33.33										
4/27/92	723.0	33.77										
4/28/92	733.1	34.19										
4/29/92	743.1	34.61										
5/1/92	753.2	35.03										
5/2/92	763.2	35.46	0.60	0.55	2.06	0.85	5.19	0.46	0.26	0.53	0.20	0.39
5/3/92	773.2	35.90										
5/4/92	783.3	36.33										
5/5/92	793.3	36.78										
5/6/92	803.3	37.21	0.40	0.57	2.88	0.89	5.82	0.51	T		T	

TCR = TOTAL COMBINED CHLORINE RESIDUAL;   TOC = TOTAL ORGANIC CARBON
CIET = ATRAZINE;   OIET = HYDROXYATRAZINE;   CIAT = DEETHYLATRAZINE
ND = "NOT DETECTED" = LESS THAN 0.1 PPB;   T = "TRACE" = LESS THAN 0.2 PPB

EFFLUENT ANALYSIS FOR FILTER #8
(ECOWATER WATER MASTER)

DATE	TOTAL VOLUME TREATED (gallons)	TOTAL ATRAZINE LOAD (mg)	TCR (mg/L)	TCR OUT:IN	TOC (mg/L)	TOC OUT:IN	CIET (ppb)	CIET OUT:IN	OIET (ppb)	OIET OUT:IN	CIAT (ppb)	CIAT OUT:IN
1/4/92	40.7	1.91	0.00	0.00	0.78	0.23	ND	0.00	ND	0.00	ND	0.00
1/7/92	80.8	3.92										
1/11/92	100.9	4.96										
1/12/92	120.9	5.91	0.05	0.04	1.46	0.43						
1/15/92	140.9	6.95										
1/16/92	161.0	7.91	0.05	0.04	1.70	0.47	ND	0.00	ND	0.00	ND	0.00
1/19/92	180.8	8.87										
1/20/92	201.0	9.81	0.10	0.08	1.85	0.53						
1/25/92	221.2	10.69										
1/27/92	241.3	11.49										
1/31/92	261.4	12.31										
2/1/92	277.0	13.07	0.00	0.00	2.01	0.59	ND	0.00	ND	0.00	ND	0.00
2/5/92	297.1	14.06										
2/7/92	317.1	15.03	0.00	0.00	2.11	0.61						
2/10/92	337.2	16.03										
2/13/92	357.3	16.98										
2/15/92	377.4	18.02										
2/16/92	397.6	19.06	0.10	0.08	2.17	0.67						
2/17/92	417.7	20.06										
2/18/92	437.7	21.07										
2/19/92	457.8	22.06										
2/20/92	477.9	23.05										
2/21/92	498.0	24.06										
2/22/92	518.0	25.06	0.10	0.09	2.40	0.68	ND	0.00	ND	0.00	ND	0.00
2/29/92	538.1	26.05										
3/1/92	558.2	27.03										
3/3/92	578.3	28.05										
3/4/92	598.3	29.03										
3/5/92	618.4	30.07										
3/6/92	638.5	31.08	0.10	0.15	2.28	0.72						
3/9/92	658.6	32.04										
3/10/92	678.7	33.00										
3/11/92	698.7	33.97										
3/12/92	718.8	34.94										
3/16/92	738.9	35.74										
3/17/92	759.0	36.68	0.05	0.11	2.66	0.78						
3/19/92	779.3	37.69										
3/20/92	799.4	38.69										
3/21/92	819.5	39.71										
3/22/92	839.5	40.73										
3/23/92	859.6	41.75										

EFFLUENT ANALYSIS FOR FILTER #8
(ECOWATER WATER MASTER)

