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FIELD SCALE EVALUATION OF COAGULANTS [redacted]ILTRATION OF GIARDIA CYSTS AND OTHER SUBSTANCES

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FIELD SCALE EVALUATION OF COAGULANTS FOR FILTRATION OF *GIARDIA* CYSTS AND OTHER SUBSTANCES

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ABSTRACT

FIELD SCALE EVALUATION OF COAGULANTS
FOR FILTRATION OF *GIARDIA* CYSTS AND OTHER SUBSTANCES

The effect of coagulant dosage on removals of *Giardia* cysts, coliform bacteria, and turbidity was evaluated for two types of raw water. These removals were found for three categories of coagulant dosages: i) optimum, ii) nonoptimum, and iii) no chemicals. The "optimum" and "nonoptimum" dosages were defined with respect to turbidity removal. Lange numbers of *Giardia* cysts and coliform bacteria passed through the rapid rate filter when chemical coagulants were not used; however, removals of greater than 99 percent were obtained by using "optimum" coagulant dosages.

The two waters tested were a 5 to 10 NTU turbidity water from Horsetooth Reservoir and a 0.4 to 0.9 NTU water from fall and winter flows of the Cache La Poudre River. All testing was done using a "package" rapid rate water treatment plant, a 1.3 l/s (20 gpm) Neptune Microfloc WATER BOY . All testing was conducted using "in-line" filtration, with hydraulic loading rates between 2.7 and 3.5 mm/s (4 and 5.2 gpm/ft^2).

Giardia cysts and coliform bacteria were injected into the raw water intake piping of the pilot plant during 31 of the 144 test runs. Of these 31 "contaminant" tests, 9 utilized raw water from the Cache La Poudre River when the turbidity was less than 1 NTU, and 22 used raw water from 5 to 10 NTU Horsetooth Reservoir.

It was determined that the polymer Magnifloc 572-C in conjunction with alum will effectively coagulate Cache La Poudre River water during the winter, i.e. when raw water turbidity levels are less than 1 NTU. By using 7.0 mg/l of alum as $Al_2(SO_4)_3\ 14H_2O$ followed by 2.0 mg/l of Magnifloc 572-C, *Giardia* cyst removals of 95 percent and coliform bacteria removals of 98 percent were obtained from raw water having 0.7 NTU turbidity and less than 1^{o}C temperature. These results confirmed findings from the laboratory scale filtration experiments.

Relationships between turbidity removals, coliform bacteria removals, and *Giardia* cyst removals were established for Horsetooth Reservoir water, and for cold, low-turbidity Cache La Poudre River water. Turbidity removal can serve as a surrogate for coliform bacteria removals and for *Giardia* cyst removals for these two waters.

This field scale study followed guidance established by laboratory scale and bench scale filtration studies which had tested a wider range of conditions, not feasible at the field scale.

Five parallel testing comparisons between the bench scale, laboratory scale, and field scale pilot plants were made in which turbidity removal vs coagulant dose was evaluated for each of the three systems. These comparisons indicated similar performances for the three systems, which helps validate the use of bench scale and laboratory scale testing to evaluate coagulants and to recommend the approximate

dosage for full scale operation. This report constitutes the results of the field scale pilot plant phase of the project area on rapid rate filtration.

ACKNOWLEDGMENTS

The operators at the Fort Collins Water Treatment Plant No. 1 continually offered invaluable advice and assistance. We learned much from them and appreciate their help. Bill Bellamy offered many helpful suggestions, and was particularly useful in the development of the "contaminant" injection and sampling system. Mohammed Al-Ani's research at the lab-scale served as guidance in selecting coagulants and dosages.

Mr. Walt Patzer, Shop Supervisor at the Engineering Research Center, was always cooperative and helpful in solving many of the problems associated with using the WATER BOY for experimental work. Miss Sandy Page, Supervisor of Word Processing, at the Engineering Research Center provided both expertise and fast turn around time as several drafts of this text were developed.

The analysis of Giardia cyst samples and procurement of cysts was done under the supervision of Dr. Charles Hibler, Professor of Pathology. We appreciate the help of Dr. Hibler and his staff and their readiness to work in coordination with our test scheduling, which often was not predictable due to a variety of factors.

The study was funded by the Environmental Protection Agency, Drinking Water Research Division, Project Number CR808650-01. Dr. Gary S. Logsdon was the project officer.

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Chapter 1: INTRODUCTION

1.1 Background

Many surface waters of the Rocky Mountains are termed "pristeen pure", as a descriptive expression of the fact that generally they are aesthetically pleasing. These waters look pure, and more often than not meet the 1 NTU turbidity standard without filtration. In addition, the coliform counts of these waters are usually low also, i.e. in the range of 100 to 1000 coliforms per 100 ml. Such levels are reduced easily to less than 1 coliform per 100 ml by conventional disinfection practice.

Rapid rate filtration is the most common means of treating these low-turbidity, low-temperature waters. However, due to the apparent high quality of the water, and the inadequate knowledge of coagulation for cold, low-turbidity water, there is not strong motivation to add coagulants prior to filtration. Under such conditions of operation the filter serves only as a strainer. Sometimes "token" chemicals are used, which may give a semblance of adequate chemical pretreatment.

When rapid rate filtration is operated as a strainer, i.e. without any chemical pretreatment, a significant portion of the contaminants present in the raw water will pass through the filtration process. A contaminant of particular concern, which is prevalent in these low-turbidity waters, is the cyst of the protozoan Giardia lamblia. The Giardia organism has only recently been implemented as a waterborne disease (Logsdon, 1981). Ingestion of one to ten cysts may cause giardiasis, an intestinal disease which has become of concern since the mid 1970's.

Giardia is a flagellated protozoan and a parasitic pathogen for a variety of animal hosts. It is believed that man, through poor sanitary habits, has contaminated the environment with this organism, and that other warm blooded animals, e.g. beavers, dogs, have further spread it through the environment. The increase in reported cases of giardiasis over recent years is reason for serious concern about development of proper chemical pretreatment methods for cold, low-turbidity waters.

The organism Giardia lamblia is a specific contaminant as defined by PL93-523, the Safe Drinking Water Act, and therefore is of regulatory concern to the Environmental Protection Agency in its administration of the Act. To learn more about how to remove Giardia lamblia cysts, by treatment of raw waters, the Drinking Water Research Division of the Municipal Environmental Research Laboratory at Cincinnati, U.S. Environmental Protection Agency, sponsored research in water treatment at Colorado State University. The project's scope encompassed three filtration technologies: rapid rate, slow sand, and diatomaceous earth, with emphasis on the operation of small systems. A particular concern in the rapid rate studies was filtration of cold, clear waters as found in the Rocky Mountain Region. The rapid rate filtration research was divided into bench scale, laboratory scale, and field scale experimental studies. The work reported herein comprises the field scale portion of the project involving rapid rate filtration.

1.2 Purpose

The propose of this study was to determine, with field scale data, effective operating conditions for removal of Giardia cysts by rapid rate filtration with emphasis on cold, low-turbidity waters.

1.3 Objective

The overall objective was to determine removals of Giardia lamblia cysts, total coliform bacteria, and turbidity as functions of coagulation conditions for cold, low-turbidity water. The specific objective was to use an actual water treatment plant, operating under ambient field conditions, to corroborate effective coagulation conditions as developed by bench and laboratory studies.

1.4 Scope

The research was conducted utilizing a 1.3 l/s (20 gpm) trailer mounted rapid rate filtration water treatment plant, called the WATER BOY by its manufacturer. This WATER BOY was loaned to Colorado State University from the Environmental Protection Agency in Cincinnati. The work plan for this field scale study was coordinated with results from bench and laboratory scale pilot plant studies.

Based upon the bench and laboratory results, the "in-line" mode of filtration was used for all field scale testing. Such ambient conditions accepted for testing included water temperatures ranging from $0^{o}C$ to $15^{o}C$, and turbidity levels ranging from < 1 NTU to 10 NTU.

During this study, the filter of the WATER BOY was challenged by injecting coliform bacteria and Giardia cysts into low-turbidity raw water. This simulated conditions at a full scale water treatment plant where contaminants are present in the raw water supply. The effectiveness of the filtration system was studied by monitoring Giardia lamblia cysts, total coliform bacteria, and turbidity in the effluent stream. Some 144 test runs were conducted, of which 31 used Giardia cysts. Nine of these 31 "contaminant" test runs used raw water from the Cache La Poudre River having turbidity of less than 1 NTU.

Three waters were used in the experimental program: Horsetooth Reservoir water, Cache La Poudre River water during spring runoff, and Cache La Poudre River water during the low-turbidity (less than 1 NTU) winter period. These three waters represent three kinds of raw water situations found in the Rocky Mountain Region, e.g. high-turbidity (>10 NTU), medium-turbidity (2 to 10 NTU), and low-turbidity (<1 NTU). Removals of Giardia lamblia cysts, total coliform bacteria, and turbidity were measured for three coagulation conditions: i) optimum dosage, ii) nonoptimum dosage, and iii) zero dosage. Hydraulic loading rates ranged between 2.7 and 3.5 mm/s (4 and 5.2 gpm/ft^2).

1.5 Significance

The results obtained provide more knowledge concerning evaluation of coagulation practice with respect to removal of Giardia cysts. The

results are intended to provide field scale experimental data for regulatory agencies, sanitary engineers, and water treatment plant operators. The effectiveness of "in-line" filtration provides impetus to build "in-line" plants; when conditions are appropriate. The "no chemical" tests demonstrate the need for coagulation prior to filtration, even when the raw water appears potable. The comparison tests between the bench scale, laboratory scale, and field scale pilot plants help to substantiate the use of bench and laboratory scale testing to evaluate coagulation for full scale operation.

1.6 Literature Review

Hudson (1981) states that the first filtration plant to serve an entire city was placed in service in 1804 at Paisley, Scotland. Before this, according to Hudson, water treatment was practiced in the home. The first era in water treatment in the United States began with the work of J. P. Kirkwood (Hazen, 1913). In 1869 Kirkwood published the report "Filtration of River Waters" which reported his investigation of water treatment practice in Europe (Hazen, 1913). European practice became the "standard" from which the American practice evolved.

Fuller (1892) and Hazen (1913) reported extensive experimental work on filtration conducted at the Lawrence Experimental Station in Massachusetts. In later work by Fuller at Louisville and Hazen at Cincinnati, guidelines for rapid rate filtration practice were developed which are still being used today (Hendricks, 1974). T. R. Camp (1964) has summarized basic theoretical foundations of rapid rate filtration related to hydraulics and removal mechanisms. O'Melia and Stumm (1967) review filtration theory using a physico-chemical approach.

The books by Weber (1972) and Sanks (1979) are compilations of state-of-the-art knowledge developed by recognized experts in the water treatment field. Sanks' book (1979) deals with all aspects of water treatment, including regulatory, economics, theory, and design. Weber's book (1972) deals mostly with theoretical aspects of water treatment, including the theory of coagulation and filtration.

The EPA report edited by Jakubowski and Hoff (1979) covers the characteristics, detection, epidemiology, and removal by water treatment of *Giardia*. The book by Jakubowski and Hoff also covers the disease giardiasis. Lange (1983) gives a summary of the work by Jakubowski and Hoff.

Logsdon (1981) reports that after reviewing the literature he found "...no research on water filtration for *Giardia* cyst removal." Logsdon (1981) states also, that filtration studies of the 1930's and 1940's were, however, conducted for removing *Entamoeba histolytica* cysts. Al-Ani and Hendricks (1983) report experimental work at Colorado State University on removing *Giardia* cysts from low-turbidity water using "in-line" filtration. The study by Al-Ani (1984) was conducted simultaneously with the study reported in this work.

Chapter 2: METHODOLOGY

The approach to the research was empirical, using a small water treatment plant, a Neptune Microfloc 1.3 l/s (20 gpm) WATER BOY, as a physical model. Using this system, removals of Giardia lamblia cysts, total coliform bacteria, and turbidity were investigated for different waters as a function of coagulant dosages. Experimental work began in November 1982, and continued as conditions permitted through January 1984. The research plan was designed for a limited amount of testing due to logistic problems of operating the 1.3 l/s (20 gpm) WATER BOY pilot plant, and due to the limited testing period available for testing the ambient water conditions desired, i.e. low-turbidity, low-temperature waters.

In this section the pilot plant is described first. Then the research plan is outlined, with descriptions of the type of tests, the testing phases, and the test conditions.

2.1 WATER BOY Pilot Plant

Appendix A describes the WATER BOY pilot plant and its operation. This section abstracts from Appendix A to indicate how the WATER BOY was used in this research.

2.1.1 Description of Pilot Plant

Figure 2-1, which is the same as Figure A-6, is a schematic diagram of the WATER BOY rapid rate water filtration plant as modified for use in this research. Figure 2-1 shows the chemical feed system, the contaminant injection system, the sampling system, and the "in-line" filtration mode, which was used in this research. Figure 2-2 is a photograph of the WATER BOY. The WATER BOY is a Neptune Microfloc model WB-27 package water treatment plant. It was purchased by the U.S. Environmental Protection Agency Drinking Water Research Division in Cincinnati and mounted on a 22 foot trailer in order to have a mobile water treatment plant as a research tool. The plant was loaned to Colorado State University for this project.

Although nominally operated at 1.3 l/s (20 gpm), the WATER BOY has an upper limit water production capacity of 1.7 l/s (27 gpm), which is 4.6 mm/s (6.75 gpm/ft^2) hydraulic loading rate. At the production rate of 1.3 l/s (20 gpm), the plant can furnish water for 192 people based upon a per capita water consumption of 568 l/day/person (150 gpd/person). The plant is flexible in operation, permitting easy conversions between the three modes of filtration, i.e. "conventional" (rapid mix, flocculation, sedimentation, filtration), "direct" (rapid mix, flocculation, filtration), and "in-line" (rapid mix, filtration).

2.1.2 Appurtenances Utilized with Pilot Plant

Additional appurtenances were added to the pilot plant to provide for chemical feed, contaminant injection, and sampling. Figure 2-1 shows these appurtenances schematically, and Table 2-1 lists them. Special attention was given to in-pipe mixing of chemicals and contaminant injection. For example, the contaminants were injected into the middle of the pipe and four elbows were added to insure proper mixing prior to influent sampling at another point in the pipe. Similar

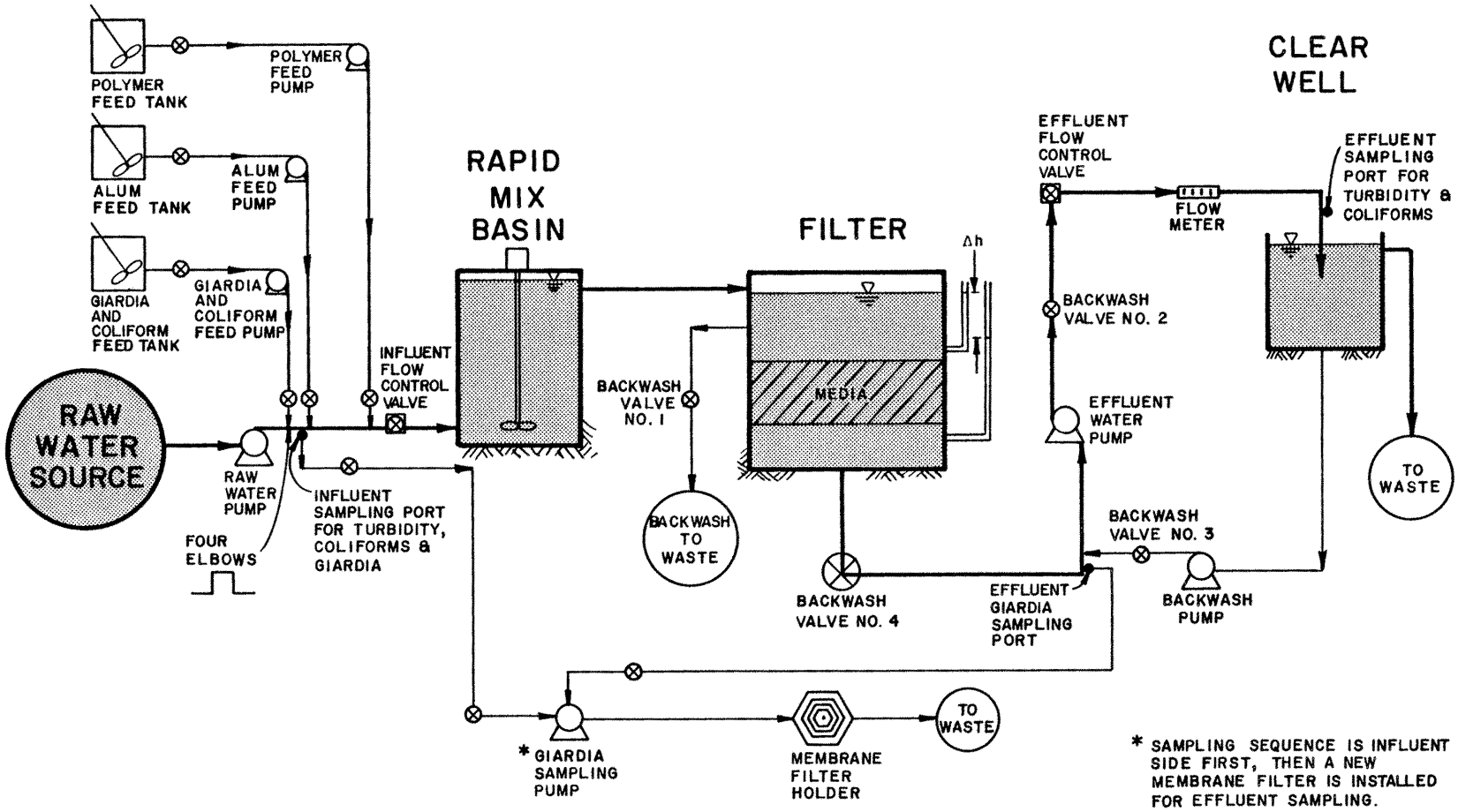

Figure 2-1. Schematic diagram of the WATER BOY pilot plant showing chemical feed, contaminant feed, and sampling systems

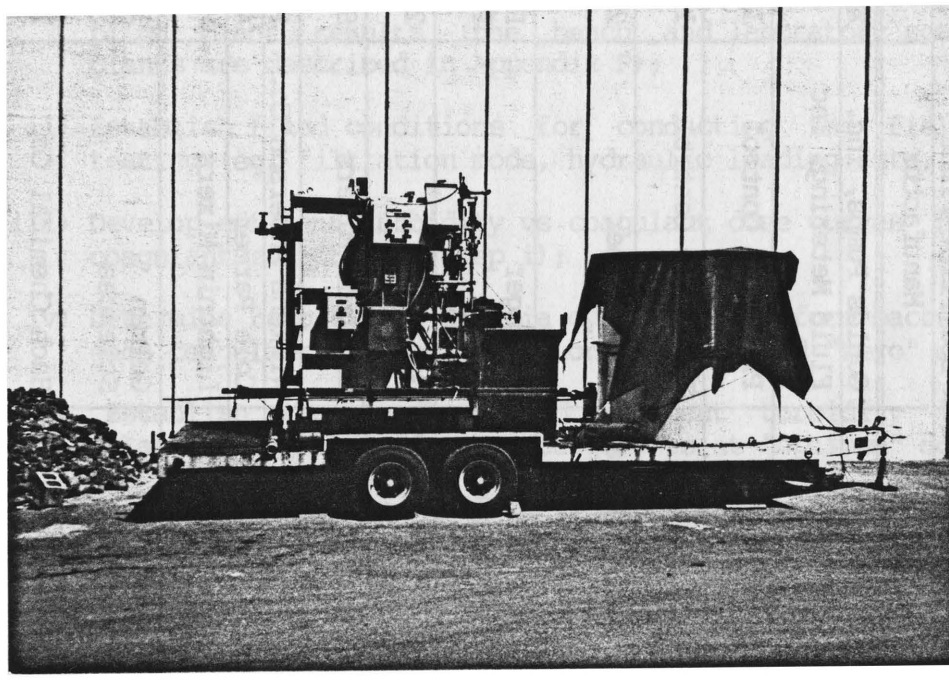

Figure 2-2. WATER BOY pilot plant on 22 foot trailer. The large cylindrical tank is the 4000 l clear well

Table 2-1. Appurtenances for[1/] WATER BOY Pilot Plant

Item	Purpose & Specifications	Manufactor	Model #
Raw Water Pump	Pumps Raw Water into Rapid Mix	Goulds Pumps, Inc.	XSH 15
Contaminant Feed Pump	Meters the contaminant batch into the main flow (0 to 1120 ml/min)	Fluid Metering, Inc	RP-D
Alum Feed Pump	Meters alum solution into main flow (0 to 75 ml/min)	Precision Control	111311-361
Polymer Feed Pump	Meters polymer solution into main flow (0 to 75 ml/min)	Precision Control	111311-361
Sodium Thiosulfate Feed Pump	Feeds $Na_2S_2O_3$ solution into effluent stream for dechlorination (50 to 1000 cc/min)	Cole Parmer	212
Giardia Sampling Pump	Diverts sampling stream from main flow through membrane filter (0 to 8.5 l/min)	Grainger	Rotary Beam Pump 1P771
Giardia Sampling Pump Motor	Drives *Giardia* sampling pump (3/4 hp)	Grainger	27846
Contaminant Batch Mixer	Agitates contaminant batch	Lightnin Mixers	Series 20
Alum Batch Mixer	Mixes alum solution	Wilkens-Anderson Co.	Power Stirrer
Polymer Batch Mixer	Mixes polymer solution	Cole Parmer	4555 H
Rapid Mix Basin Mixer	Disperses chemicals in rapid mix basin (1/4 hp) 1725 rpm	Lightnin Mixers	Mark II
Membrane Filter Holder	Holds 5 μm pore size 293 mm diameter membrane filters made by Nucleopore Corporation	Gelman Sciences	11873
Ratio Turbidimeter	Measures grab samples for turbidity	Hach Chemical Co.	18900-10
Flow-through Turbidimeter	Monitor influent and effluent turbidity	Hach Chemical Co.	1720-A

[1/] WATER BOY was Neptune Microfloc Model WB-27 package water treatment plant. The WATER BOY is described in Appendix A.

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[1/] WATER BOY was Neptune Microfloc Model WB-27 package water treatment plant. The WATER BOY is described in Appendix A.

precautions were taken to insure representative effluent samples. Appendix A describes the modifications for these purposes.

2.2 Research Plan

2.2.1 Strategy

The research plan is enumerated below. It represents the strategy for conducting the experimentation.

i) Select coagulants based upon bench scale and laboratory scale pilot plant results (the bench and laboratory scale pilot plants are described in Appendix F);

ii) Establish fixed conditions for conducting the field scale testing (eg. filtration mode, hydraulic loading rate, etc.);

iii) Develop effluent turbidity vs coagulant dose curves for each coagulant selected in step i);

iv) Determine removals of Giardia cysts and coliform bacteria for each coagulant at "optimum","nonoptimum", and "zero" dosages;

v) Establish the headloss and effluent turbidity vs time relations for the effective coagulants at "optimum" dosage.

vi) Execute steps i) to v) for Horsetooth Reservoir water and for low-turbidity Cache La Poudre River water.

vii) Compare the bench, laboratory, and field plants by parallel testing.

Step vii) was to investigate if the bench, laboratory, and field plants yield similar results.

2.2.2 Types of Tests

The research plan encompassed four categories of testing: i) effluent turbidity vs coagulant dose; ii) Giardia cyst and coliform bacteria removals vs coagulant dose; iii) headloss and effluent turbidity vs time; and iv) parallel testing the bench, laboratory, and field plants. These testing categories are described below.

Effluent Turbidity vs Coagulant Dose. The effluent turbidity vs coagulant dose tests were to establish relationships between finished water turbidity and coagulant dosage, for specified conditions (e.g. type of water, hydraulic loading rate, etc.). The purpose was to determine the "optimum" coagulant dosage range for the field scale pilot plant, as defined by turbidity removal. The effluent turbidity after one-hour of operation was taken as the "stabilized" turbidity. No Giardia cysts or coliform bacteria were injected during these tests.

Giardia Cyst and Coliform Bacteria Removals vs Coagulant Dose. Once the relationship between effluent turbidity and coagulant dosage was established, tests were performed to determine removals of Giardia

cysts and coliform bacteria at "optimum" and "nonoptimum" chemical dosages, and at "zero" dosage. The "zero" dosage tests were to establish a "baseline" to compare Giardia cyst and coliform bacteria removals with the same tests using coagulant chemicals.

The Giardia cyst and coliform bacteria removals vs coagulant dose testing protocol consisted of: i) backwashing; ii) starting the raw water pump, the chemical feed pumps, and the contaminant injection pump; iii) waiting for one-hour for the system to stabilize; iv) sample influent and effluent for Giardia cysts and coliform bacteria concentrations.

Headloss and Effluent Turbidity vs Time. The headloss vs time and effluent turbidity vs time tests were run together. These tests were to evaluate the practical aspects of filtration, e.g. whether adequate run time is possible before backwashing is required. The run was continued long enough to establish the headloss vs time and the effluent turbidity vs time relations. Some runs were continued until turbidity breakthrough occurred, or until terminal headloss, i.e. about 7 feet of water, occurred. This testing was not the main focus of the experimentation and was not done for the low-turbidity testing. These tests were performed mostly during the filtration testing of spring runoff water.

Comparisons Between the Bench, Laboratory, and Field Plants. The parallel testing between the bench, laboratory, and field plants were to compare the three systems. The bench scale and laboratory scale pilot plants are described in Appendix F. These comparisons were to evaluate how well the bench scale and laboratory scale plants predict the operation of the WATER BOY. During these parallel tests, each pilot plant developed effluent turbidity vs coagulant dosage curves for the same water and coagulant, and used the same conditions of filtration, eg. filtration mode, filtration media, etc. The resulting plots of effluent turbidity vs chemical dose were used as the basis for comparing the three systems.

2.2.3 Testing Phases

The four experimental phases were: i) Familiarization testing; ii) Spring Runoff testing; iii) Horsetooth Reservoir testing; and iv) Low-Turbidity testing. They are described below.

Familiarization Testing. The familiarization testing was conducted from 11/9/82 to 2/9/83. The WATER BOY was located on the floor of the hydraulics laboratory at the Engineering Research Center and used water from Horsetooth Reservoir. The purpose was to develop experience with the pilot plant and to determine the sizing for appurtenances such as chemical storage tanks, chemical feed pumps, etc. Appendix E contains effluent turbidity vs time curves obtained during this testing phase. From work in this testing phase, the "stabilized" turbidity was determined as the effluent turbidity after one-hour of operation. During this phase, the WATER BOY appurtenances included only those for injecting chemicals, sampling turbidity, and measuring headloss. The Giardia cyst and coliform bacteria feed and sampling systems were not installed until the Horsetooth Reservoir testing phase.