DATE	TOTAL VOLUME TREATED (gallons)	TOTAL ATRAZINE LOAD (mg)	TCR (mg/L)	TCR OUT:IN	TOC (mg/L)	TOC OUT:IN	CIET (ppb)	CIET OUT:IN	OIET (ppb)	OIET OUT:IN	CIAT (ppb)	CIAT OUT:IN
3/24/92	879.7	42.77	0.10	0.08	2.18	0.76	ND	0.00	ND	0.00	ND	0.00
3/25/92	899.8	43.59										
3/26/92	919.8	44.41										
3/27/92	939.9	45.35										
3/28/92	960.0	46.27										
3/30/92	980.1	47.16										
3/31/92	1,000.2	48.05	0.00	0.00	2.03	0.78	ND	0.00	ND	0.00	ND	0.00
4/1/92	1,020.2	48.91										
4/2/92	1,040.3	49.77										
4/3/92	1,060.4	50.65										
4/4/92	1,080.7	51.53										
4/6/92	1,100.8	52.45										
4/7/92	1,120.9	53.38										
4/8/92	1,141.0	54.29	0.10	0.10	1.84	0.80	ND	0.00	ND	0.00	ND	0.00
4/9/92	1,161.0	55.17										
4/10/92	1,181.1	56.02										
4/11/92	1,201.2	56.86										
4/12/92	1,221.3	57.77										
4/13/92	1,241.3	58.68										
4/16/92	1,261.4	59.54										
4/18/92	1,281.5	60.42	0.05	0.13	1.70	0.75						
4/20/92	1,301.6	61.24										
4/21/92	1,321.7	62.05										
4/22/92	1,341.7	62.93										
4/23/92	1,361.8	63.81										
4/25/92	1,381.9	64.68	0.10	0.06	3.11	0.82						
4/25/92	1,402.0	65.60										
4/26/92	1,422.0	66.48										
4/27/92	1,442.1	67.36										
4/28/92	1,462.2	68.19										
4/29/92	1,482.3	69.03										
5/1/92	1,502.3	69.87										
5/2/92	1,522.4	70.73	0.10	0.09	1.94	0.80	ND	0.00	ND	0.00	ND	0.00
5/3/92	1,542.5	71.60										
5/4/92	1,562.6	72.46										
5/5/92	1,582.7	73.37										
5/6/92	1,602.7	74.23	0.10	0.14	2.70	0.84	ND	0.00	ND	0.00	ND	0.00

TCR = TOTAL COMBINED CHLORINE RESIDUAL;   TOC = TOTAL ORGANIC CARBON
CIET = ATRAZINE;   OIET = HYDROXYATRAZINE;   CIAT = DEETHYLATRAZINE
ND = "NOT DETECTED" = LESS THAN 0.1 PPB;   T = "TRACE" = LESS THAN 0.2 PPB

APPENDIX C

CALCULATIONS OF NET CUMULATIVE

ATRAZINE LOAD

Table 1C. Filter #1 Atrazine Loading Calculations

ATRAZINE IN (µg/L)	CONC. OUT (µg/L)	ATRAZINE ADSORBED (µg/L)	AVG. ABSORBED (µg/L)	VOLUME TREATED (L)	ATRAZINE APPLIED (mg)	NET ADSORBED (mg)
12.43	1.95	10.48		158.6	1.97	1.66
12.64	2.10	10.54	10.51	463.3	6.10	4.87
12.81	2.21	10.60	10.57	465.6	5.49	4.92
13.18	3.20	9.98	10.29	913.7	12.01	9.40
13.28	3.35	9.93	9.96	461.8	6.09	4.60
12.30	3.27	9.03	9.48	457.6	5.62	4.34
13.36	4.52	8.84	8.94	458.0	6.11	4.09
11.68	4.16	7.52	8.18	456.5	5.28	3.73
11.97	4.58	7.39	7.46	534.1	6.25	3.98
11.58	4.42	7.16	7.28	537.1	6.20	3.91
12.07	4.85	7.22	7.19	382.7	4.29	2.75
11.28	4.81	6.47	6.85	536.7	6.10	3.68
11.34	4.93	6.41	6.44	305.1	3.52	1.96
				SUM:	75.03	53.89