Spring Runoff Testing. The spring runoff testing was conducted from 4/23/83 to 6/1/83 at the Fort Collins Water Treatment Plant No. 1. The water used for testing was from the Cache La Poudre River during spring runoff. The intent was to begin testing in early March to experiment with low-turbidity, i.e. less than 1 NTU, raw water. Disruption of electric power, however, required replacement of a buried cable. This delayed the start up of the WATER BOY and the testing did not begin until after the start of the spring runoff in late April. So, when the spring runoff began, it was decided to go ahead and treat the high turbidity water. Appendix C contains the results from Spring Runoff testing.

During spring runoff, the raw water turbidities of the Cache La Poudre River ranged between 12 and 44 NTU, and raw water temperatures ranged between 7 and 10 ^{o}C. The river's properties were continually changing, raw water turbidity fluctuations were as much as 10 NTU per hour.

Horsetooth Testing. The Horsetooth Reservoir testing was conducted from 7/3/83 to 8/31/83 at the Engineering Research Center at Colorado State University using Horsetooth Reservoir water as a raw water source. During the first part of this phase, the contaminant injection and sampling system was incorporated into the flow scheme of the WATER BOY, and tests were run to establish procedures for tests to determine removals of Giardia cysts and coliform bacteria. Once the protocol for Giardia cysts and coliform bacteria removals vs coagulant dose tests was established, 22 of these tests were conducted with Horsetooth water.

Although the focus of this research was to determine removals using raw waters with turbidities less than 1 NTU, the Horsetooth Reservoir testing validated testing procedures, and provided results to compare those obtained from low-turbidity testing. Horsetooth Reservoir provided a raw water source with predictable and relatively constant properties. The turbidity and temperature ranges for Horsetooth Reservoir water are 3 to 12 NTU and 2 to 15 ^{o}C, respectively, over the annual cycle.

Horsetooth Reservoir water has low-turbidity when compared to water sources which have turbidities as high as 100 to 200 NTU. But if compared to the water of the Cache La Poudre River during late fall and winter, Horsetooth Reservoir water is within a "medium" range of turbidity.

The traditional filtration practice is comprised of: i) particle destabilization by coagulation, ii) floc production, and iii) floc penetration into the filter. This practice is applicable to Horsetooth Reservoir water. But when the raw water turbidity is below 1 NTU, this traditional practice of filtration does not seem to work. So, since Horsetooth Reservoir water could be properly coagulated and filtered in accordance with traditional practice, the use of this water source enabled development of confidence in the WATER BOY's operation. This confidence was extended to the coliform and Giardia cyst sampling protocols, respectively.

In using Horsetooth Reservoir water the WATER BOY could be setup inside the Engineering Research Center at Colorado State University. This facilitated development of procedures since there was no need to protect against freezing. Also the Engineering Research Center shop and supply room were nearby. For these reasons Horsetooth water was used to develop the Giardia cyst and coliform bacteria injection and sampling procedures.

Low-Turbidity Testing. The low-turbidity testing was conducted from 11/1/83 to 1/8/84 at the Fort Collins Water Treatment Plant No. 1 using Cache La Poudre River water during late fall and early winter. During this testing phase, the raw water turbidity was always less than 1 NTU.

Traditional filtration practice does not address the problem of low-turbidity, i.e. less than 1 NTU, raw waters. Also, no acceptable mechanism has been formulated to explain how to treat such waters with essentially "no particles". So, the low-turbidity testing phase was the main interest of this research project.

The low-turbidity testing was also the most difficult phase of the research, due not only to the problems of treating the low-turbidity water, but also due to the fact that the air temperatures were often below freezing, and due to the project-imposed requirement that effluent from the WATER BOY must be chlorinated and then dechlorinated during runs which used Giardia cysts and coliform bacteria. Another problem of the low-turbidity testing phase was disposal of the backwash from the Giardia cyst and coliform bacteria removals vs coagulant dose testing, where the backwash water contained high concentrations of both cysts and bacteria.

Careful considerations were given to the above problems. For example, to prevent damage from freezing temperature, the WATER BOY was drained every evening after testing. And to protect against bacteria and Giardia cyst hazards the plant was set up near the inlet to the Fort Collins Water Treatment Plant's septic system where the backwash water was placed during Giardia cyst and coliform bacteria removal testing. Also, the effluent was chlorinated with 10 mg/l of chlorine, then a detention time of 50 minutes was provided prior to dechlorination with sodium thiosulfate. This chlorination-dechlorination was provided only during runs in which Giardia cysts and coliform bacteria were used.

2.2.4 Test Conditions

In this section, the conditions of the experimental testing are explained. These conditions are: i) variables, ii) raw water, iii) filtration conditions, and iv) coagulants.

Variables. To accomplish the objectives of the research, some independent variables were maintained constant, i.e. fixed, while other independent variables were changed from one test run to the next. The independent variables changed were: type of primary coagulant, or dosage of primary coagulant.

All variables, independent and dependent, are illustrated in Figure 2-3, which shows the overall large testing space and the portion tested in this study. The long lines from the origin represent the possible ranges for a specific variable. The range actually tested is indicated by a specific region on this line. For example, the line labeled "water source" represents the many thousand water sources of the world. But in this project, only three waters were tested, i.e. Horsetooth Reservoir water, Cache La Poudre River water during spring runoff, and Cache La Poudre River water during low-turbidity. These three waters are indicated as specific points on this line.

These variables illustrated in Figure 2-3 are grouped below as dependent and independent variables, showing how they pertain to the testing program.

Dependent variables:

i) effluent turbidity

ii) Giardia percent removal

iii) coliform percent removal

iv) headloss across filter

Independent variables:

i) primary coagulant: type and dosage

ii) secondary coagulant: type and dosage

iii) water source: Horsetooth Reservoir and Cache La Poudre River

iv) turbidity (ambient)

v) alkalinity (ambient)

vi) temperature (ambient)

vii) pH (ambient)

viii) rapid mix: G and T (fixed)

ix) mode of filtration: in-line

x) hydraulic loading rate (fixed)

xi) concentration of loading parameters:
coliform bacteria
Giardia cysts

Raw Water. Three types of water were used in the study: i) Horsetooth Reservoir water, ii) Cache La Poudre River water during spring runoff, and iii) Cache La Poudre River water during late fall and

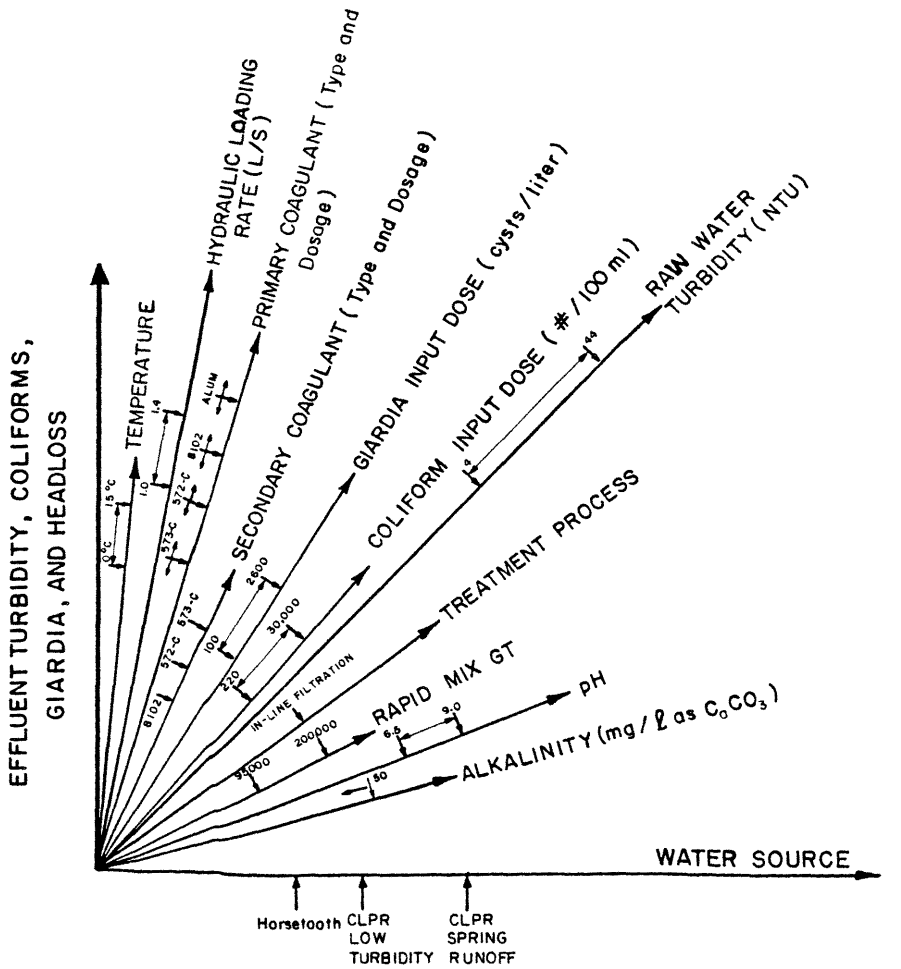

Figure 2-3. Dependent and independent variables. Bold vertical line represents dependent variables. The other lines illustrate the possible range of conditions. The actual conditions tested are shown as sections or points on these other lines.

winter when the raw water turbidity was less than 1 NTU. Table 2-2 shows the raw water characteristics of these waters.

Filtration Conditions. All testing was conducted using "in-line" filtration, with hydraulic loading rates between 2.7 and 3.5 mm/s (4 and 5.2 gpm/ft^2). Table 2-3 shows the ranges of filtration conditions which were tested. Several of these conditions are interrelated. For example, if the flow rate is decreased then the hydraulic loading rate is decreased and the rapid mix detention time is increased.

Figure 2-4 illustrates "in-line" filtration, which is conventional filtration without flocculation or sedimentation, i.e. injection of the chemicals, rapid mixing, and then filtration. During "in-line" filtration, all material removed from the raw water, and the chemicals added to remove this material are collected within the filter; therefore this mode of filtration is useful only for waters with low-turbidity, eg. less than 10 NTU. The reason why the "in-line" mode of filtration was chosen for the field scale testing is discussed below.

The laboratory pilot plant, which is described in Appendix F, had performed tests to ascertain which mode of filtration (conventional, direct, or "in-line") is superior for work with low-turbidity waters. The results indicated all three modes yield approximately the same effluent turbidity and headloss (Al-Ani, 1984). Therefore, since removing a process from the treatment train affords lower capital and operating costs, the "in-line" filtration mode was chosen as the filtration mode in which to conduct the field scale research.

Coagulants. Manufacturer's data on the three polymers used are presented in Appendix G. These polymers and alum were tested in the following combinations:

i) No Chemicals, i.e. filter used as strainer,

ii) Magnifloc 572-C as sole coagulant,

iii) Magnifloc 573-C as sole coagulant,

iv) Nalco 8102 as sole coagulant,

v) Alum as sole coagulant,

vi) Alum followed by Nalco 8102,

vii) Alum followed by Magnifloc 572-C,

The reasons why these specific coagulants were selected for study is discussed below.

Prior to and coinciding with the field scale study using the WATER BOY, bench scale and laboratory scale pilot studies were conducted. One of the objectives was to determine the most effective coagulants for treating cold, low-turbidity water. These pilot studies indicated that the polymers Magnifloc 572-C and Magnifloc 573-C are effective in

Table 2-2.[1/] Raw Water Characteristics (average yearly ranges)

Characteristic	Horsetooth Water	Cache La Poudre During Spring Runoff	Cache La Poudre During Low Turbidity
Turbidity (NTU)	3 to 12	10 to 11	0.5 to 1.5
Temperature (C)	2 to 15	6 to 12	<1 to 7
pH	7.0 to 8.0	7.0 to 8.0	7.5 to 8.0
Alkalinity	10 to 50	30 to 40	35 to 45

[1/] Source: Summary of Chemical Analysis, 12 month averages, City of Fort Collins, 1981.

Table 2-3[1/]. WATER BOY Filtration Conditions (as tested)

Condition	Range of Value Tested
Flow Rate, l/s (gpm)	1.0 to 1.4 (16 to 22)
Hydraulic Loading Rate, mm/sec (gpm/ft^2)	2.7 to 3.5 (4 to 5.2)
Rapid Mix Detention Time, T sec (minutes)	145 to 250 (2.4 to 4.2)
Rapid Mix Velocity Gradient, G per sec	660 to 780
Rapid Mix GT	95000 to 200000
Turbidity of Water NTU	0.4 to 44
Temperature of Water ^{o}C	<1 to 13

[1/] Abstracted from Table B-1.

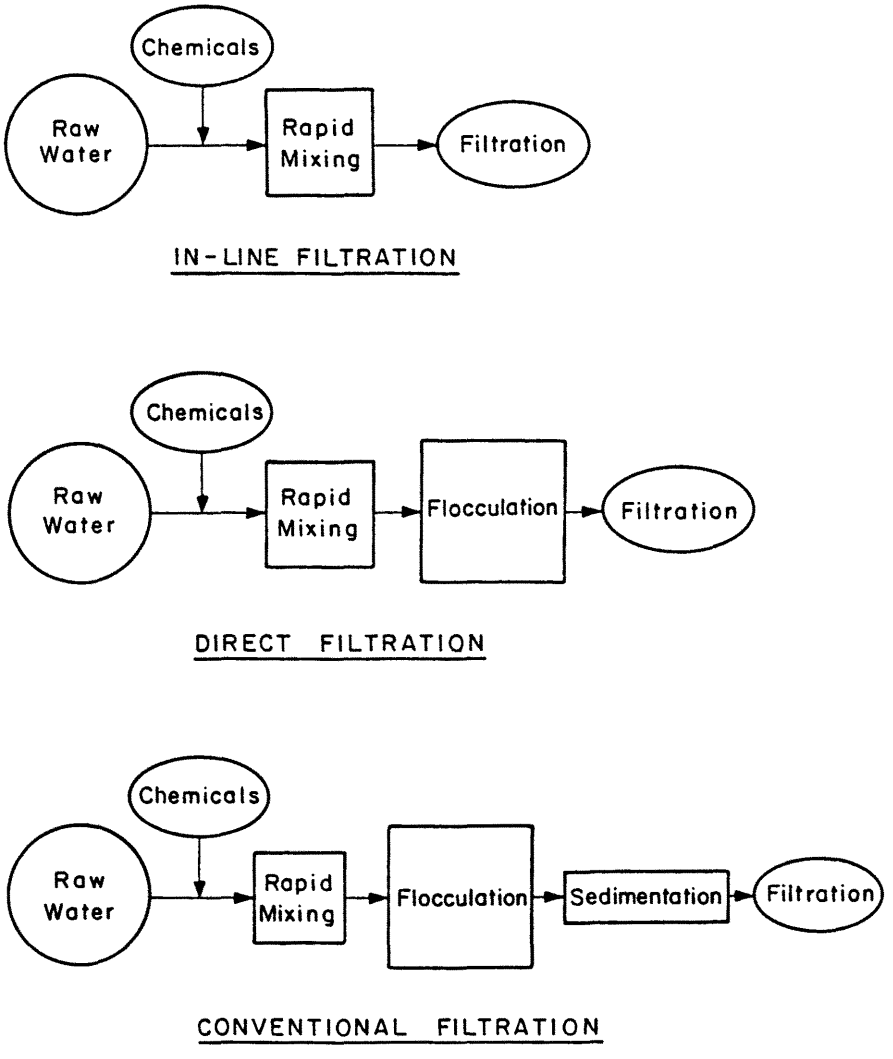

Figure 2-4. Schematics of in-line, direct, and conventional filtration.

treating cold, low-turbidity water when used with alum (Al-Ani, 1984). Therefore three of the four coagulants selected for this field scale study were: alum, Magnifloc 572-C, and Magnifloc 573-C.

The fourth coagulant used was Nalco 8102. This polymer is used commonly in the Rocky Mountain region, as indicated by a survey of chemical pretreatment, given in Appendix H. The survey was done to see which chemicals are used in practice, as another means of screening polymers from the hundreds available.

2.3 Sampling and Measurements

The following sections describe sampling and measurement of turbidity, headloss, total coliform bacteria, and *Giardia* cysts.

2.3.1 Turbidity Sampling and Measurement

Figure 2-5 shows the Hach Ratio Turbidimeter model 18900-10 used to measure turbidity during the Familiarization testing phase and during the Horsetooth testing phase. A similar Hach Ratio Turbidimeter model 18900-10 was used to measure turbidity during the Spring Runoff testing phase and during the Low-Turbidity testing phase. Figure 2-6 shows the two Hach Flow-Through Turbidimeters model 1720-A mounted on the WATER BOY which were used to monitor the influent and effluent turbidity during all the testing phases.

All recorded turbidity readings were obtained from grab samples measured with the Hach Ratio Turbidimeters model 18900-10. Figure 2-1 shows the points where the influent and effluent grab samples were taken.

2.3.2 Coliform Sampling and Measurement

Influent and effluent coliform samples were obtained from the same ports as turbidity samples as shown in Figure 2-1. Coliform samples were obtained in autoclaved bottles and taken to the microbiology laboratory, where culturing was in accordance with total coliform membrane filter procedures (Standard Methods, 1980).

The coliform source was wastewater primary effluent. The primary effluent was mixed with raw water and placed into the *Giardia* and coliform feed tank, 50 liter capacity, and then metered into the main flow stream. The injection procedure for coliforms is discussed below in section 2.3.4.

2.3.3 Headloss Measurement

Figure 2-7 shows the headloss board used to measure headloss across the filter. Water piezometers were used to measure head, with taps located above and below the filter media.

2.3.4 *Giardia* Cyst Procurement and Injection

Giardia cysts were obtained from dog feces obtained from the Larimer County Humane Society, Fort Collins, Colorado. The fecal samples were

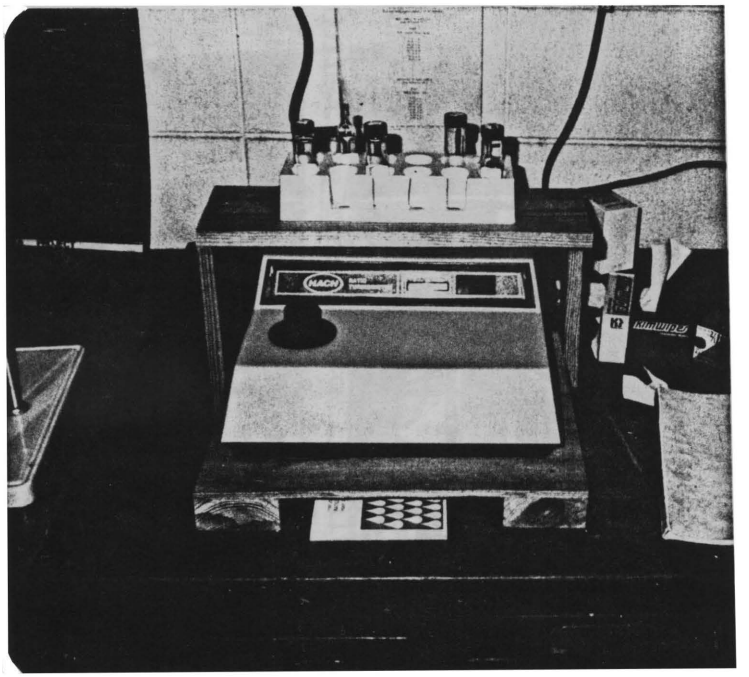

Figure 2-5. Hach ratio turbidimeter model 18900-10 used to measure turbidity

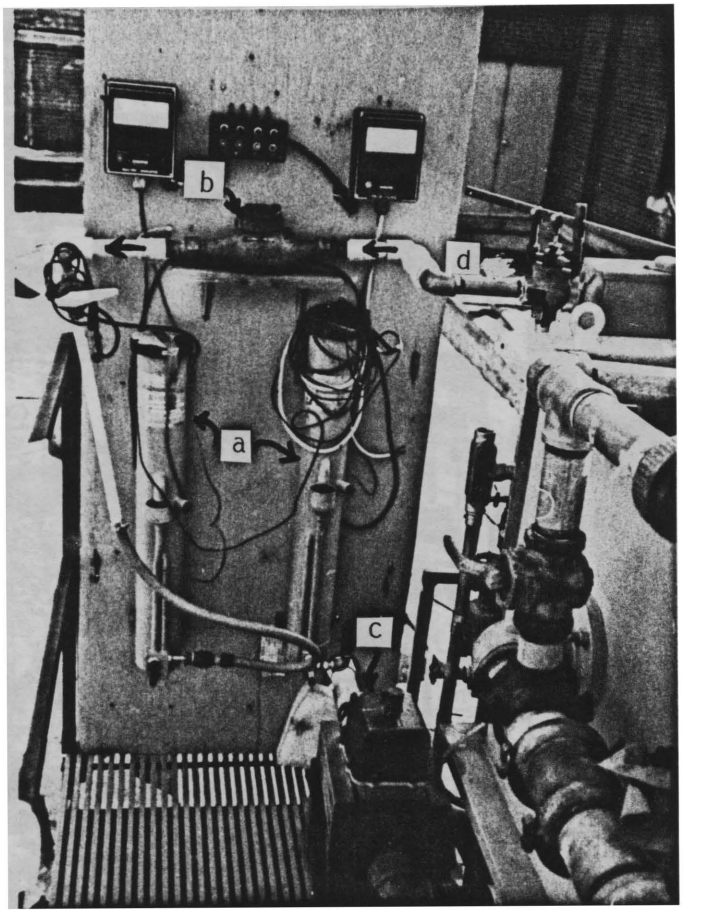

Figure 2-6. a) Hach flow-through turbidimeters, b) flow meter used to measure main flow, c) backwash valve #1, d) effluent flow control valve

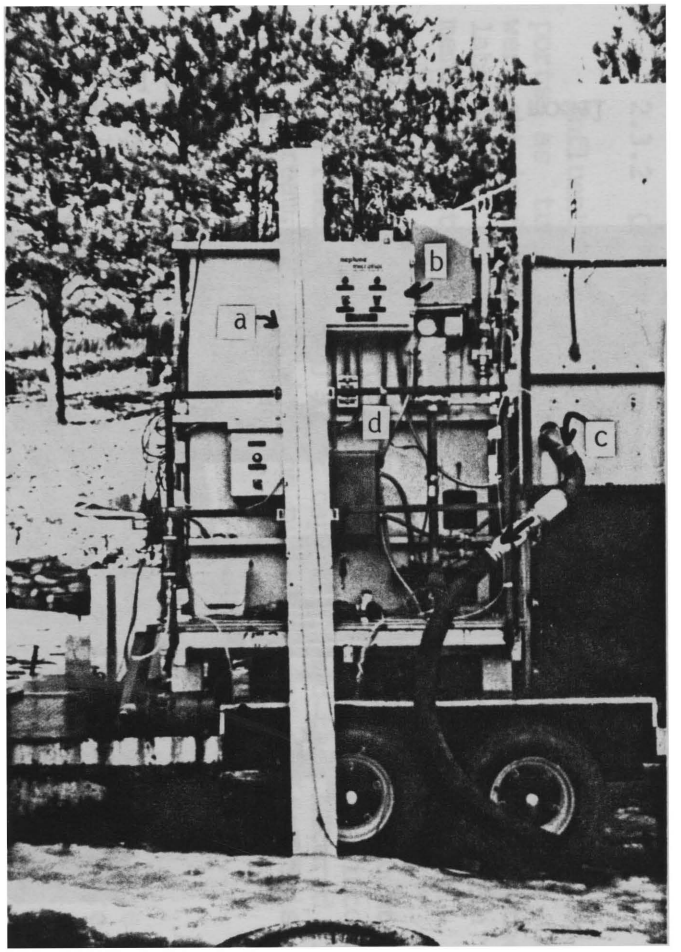

Figure 2-7. Side view of WATER BOY: a) headloss board with piezometers, b) main control panel, c) backwash hose, d) minor control panel

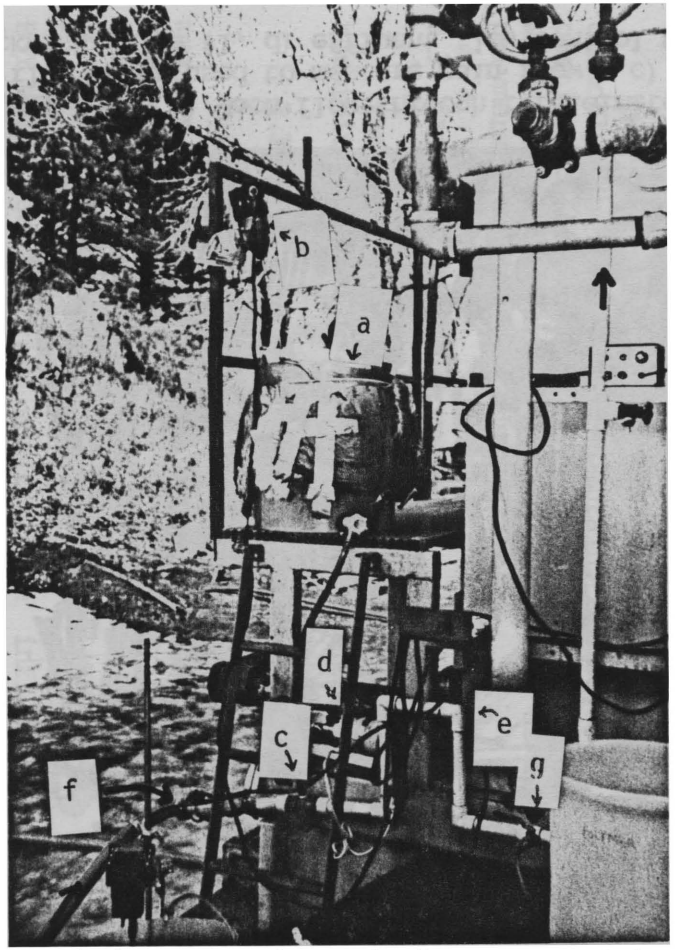

Figure 2-8. Contaminant feed system: a) batch tank, b) mixer, c) injection port, d) metering pump, e) four elbows for mixing contaminants with raw water, f) raw water line, g) influent sampling port for Giardia, coliforms, and turbidity

taken to Dr. Hibler's laboratory at Colorado State University and checked for the presence of cysts. If cysts were present, then the sample was weighed and then added to an equal weight of cool, distilled water and stored at between 2 and 8 ^{o}C until used. Dog feces were not used if over 10 days old. When used, this suspension of dog feces and distilled water was placed into the Giardia and coliform feed tank where it was mixed with raw water.

Figure 2-8 shows the contaminant injection system used to inject the mixture. This mixture of raw water, dog feces suspension, and wastewater primary effluent was agitated by a mixer while it was metered into the main flow stream by a positive displacement pump.

2.3.5 Giardia Sampling

Giardia sampling was done by passing a sampling stream, tapped from the influent and effluent pipes, respectively, through a membrane filter. Figure 2-1 shows the points in the flow scheme where the influent and effluent were sampled for Giardia. Figure 2-9 shows the membrane filter apparatus used to hold the 293 mm diameter, 5-micrometer pore size, polycarbonate filters made by Nucleopore Corporation.