Overall Atrazine Adsorbed: (53.89/75.03) x 100 = 71.8%

Table 2C. Filter #1 Net Cumulative Atrazine Load

ATRAZINE CONC.		NET CUMULATIVE	NET CUMULATIVE
INFLUENT (µg/L)	EFFLUENT (µg/L)	ATRAZINE ADSORBED (mg)	ATRAZINE LOAD (mg Atrazine/g Carbon)
12.43	1.95	1.66	0.0041
12.64	2.10	6.53	0.0163
12.81	2.21	11.45	0.0286
13.18	3.20	20.85	0.0520
13.28	3.35	25.45	0.0635
12.30	3.27	29.79	0.0743
13.36	4.52	33.88	0.0845
11.68	4.16	37.61	0.0938
11.97	4.58	41.59	0.1037
11.58	4.42	45.50	0.1135
12.07	4.85	48.25	0.1203
11.28	4.81	51.93	0.1295
11.34	4.93	53.89	0.1344

Filter #1:   401 grams net dry wt. activated carbon

Table 3C.   Filter #2 Atrazine Loading Calculations

ATRAZINE IN (µg/L)	CONC. OUT (µg/L)	ATRAZINE ADSORBED (µg/L)	AVG. ABSORBED (µg/L)	VOLUME TREATED (L)	ATRAZINE APPLIED (mg)	NET ADSORBED (mg)
12.43	3.82	8.61		48.8	0.61	0.42
12.53	5.10	7.43	8.02	83.3	1.09	0.67
13.73	5.46	8.27	7.85	20.1	0.28	0.16
12.64	5.49	7.15	7.71	18.9	0.24	0.15
12.81	5.49	7.32	7.23	114.3	1.35	0.83
12.52	6.43	6.09	6.70	74.6	0.96	0.50
13.18	7.40	5.78	5.94	152.9	2.03	0.91
13.28	7.25	6.03	5.90	113.2	1.49	0.67
12.30	6.99	5.31	5.67	111.3	1.37	0.63
13.36	9.12	4.24	4.78	110.9	1.47	0.53
11.68	8.34	3.34	3.79	109.0	1.27	0.41
11.97	8.53	3.44	3.39	130.6	1.53	0.44
11.58	7.70	3.88	3.66	131.3	1.51	0.48
12.07	8.41	3.66	3.77	94.6	1.06	0.36
11.28	8.19	3.09	3.38	130.2	1.48	0.44
11.34	8.57	2.77	2.93	74.9	0.86	0.22
					-------	-------
				SUM:	18.60	7.82

Overall Atrazine Adsorbed: (7.82/18.60) x 100 = 42.0%

Table 4C.   Filter #2 Net Cumulative Atrazine Load

| ATRAZINE CONC. | | NET CUMULATIVE | NET CUMULATIVE |
| INFLUENT | EFFLUENT | ATRAZINE ADSORBED | ATRAZINE LOAD |
(ug/L)	(ug/L)	(mg)	(mg Atrazine/g Carbon)
12.43	3.82	0.42	0.0074
12.53	5.10	1.09	0.0191
13.73	5.46	1.25	0.0219
12.64	5.49	1.40	0.0246
12.81	5.49	2.23	0.0391
12.52	6.43	2.73	0.0479
13.18	7.40	3.64	0.0639
13.28	7.25	4.31	0.0756
12.30	6.99	4.94	0.0867
13.36	9.12	5.47	0.0960
11.68	8.34	5.88	0.1032
11.97	8.53	6.32	0.1109
11.58	7.70	6.80	0.1193
12.07	8.41	7.16	0.1256
11.28	8.19	7.60	0.1333
11.34	8.57	7.82	0.1372