The following outline lists the steps involved in obtaining an influent, or effluent, Giardia sample. The only difference between an influent and an effluent sample was the point where the sampling stream was withdrawn from the main stream. Again, Figure 2-1 shows the Giardia cyst sampling ports.

i) Place membrane filter on stainless steel support plate, and securely screw on top of filter holder.

ii) Attach sampling port to the Giardia sampling pump. Giardia sampling pump is shown in Figure 2-10.

iii) Attach sampling pump to membrane filter.

iv) Open sampling port and turn on sampling pump.

v) Open air vent on membrane filter holder until water comes out, then close air vent. This bleeds air from filter holder.

vi) Collect the effluent from the filter holder in a calibrated tank. The flow rate was about 2 gpm; this represents about 10 percent of the main flow stream.

vii) Pass the sampling stream through the filter holder until the headloss across membrane filter reaches about 20 psi, then turn-off pump and close port.

viii) Wait a few minutes until the water goes through the filter holder and into the calibrated tank.

ix) Record amount of water collected in calibrated tank.

x) Disconnect sampling pump from filter holder.

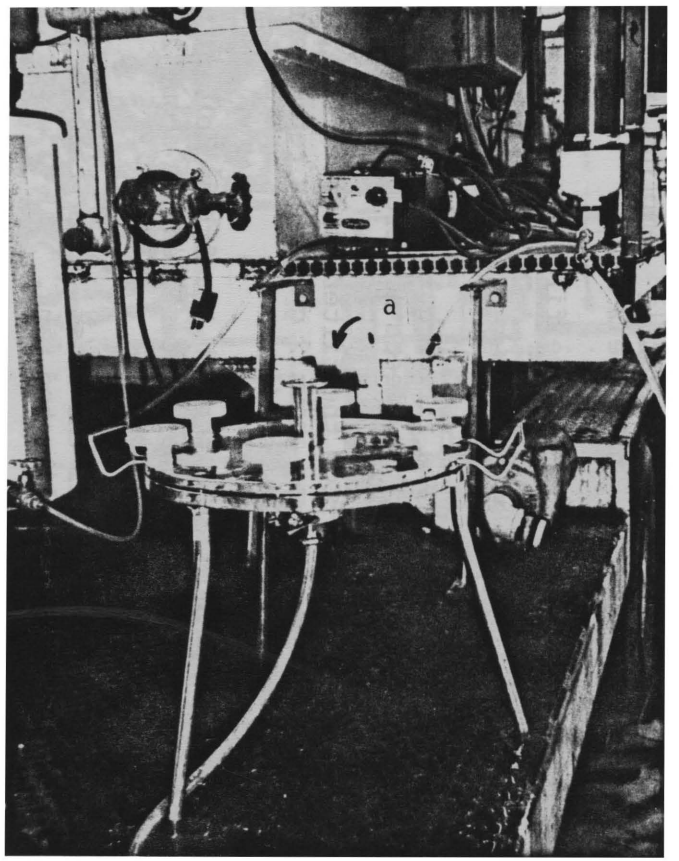

Figure 2-9. a) Membrane filter holder used to hold 5 μm pore size, 293 mm diameter membrane filters

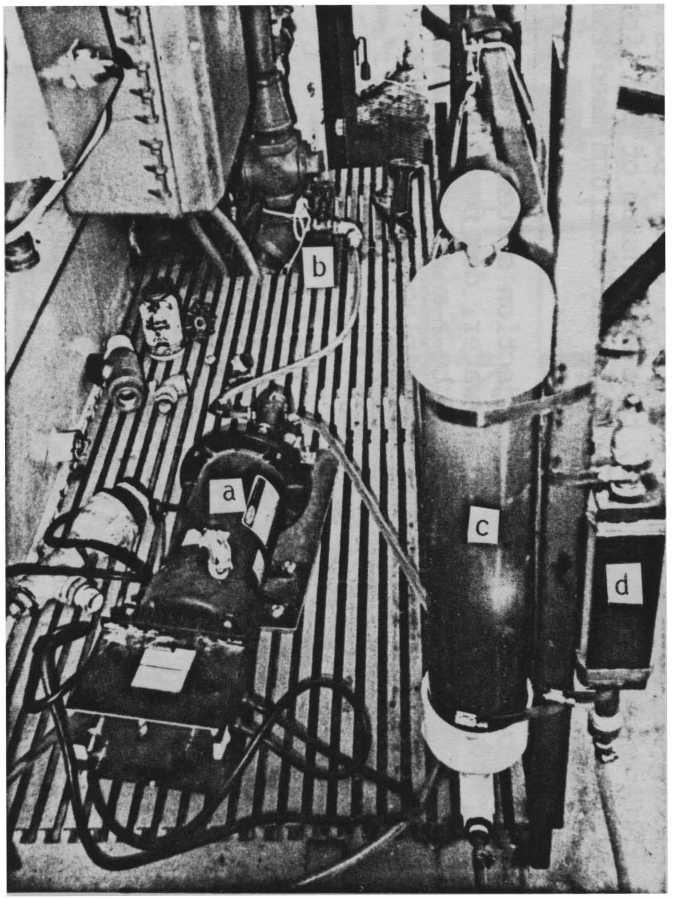

Figure 2-10. a) Giardia sampling pump, b) effluent sampling port for Giardia, c) dampener to stabilize the sampling stream, d) flow meter used to measure sampling flow rate

xi) Tilt membrane filter holder over a glass pyrex tray and open the holder slowly allowing excess water to flow into tray. This is shown in Figure 2-11.

xii) Take top of filter holder off and rinse it, allowing the wash water to flow into the pyrex tray. Figure 2-12 shows this.

xiii) Tilt filter holder over tray and rinse cysts from membrane filter into tray. Shown in Figure 2-13.

xiv) Pour contents of tray into a mason jar labeled with sample number, as shown in Figure 2-14. Spray off tray to assure complete transfer of sample.

xv) Refrigerate sample immediately.

2.3.6 Giardia Cyst Counting

All cysts were counted by Dr. Charles Hibler, College of Veterarian Medicine, Colorado State University. Appendix I describes the micropipette technique which Dr. Hibler used to count the cysts.

2.4 Data Management

Each of the 144 test runs used a data sheet as shown in Figure 2-15. All the data for a given run was recorded on one of these sheets, including reduced data such as detected influent *Giardia* and coliform concentrations. In this way, any information on a run could be obtained by referring to the respective data sheet.

From these individual data sheets, a "master" table, Table B-1, was constructed. From this master table, all figures and tables illustrating the experimental testing were constructed.

The curves drawn on the figures are not intended to convey statistical analysis of the data. These curves are "best fits" according to the author, and are to aid the reader in locating data points.

2.5 Quality Control

To assure that valid measurements were being obtained, a quality control plan was developed. The plan was implemented into daily experimental procedures by use of the data sheet shown in Figure 2-15.

2.5.1 Flow Measurements

Flow rates were made volumetrically, and documented on the individual test data sheets. In this way, there were no discrepancies as to flow rates being obtained from pump settings. Most pumps tend to change flow as the pressure varies.

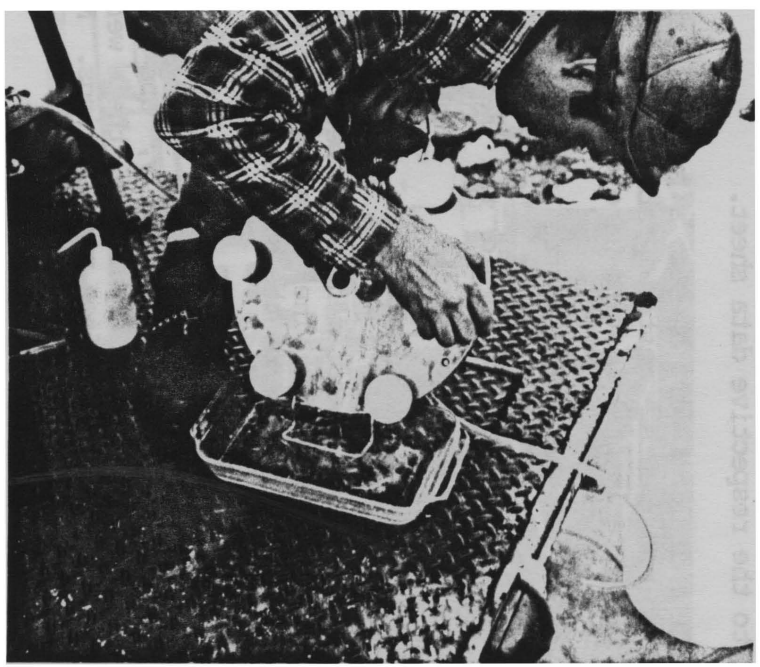

Figure 2-11. Membrane filter holder being opened allowing excess water to flow into pyrex tray

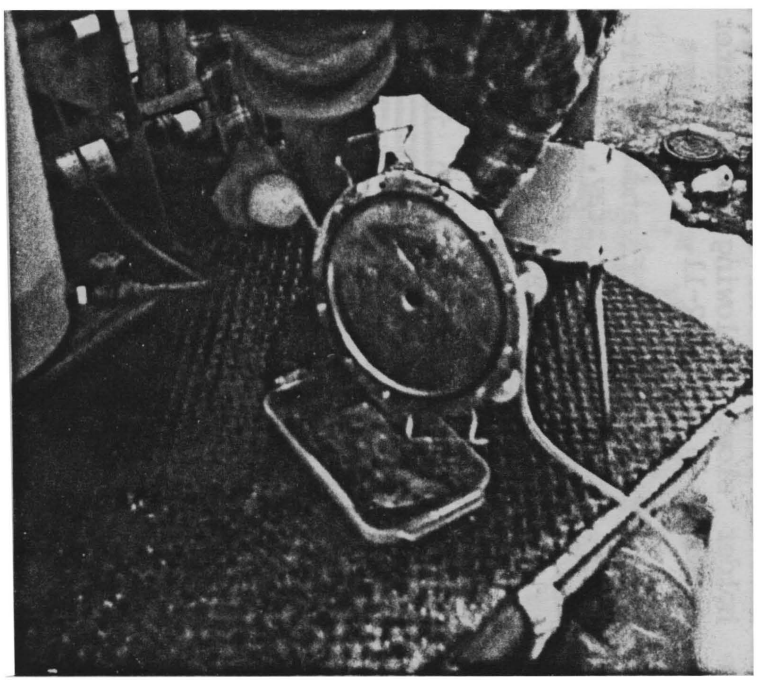

Figure 2-12. Top of membrane filter holder being rinsed, allowing wash water to flow into pyrex tray

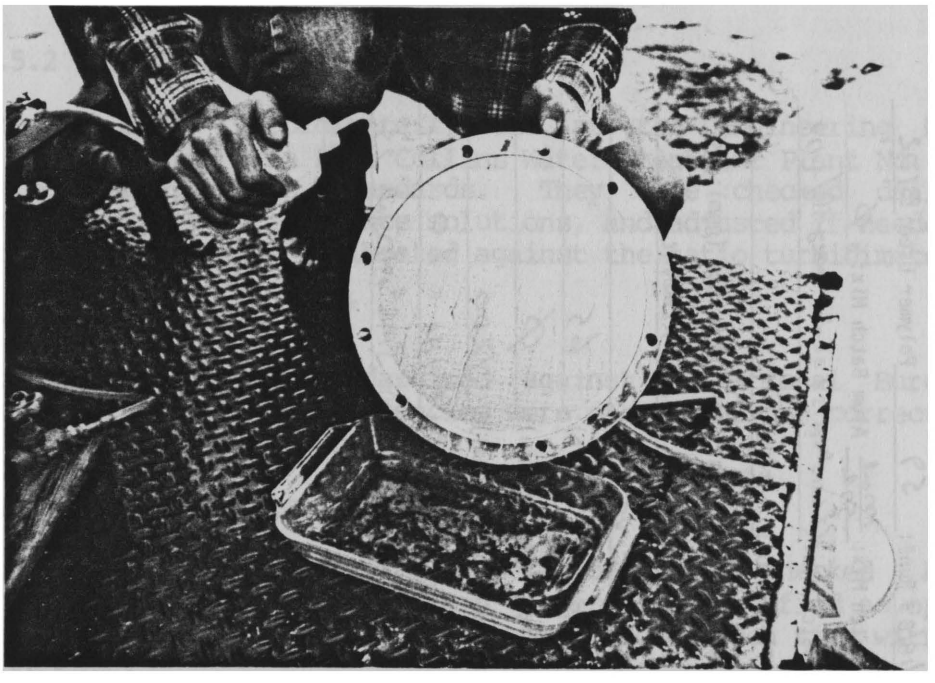

Figure 2-13. Membrane filter being rinsed. The cysts which were strained from the sampling stream are transferred to the pyrex tray

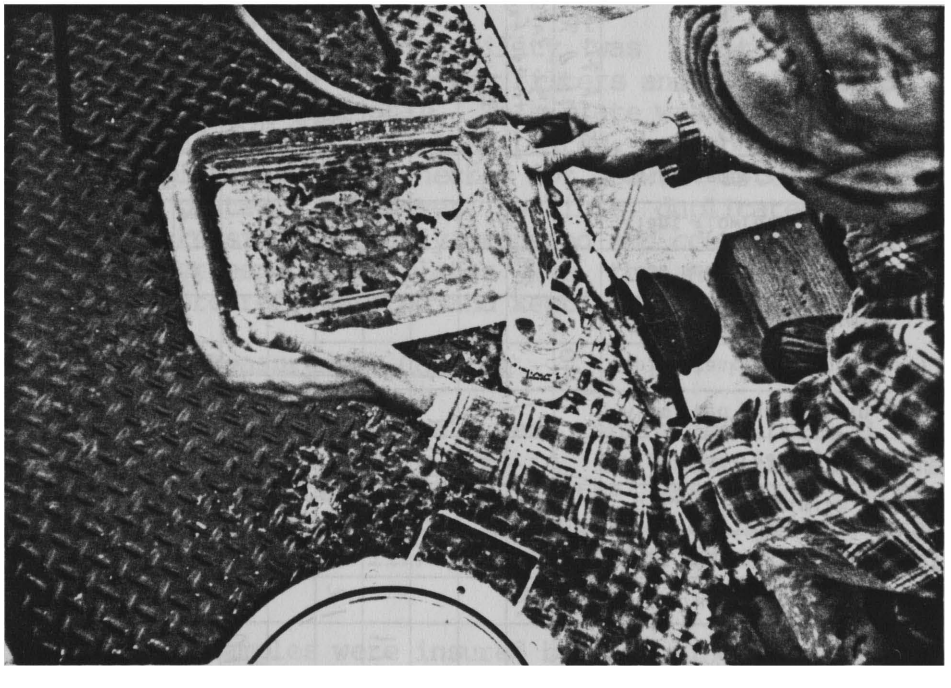

Figure 2-14. Transferring the contents of the pyrex tray to the mason jar

Date: 7/18/83 Run#: 59 Polymer Used: 8102

Polymer Batch Mix: ~~700ml~~ 500 Alum Batch Mix: ∅

Giardia Batch Mix: (3.6x10^6 cysts ∉ 32 of primary eff)/4.0 L

Type of Filtration: IN-LINE

Type of Water: HT Avg. Plant flow rate (gpm): 22

Purpose of Run: Above opt GIARDIA REMOVAL, ∉ coliform conc vs. time

Avg. poly feed rate (ml/min): 65

Avg. Alum feed rate (ml/min): ∅

Inf Coliform Count (#/100ml): 1200

Eff Coliform Count (#/100ml): @1Hr = 20

Inf Giardia Count (cysts/liter): JMG#13(12 gal) 25

Eff Giardia Count (cysts/liter): JMG#14(40 gal) Zero

Calculations:

WB - coliform samples

JMG - GIARDIA SAMPLES

$DCC = \text{DESIGNED cyst conc} = \frac{(3.6 \times 10^6)(.21)}{4.0} \frac{1}{(22)3.785}$

$= \boxed{210 \text{ cyst/liter}}$

$\text{Poly feed} = \frac{(65)\left(\frac{100}{50}\right)}{(22)3.785} = 11 \text{ mg/l}$

Time	Inf Turbidity (NTU)	Eff Turbidity (NTU)	Diff. Head (ft. of HOH)	Poly tank reading(liters)	Poly feed rate(ml/min)	Alum tank reading(liters)	Alum feed rate(ml/min	Spike tank reading(liters)	Spike feed rate(ml/min)	Flow meter reading(cu. ft)	Plant flowrate(gpm)	water temperature	COMMENTS
0:23				50				40					Start Flow & Feed Pumps
0:30			.8							368			WB#2 taken (eff coliform)
0:35	6.5											12°C	WB#3
0:40													WB#4
0:55		1.1											WB#5 & WB#6
1:00			1.2									12°C	Start sampling for inf cysts
1:06													Stop sampling for inf cysts
1:25	6.5	1.0											Start sampling for eff cysts
1:35										559	22		WB#7
1:45			1.3	45.5	65			25	210				Stop sampling for Eff cysts

COMMENTS: pH of RAW WATER = 6.6

WB#1 IS PURE primary eff.; WB#6 IS Inf sample

Figure 2-15. Sample data sheet

2.5.2 Turbidimeters

The Hach Ratio Turbidimeters, one at the Engineering Research Center and one at the Fort Collins Water Treatment Plant No. 1, were calibrated with formazin standards. They were checked daily with manufacturer-supplied reference solutions, and adjusted if needed. The flow-through meters were calibrated against the ratio turbidimeters.

2.5.3 Temperature

Thermometers were standardized against a National Bureau of Standards Thermometer. Discrepancies were marked and the correction was applied when used.

2.5.4 Microbiological Controls

Autoclave. The autoclave operation was checked by the manufacturer, and all instruments and gauges were certified as operating correctly. In addition, the autoclave was checked each time with heat-sensitive tape.

Incubator and Water Bath. The temperatures of the incubator and water bath were checked every other day when in use. The incubator was allowed to stabilize for two hours when temperature adjustments were made.

Bacterial Analyses. Filter sterility was monitored by randomly choosing one of the 0.45 micrometer filters and placing it on a petri dish of the standard coliform agar. This plate was then put through the same incubation as one of the other plates, but no water was filtered through it. The plate was then checked for growth after 24-hours, as were the other plates. Whenever possible, duplicate plates of each sample dilution were simultaneously prepared and counted. The average number between corresponding plates was the number reported. Once prepared, plates were refrigerated and kept for no longer than ten days.

2.5.5 Giardia Measurement Control

The measurement of *Giardia* cysts was controlled by: i) insuring that the concentrations of cysts in the sampling streams were representative of the concentrations in the main flow stream; ii) sampling the influent water, after the cysts were injected, exactly as the effluent was sampled; and iii) performing "no chemical" *Giardia* cyst runs.

Representative samples were insured by following standard sampling procedures. For example, the sampling streams were taken from the center of the pipe, and the velocities of the sampling streams were made equal to the velocity of the main flow stream. Also, the influent sampling port was directed upstream to allow the "stream lines" direct access to the port.

The influent sample was obtained exactly as the effluent sample, i.e., both streams were run through the same pump, and then through the

membrane filter holder. The sampling sequence was to sample the influent side first, then insert a new membrane filter and sample the effluent.

The "no chemical" Giardia cyst removal tests established references to compare removals when chemicals were used. In this way the effect of coagulant dosage could be evaluated.

Chapter 3: RESULTS AND DISCUSSION

To investigate the role of different coagulants and their dosages on filtration effectiveness 144 test runs were completed using the WATER BOY pilot plant. These tests were conducted during periods from November 1982 to January 1984. Three waters were used in the tests, each having different characteristics. They included: i) Horsetooth Reservoir water; ii) Cache La Poudre River water during spring runoff; and iii) Cache La Poudre River water when the turbidity was less than 1 NTU. Table B-1, in Appendix B, is a "master" data table containing the experimental data from testing with all three waters.

From the Horsetooth Reservoir and Low-Turbidity tests, effluent turbidity vs coagulant dose curves were developed. From these turbidity-dose curves, "optimum" dosages and "nonoptimum" dosages were obtained. Evaluations of removals of Giardia cysts, and coliform bacteria were performed using these "optimum" and "nonoptimum" dosages, and using a coagulant dosage of "none".

Evaluations of removals of Giardia cysts and coliform bacteria were not done during spring runoff; the data obtained showing turbidity removals are given in Appendix C. In addition, comparisons were made between the bench, laboratory, and field scale pilot plants in order to ascertain the relationships in their performance. These results are given in Appendix D.

3.1 Familiarization Testing

The first testing period, 11/9/82 to 2/9/83, was a "familarization" testing phase to develop experience with the pilot plant and to ascertain the sizing for various appurtenances such as chemical storage tanks, chemical feed pumps, etc. For this phase of testing, the WATER BOY was set up on the floor of the Hydraulics Laboratory at the Engineering Research Center where there was easy access to raw water from the adjacent Horsetooth Reservoir and where a machine shop and other support systems were located. Appendix E contains effluent turbidity vs time curves for the familiarization testing phase. Twenty two tests were performed during this phase.

The results of twelve of these tests, representative of the 22 tests completed, are given in Appendix E in graphical form as effluent turbidity vs time curves. These curves show that within about one-hour the effluent turbidity was "stabilized", i.e. did not change significantly with time. From these results the run time of one-hour was used as an index time for sampling in subsequent testing. Also, the familarization phase served as a learning period for using the WATER BOY.

3.2 Horsetooth Testing

Sixty eight tests were performed using Horsetooth Reservoir water, exclusive of the familiarization testing. These 68 tests included 46 effluent turbidity vs chemical dose tests. From these data typical U-shaped curves were developed. Based on these curves, three categories of chemical dosages were designated: "zero" dose, "optimum" dose, and "nonoptimum" dose. These dose categories were used to evaluate the

effectiveness of coagulant dosage on removal of Giardia cysts and coliform bacteria.

3.2.1 Coagulant Dosage Determination

Four chemical coagulants were used in testing with Horsetooth Reservoir water to obtain curves of effluent turbidity vs dose of coagulant. Figures 3-1 to 3-4 show the four curves for Magnifloc 573-C, Nalco 8102, Magnifloc 572-C, and alum, respectively. The four curves all have the classical U-shape, permitting determination of "optimum" coagulant dosages. The "optimum" dosages so determined were then used during test runs in which coliform bacteria and Giardia cysts were injected into the influent piping of the WATER BOY. These curves also permitted selection of the "nonoptimum" coagulant dosages, which comprised part of the testing program in which Giardia cyst and coliform bacteria removals were evaluated.

Each of the three polymers used had the capability to reduce turbidity levels from 7.0 NTU, in the raw water, to 0.5 NTU for the product water, after one-hour of operation. After several hours of operation the turbidity levels were reduced to 0.15 NTU. This indicates that the polymers were highly effective in turbidity removal, using raw water from Horsetooth Reservoir. Similar results were obtained in the lab-scale pilot work conducted by Al-Ani (1984). Therefore these polymers were expected to be effective in removal of bacteria and Giardia cysts. Alum was tested also, as seen in Figure 3-4, producing finished water turbidity of 1.2 NTU, after one hour of operation.

3.2.2 Effect of Coagulant Dose on Filtration

After determination of "optimum" dosages of coagulants, based upon turbidity removal, and after selection of "nonoptimum" dosages to be used in testing, removals of coliform bacteria and Giardia cysts were evaluated using the WATER BOY. This evaluation was performed using coagulant dosages categorized as "none", "optimum", and "nonoptimum". Table 3-1 summarizes the turbidity, coliform bacteria, and Giardia cyst removal data from 21 tests classified according to the type of coagulant dosage used.

Zero Coagulant Dose Tests. The first seven runs of Table 3-1, were tests in which "zero" coagulant dose was used, designated as "none". These tests were performed to establish a reference for evaluating Giardia cyst and coliform bacteria removals when coagulants were used.

Results showed that large numbers of cysts passed through the WATER BOY filter when chemicals were not used. Removals of Giardia cysts were less than one percent in three of the seven tests, while two others gave removals of 41 and 84 percent. Results for one of the seven tests showed a removal of >99 percent, which cannot be explained at this time. The results were supported by removals of turbidity and coliform bacteria. Turbidity removals ranged from 3 to 14 percent while coliform bacteria removals were about 30 percent for two tests. Only two coliform removal results are reported in the first seven tests due to difficulties in establishing proper dilutions in the analyses. These results further establish the contention that rapid rate filtration must