Filter #2:   57 grams net dry wt. activated carbon

Table 5C. Filter #4 Atrazine Loading Calculations

ATRAZINE IN ($\mu g/L$)	CONC. OUT ($\mu g/L$)	ATRAZINE ADSORBED ($\mu g/L$)	AVG. ABSORBED ($\mu g/L$)	VOLUME TREATED (L)	ATRAZINE APPLIED (mg)	NET ADSORBED (mg)
12.43	ND	12.43		154.4	1.92	1.92
12.64	ND	12.64	12.54	454.6	5.70	5.70
13.18	ND	13.18	12.91	1348.4	17.41	17.41
12.30	ND	12.30	12.74	911.9	11.62	11.62
13.36	ND	13.36	12.83	457.3	5.87	5.87
12.29	0.09	12.20	12.78	227.9	2.92	2.91
11.68	0.08	11.60	11.90	227.9	2.73	2.71
11.97	0.15	11.82	11.71	532.6	6.30	6.24
11.58	0.25	11.33	11.58	531.8	6.26	6.16
12.07	0.37	11.70	11.52	380.0	4.49	4.38
11.28	0.34	10.94	11.32	532.2	6.21	6.02
11.34	0.55	10.79	10.86	304.0	3.44	3.30
				SUM:	74.87	74.24

Overall Atrazine Adsorbed: (74.24/74.87) x 100 = 99.2%

Special Note: Averaged influent concentrations were used to
                     calculate the amount of atrazine applied to this
                     filter. Effluent concentrations below 0.20 $\mu g/L$
                     were normally reported as "Trace", an exception was
                     made here so an estimate could be made of the net
                     atrazine adsorbed.

Table 6C. Filter #4 Net Cumulative Atrazine Load

| ATRAZINE CONC. | | NET CUMULATIVE | NET CUMULATIVE |
INFLUENT (μg/L)	EFFLUENT (μg/L)	ATRAZINE ADSORBED (mg)	ATRAZINE LOAD (mg Atrazine/g Carbon)
12.43	ND	1.92	0.0029
12.64	ND	7.62	0.0115
13.18	ND	25.03	0.0379
12.30	ND	36.65	0.0555
13.36	ND	42.52	0.0644
12.29	0.09	45.43	0.0688
11.68	0.08	48.14	0.0729
11.97	0.15	54.38	0.0824
11.58	0.25	60.54	0.0917
12.07	0.37	64.92	0.0984
11.28	0.34	70.94	0.1075
11.34	0.55	74.24	0.1125

Special Note: Effluent   concentrations   below   0.20 μg/L   were
                  normally reported as "Trace", an exception was made
                  here so an estimate could be made of the net
                  cumulative atrazine load.

Filter #4: 660 grams net dry wt. activated carbon

Table 7C. Filter #5 Atrazine Loading Calculations

ATRAZINE IN (μg/L)	CONC. OUT (μg/L)	ATRAZINE ADSORBED (μg/L)	AVG. ABSORBED (μg/L)	VOLUME TREATED (L)	ATRAZINE APPLIED (mg)	NET ADSORBED (mg)
10.87	0.05	10.82		76.1	0.83	0.82
12.81	0.12	12.69	11.75	59.0	0.70	0.69
12.84	0.13	12.71	12.70	75.3	0.97	0.96
13.56	0.15	13.41	13.06	157.8	2.08	2.06
13.18	0.30	12.88	13.14	239.2	3.20	3.14
12.30	0.22	12.08	12.48	478.8	6.10	5.98
13.36	0.53	12.83	12.45	240.0	3.08	2.99
11.68	0.39	11.29	12.06	240.0	3.00	2.89
11.97	0.49	11.48	11.38	279.7	3.31	3.18
11.58	0.46	11.12	11.30	279.7	3.29	3.16
11.42	0.45	10.97	11.04	200.6	2.31	2.21
11.28	0.43	10.85	10.91	280.1	3.18	3.05
11.34	0.52	10.82	10.84	159.7	1.81	1.73
				SUM:	33.86	32.86

Overall Atrazine Adsorbed: (32.86/33.86) x 100 = 97.0%

Special Note: Averaged influent concentrations were used to calculate the amount of atrazine applied to this filter. Effluent concentrations below 0.20 μg/L were normally reported as "Trace", an exception was made here so an estimate could be made of the net atrazine adsorbed.