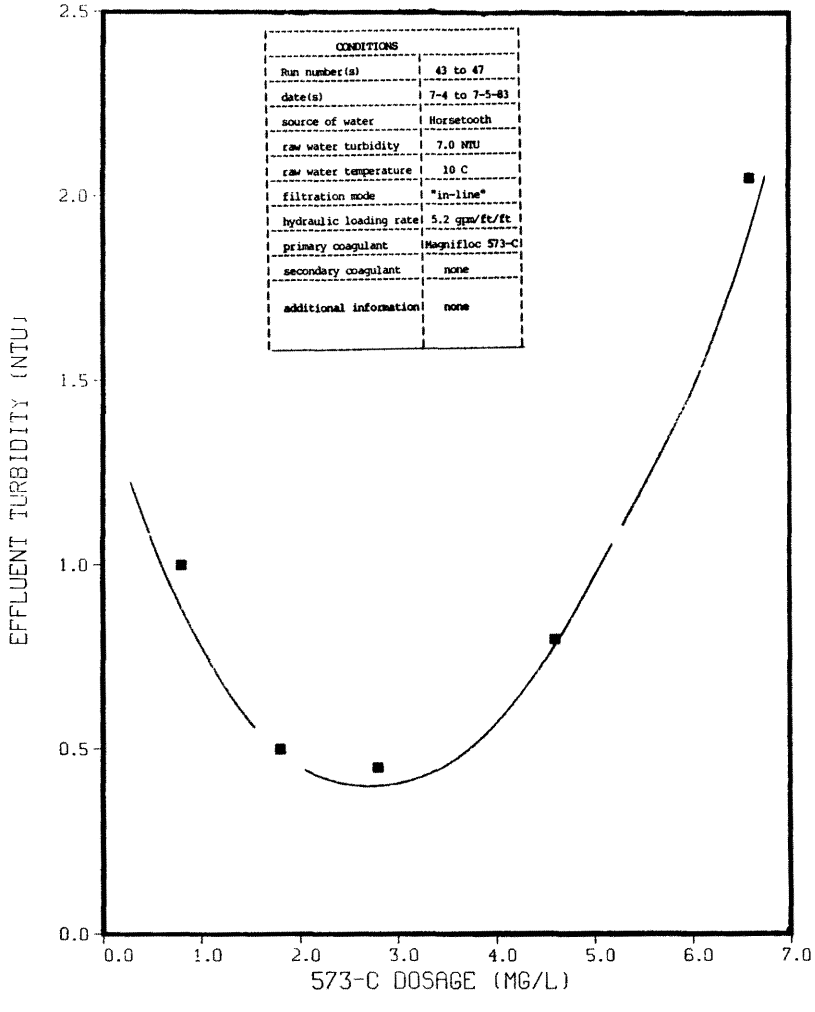

Figure 3-1. Effluent turbidity vs dose of Magnifloc 573-C. Horsetooth water

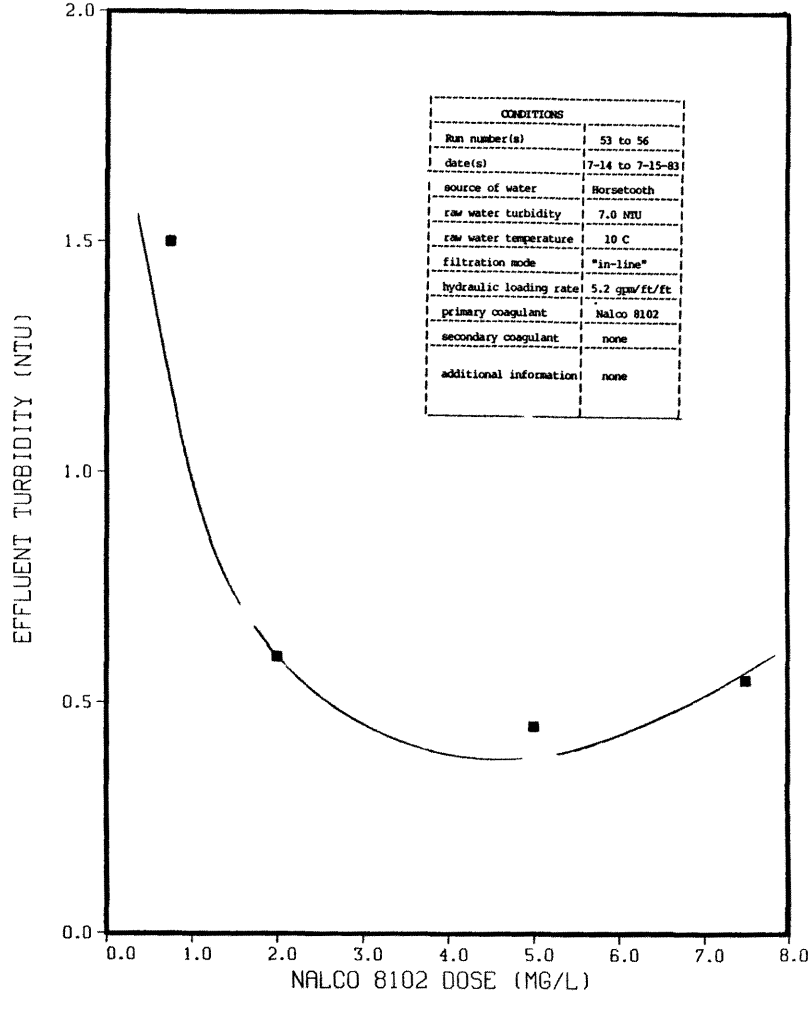

Figure 3-2. Effluent turbidity vs dose of Nalco 8102. Horsetooth water

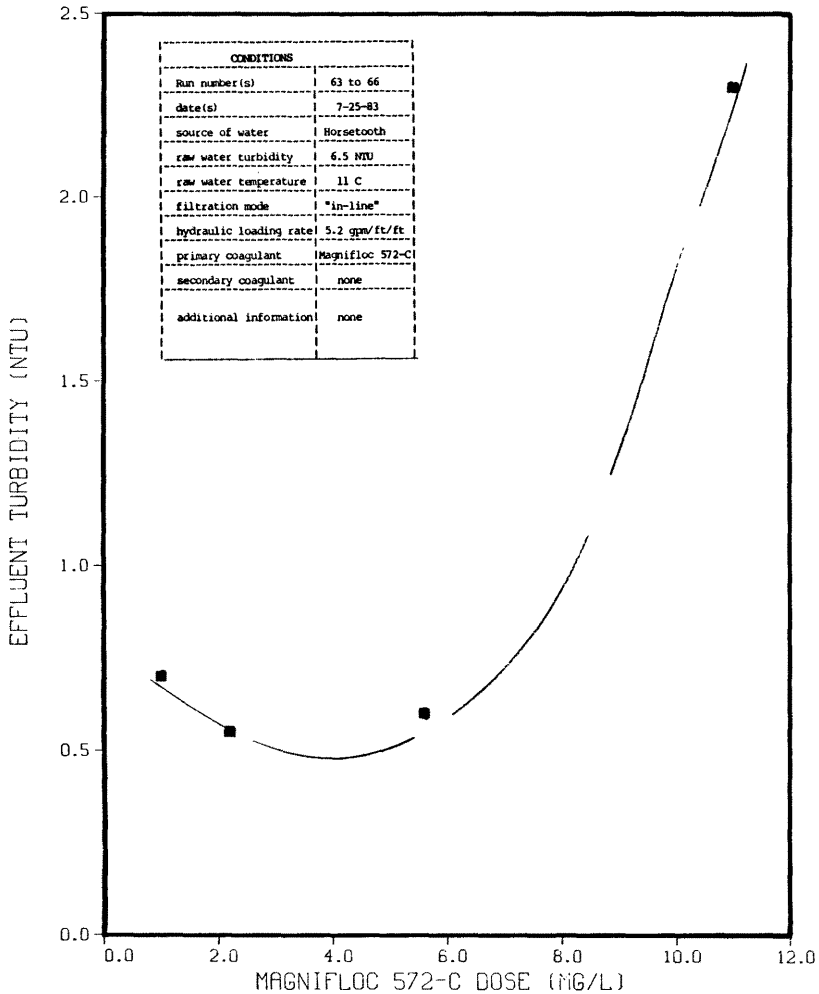

Figure 3-3. Effluent turbidity vs dose of Magnifloc 572-C. Horsetooth water

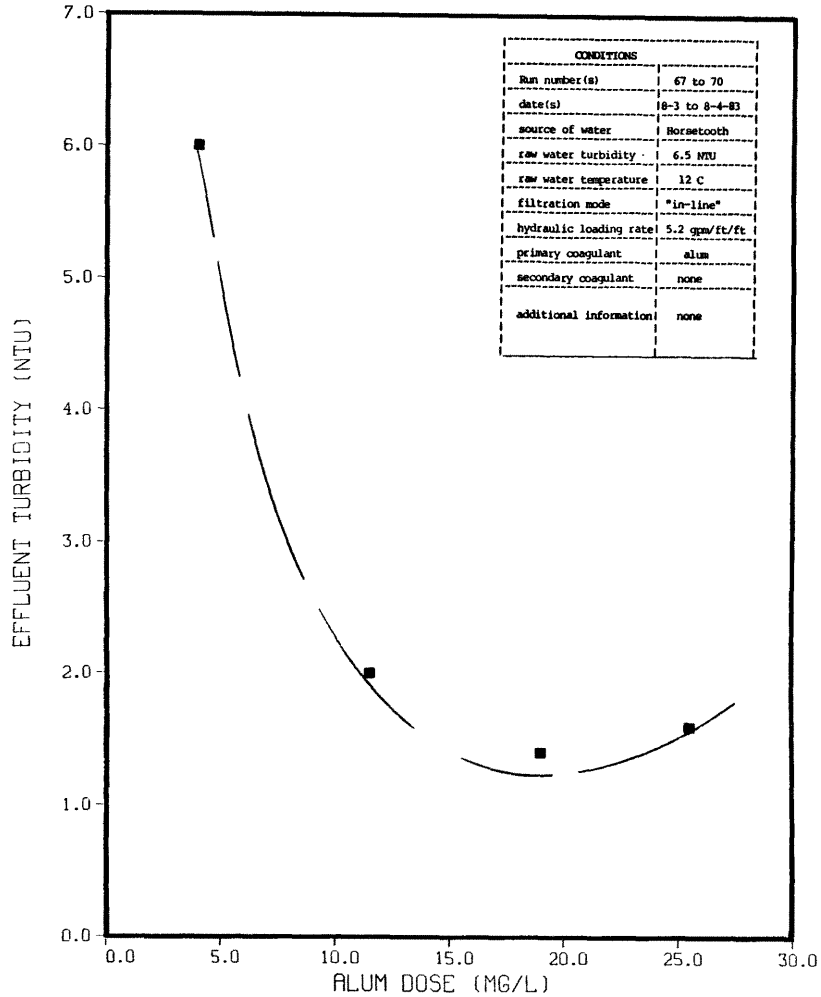

Figure 3-4. Effluent turbidity vs dose of alum as $Al_2(SO_4)_3 \cdot 14H_2O$. Horsetooth water

TABLE 3-1. Effect of Coagulant Dosages on Removals of Coliform Bacteria and *Giardia* Cysts for Horsetooth Water[1/][11/]

Run #	Coagulant Dosage Category[2/][3/]	Coagulant Used		Percent Removals[10/]		
		Chemical Species[6/]	Chemical Dosage[5/] (mg/l)	Turbidity	Coliforms[8/][12/]	*Giardia* Cysts[4/][7/][13/]
50	None	None	0	+	*	>99
57	None	None	0	14	*	<1
60	None	None	0	14	*	84
61	None	None	0	11	*	<1
62	None	None	0	13	*	<1
74	None	None	0	9	33	**
99	None	None	0	3	27	41
49	optimum	573-C	2.5	93	*	>99
52	optimum	8102	2.5	+	95	>99
58	optimum	8102	5.5	94	*	>99
73	optimum	572-C	2.5	93	97	**
76	optimum	alum	25	97	96	**
90	optimum	8102	4.0	94	>99	>99
92	optimum	alum	12	76	98	97
98	optimum	alum	15	84	98	94
105	optimum	alum/8102	15/4	89	98	93
106	optimum	alum/8102	15/4	90	96	>99
51	nonoptimum	573-C	8.0	+	>99	>99
59	nonoptimum	8102	11.0	86	98	>99
75	nonoptimum	572-C	1.0	76	81	**
91	nonoptimum	8102	1.0	83	96	>99

1/ Abstracted from Table B-1
2/ Three dosage categories are: i) no coagulants used, indicated as "none"; ii) "optimum" coagulant dosage is with respect to turbidity removal; iii) "nonoptimum" coagulant dosage is a dosage greater than or less than "optimum."
3/ "Optimum" and "nonoptimum" are dosages based on Figures 3-1 to 3-4
4/ Based on detected influent cyst concentration
5/ Alum dose reported is mg/l as $Al_2(SO_4)_3 \cdot 14H_2O$
6/ Nalco 8102, Magnifloc 572-C, Magnifloc 573-C
7/ Double asterisk indicates cysts used were of questionable viability
8/ Asterisk indicates no data; missed dilution range
9/ No effluent turbidity sample taken obtained
10/ Data represents removals after one hour of filtration
11/ Influent turbidity levels were 7.0 NTU for all tests and water temperatures ranged between 10 and 12°C
12/ Influent coliform concentrations ranged from 220/100 ml to 30000/100 ml; median was 8700/100 ml
13/ Influent detected *Giardia* cyst concentrations ranged between 10/1 to 2000/1; median was 110/1

be preceded by chemical coagulation to ensure effective treatment for production of drinking water.

Optimum Coagulant Dosage Tests. Ten tests in Table 3-1 used "optimum" dosages of coagulant. These ten runs are the second group of tests shown. The first eight tests used only a primary coagulant chemical, and the last two used alum as a primary coagulant and a polymer as a secondary coagulant. The tests using "optimum" coagulant dosages were performed with expectation that high removals of coliform bacteria and Giardia cysts would occur, as established by Al-Ani (1984) in lab-scale work. For these "optimum" dosage tests, Table 3-1 shows that removals of turbidity, coliform bacteria, and Giardia cysts all exceeded 90 percent, with only four exceptions, i.e. for turbidity when alum was used either alone or as the primary coagulant.

The data in Table 3-1 show that removals of Giardia cysts exceeded 99 percent in five of the eight test runs having Giardia data. Cysts were not detected in the product water in these cases. Removals of less than 99 percent occurred only when alum was used; the reason is not evident. Removals of coliform bacteria exceeded 94 percent in all cases. Turbidity removals exceeded 90 percent with only four exceptions as noted above.

The cyst concentrations it may be noted were 10, 30, 45, 250, 800, 2000, 200, 75 cysts/liter for Runs 49, 52, 58, 90, 92, 98, 105, and 106, respectively. While alum could be less effective than the polymers, the cyst concentrations, which were not controlled easily, partially due to logistic problems, were quite high for the tests with alum. At the same time, however, the turbidity vs alum dose curve, shown in Figure 3-4, indicates that alum is less effective as a coagulant than the polymers tested (see Figures 3-1, 3-2, 3-3). These results indicate areas where further research effort is needed; i.e., to both better define the relationships and to explain the behaviors noted.

Nonoptimum Coagulant Dosage Tests. The "nonoptimum" coagulant dosage tests, which used polymer only, are the last four tests shown in Table 3-1. Cysts were not detected in the effluent for any of these "nonoptimum" Giardia test runs, while turbidity removals ranged between 76 and 86 percent, and removals of coliform bacteria ranged from 81 to >99 percent. Runs 51 and 59 used above-optimum dosages of Magnifloc 573-C and Nalco 8102, respectively. Runs 75 and 91 used below-optimum dosages of Magnifloc 572-C and Nalco 8102, respectively. Table 3-1 shows the dosages used, which can be related to the turbidity-dose curves in Figures 3-1 to 3-4 for the purpose of ascertaining the deviation from optimum. The "nonoptimum" dose tests were run to ascertain the sensitivity of removals of turbidity, bacteria, and Giardia cysts to deviations from optimum coagulant dosages, which could occur in practice. These results indicate that for Horsetooth Reservoir water, removals are not highly sensitive to coagulant dosage, but removals are not as high as when optimum dosages are used.