Table 8C.   Filter #5 Net Cumulative Atrazine Load

| ATRAZINE CONC. | | NET CUMULATIVE | NET CUMULATIVE |
| INFLUENT | EFFLUENT | ATRAZINE ADSORBED | ATRAZINE LOAD |
(μg/L)	(μg/L)	(mg)	(mg Atrazine/g Carbon)
10.87	0.05	0.82	0.0010
12.81	0.12	1.51	0.0019
12.84	0.13	2.47	0.0030
13.56	0.15	4.53	0.0056
13.18	0.30	7.67	0.0094
12.30	0.22	13.65	0.0167
13.36	0.53	16.64	0.0204
11.68	0.39	19.53	0.0240
11.97	0.49	22.71	0.0279
11.58	0.46	25.87	0.0317
11.42	0.45	28.08	0.0345
11.28	0.43	31.13	0.0382
11.34	0.52	32.86	0.0403

Special Note: Effluent concentrations below 0.20 μg/L were
                  normally reported as "Trace", an exception was made
                  here so an estimate could be made of the net
                  cumulative atrazine load.

Filter #5:   815 grams net dry wt. activated carbon

Table 9C. Filter #7 Atrazine Loading Calculations

ATRAZINE IN (µg/L)	CONC. OUT (µg/L)	ATRAZINE ADSORBED (µg/L)	AVG. ABSORBED (µg/L)	VOLUME TREATED (L)	ATRAZINE APPLIED (mg)	NET ADSORBED (mg)
12.43	0.13	12.30		76.5	0.95	0.94
12.64	0.40	12.24	12.27	227.5	3.00	2.79
12.81	1.04	11.77	12.01	227.9	2.68	2.74
13.56	2.05	11.51	11.64	229.0	3.01	2.67
13.18	2.16	11.02	11.27	228.2	3.00	2.57
13.28	2.42	10.86	10.94	227.9	3.01	2.49
12.30	2.74	9.56	10.21	227.9	2.80	2.33
13.36	4.81	8.55	9.06	228.2	3.04	2.07
11.68	4.33	7.35	7.95	227.9	2.63	1.81
11.97	4.88	7.09	7.22	266.1	3.12	1.92
11.58	5.09	6.49	6.79	265.7	3.07	1.80
11.42	5.53	5.89	6.19	190.0	2.13	1.18
11.28	5.19	6.09	5.99	266.1	3.02	1.59
11.34	5.82	5.52	5.81	151.8	1.75	0.88
				SUM:	37.21	27.78

Overall Atrazine Adsorbed: (27.78/37.21) x 100 = 74.7%

Table 10C.   Filter #7 Net Cumulative Atrazine Load

| ATRAZINE CONC. | | NET CUMULATIVE | NET CUMULATIVE |
| INFLUENT | EFFLUENT | ATRAZINE ADSORBED | ATRAZINE LOAD |
(µg/L)	(µg/L)	(mg)	(mg Atrazine/g Carbon)
12.43	0.13	0.94	0.0070
12.64	0.40	3.73	0.0276
12.81	1.04	6.47	0.0479
13.56	2.05	9.14	0.0677
13.18	2.16	11.71	0.0867
13.28	2.42	14.20	0.1052
12.30	2.74	16.53	0.1224
13.36	4.81	18.60	0.1378
11.68	4.33	20.41	0.1512
11.97	4.88	22.33	0.1654
11.58	5.09	24.13	0.1787
11.42	5.53	25.31	0.1875
11.28	5.19	26.90	0.1993
11.34	5.82	27.78	0.2058

Filter #7:   135 grams net dry wt. activated carbon

Filter #3:   568 grams net dry wt. activated carbon

               Cumulative Atrazine Adsorbed: 37.61 mg

               Cumulative Atrazine Load = 37.61 mg Atrazine/568 g Carbon

                                 = 0.066 mg Atrazine/g Carbon

Filter #6:   574 grams net dry wt. activated carbon

               Cumulative Atrazine Adsorbed: 37.22 mg

               Cumulative Atrazine Load = 37.22 mg Atrazine/574 g Carbon

                                 = 0.065 mg Atrazine/g Carbon

Filter #8:   183 + 319 = 502 grams net dry wt. activated carbon plus
                                   fiber

               Cumulative Atrazine Adsorbed: 74.23 mg

               Cumulative Atrazine Load = 74.23 mg Atrazine/502 g Carbon

                                 = 0.15 mg Atrazine/g Carbon