3.2.3 Associations Between Dependent Variables

Turbidity vs Giardia. Table 3-1 shows results for tests in which Giardia cyst removals were obtained. Figure 3-5 shows these data for

percent removals of Giardia cysts plotted against percent removal of turbidity. The plot shows that when removal of turbidity is high then removal of Giardia cysts is high also, e.g. exceeding 90 percent. The plot shows also that low removals of Giardia cysts occurred only when removals of turbidity were low also. The curve shown was drawn to indicate an association between the group of plotted points in the upper right portion of the plot and a fewer number of points in the lower left; it has no statistical significance. The curve shown has a rationale, however, based upon the work of Al-Ani and Hendricks (1983), which shows a similar association in a three-dimensional histogram plot. Their work shows that generally when turbidity removal exceeds 80 percent, Giardia cyst removal will exceed 98 percent. This work, at the field scale, supports their findings, except Figure 3-5 indicates that Giardia removals exceed 90 percent (not 98 percent) when turbidity removal exceeds 80 percent. This supports generally their contention that turbidity removal can be used as a surrogate for Giardia cyst removal.

Coliforms vs Giardia. Table 3-1 shows results for 10 tests in which coliform bacteria removals were obtained along with corresponding removals of Giardia cysts. Figure 3-6 is a plot showing percent removal of Giardia cysts vs percent removal of coliform bacteria. The plot shows that when removals of coliform bacteria are high then removals of Giardia cysts are high also. Only one point was obtained for low removals. The curve shown was drawn to indicate an association between the one point on the left side and the group of points on the right. These results are consistant also with those of Al-Ani (1984) and support the contention that removal of coliform bacteria can serve as an indicator of removal of Giardia cysts. The results indicate that when high removals of turbidity or coliform bacteria occur, then effective filtration is likely.

Turbidity vs Coliforms. Figure 3-7 shows plotted points, also obtained from Table 3-1, for percent removal of turbidity vs percent removal of coliform bacteria. The association between the two groups of plotted points is similar to the previous two plots, i.e. if 80 percent removal of turbidity occurs then removal of coliform bacteria can be expected to exceed 95 percent.

Coliforms vs Standard Plate Count. Standard plate count measurements for the influent and effluent streams were made for only two runs, Runs 51 and 52. Removals were 99 percent and 98 percent, respectively with influent concentrations 29,000/ml and 15,000/ml. Removals of coliform bacteria were >99 percent and 95 percent for these two runs. Standard plate counts were not run routinely since coliform bacteria data were used and it was necessary to set priorities in order to control the work load.

3.2.4 Effect of Run Time on Filtration Effectiveness

Coliform bacteria concentrations in the product water were measured at intervals of time in Run 59. This was done during the initial 70 minutes of filter operation after backwash. Figure 3-8 is a plot of the data obtained. The coagulant dosage was "nonoptimum", i.e. 11.0 mg/l of Nalco 8102. Figure 3-8 shows that coliform counts in the effluent

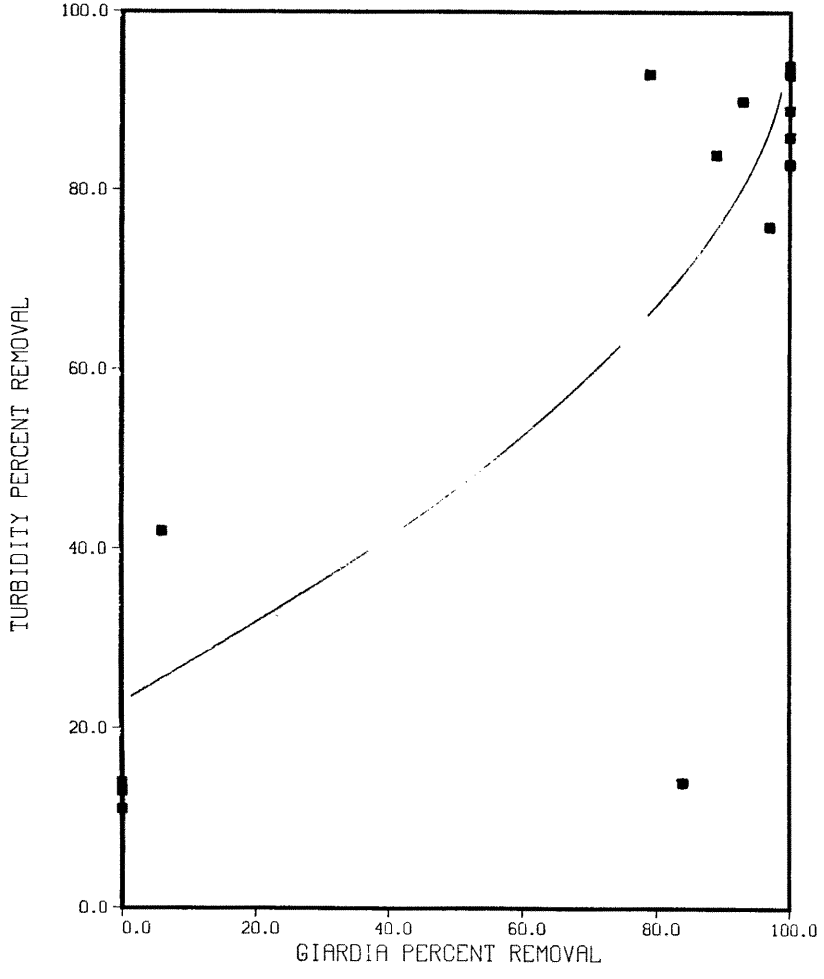

Figure 3-5. Percent removal of turbidity vs percent removal of Giardia cysts. Horsetooth water. Raw water characteristics were 7.0 NTU and temperature 10-12°C

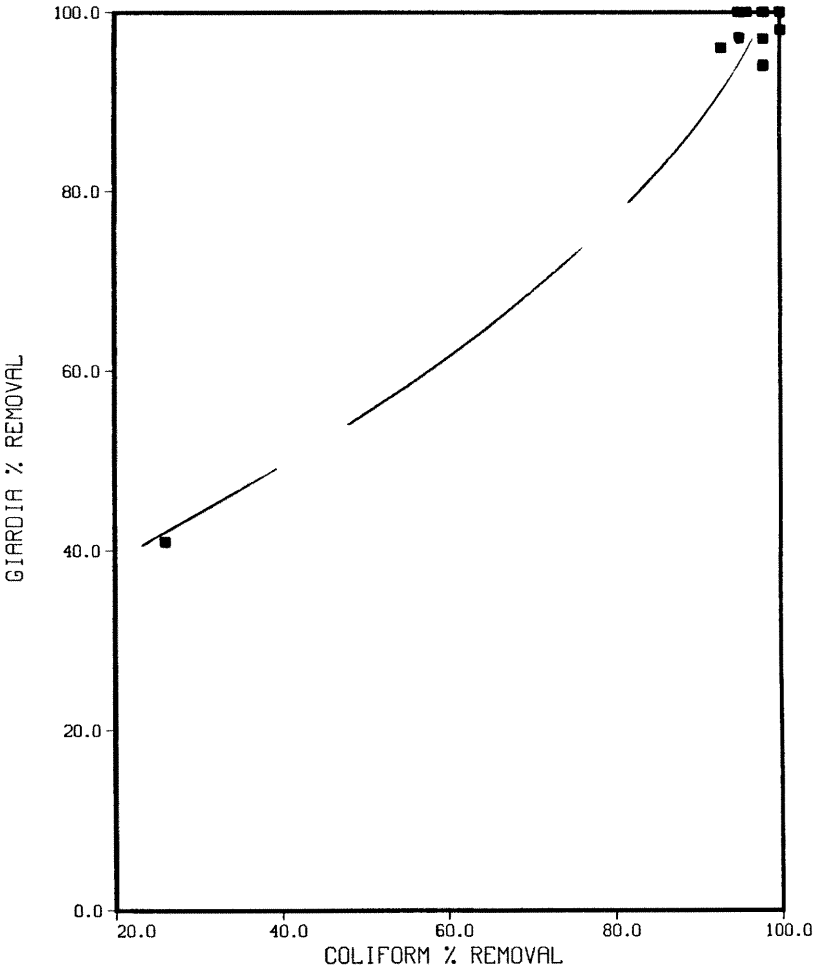

Figure 3-6. Percent removal of coliform bacteria vs percent removal of Giardia cysts. Horsetooth water. Raw water characteristics were 7.0 NTU and 10-12°C

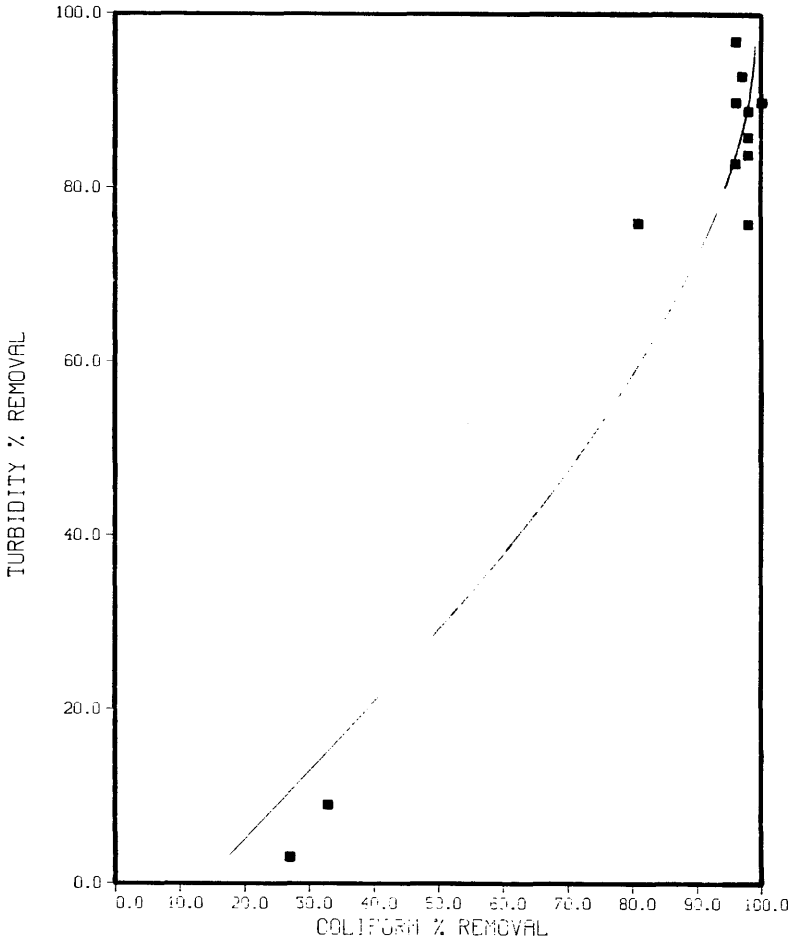

Figure 3-7. Percent removal of turbidity vs percent removal of coliform bacteria. Horsetooth water. Raw water characteristics were 7.0 NTU and 10-12°C

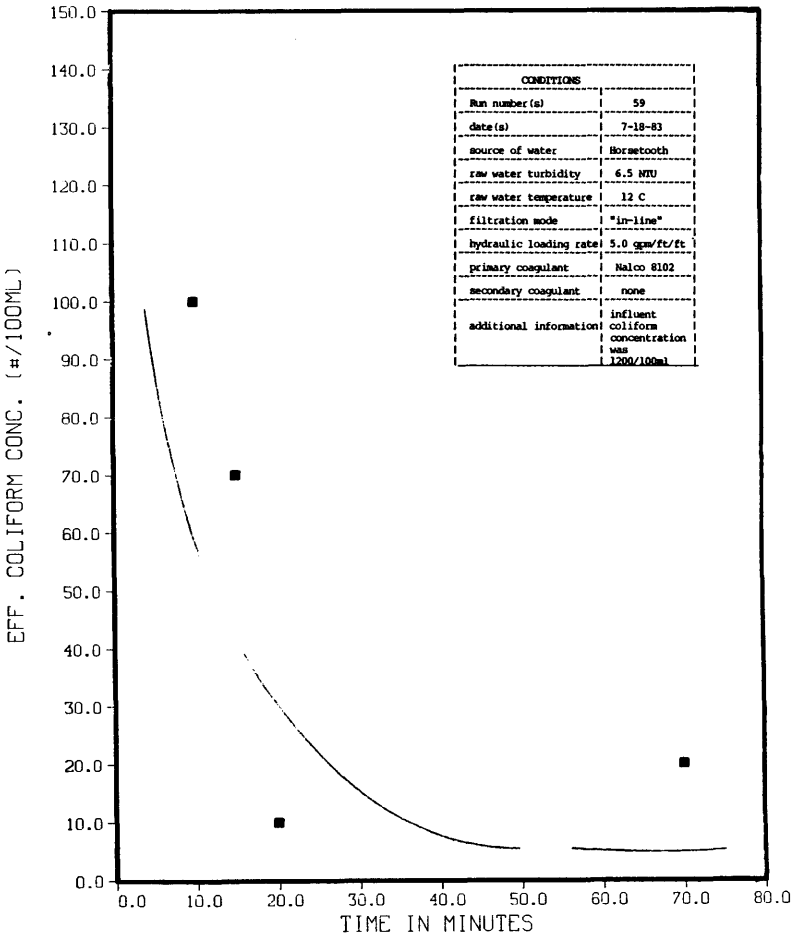

Figure 3-8. Effluent coliform bacteria concentrations vs time. Horsetooth water

water dropped to 10/100 ml within 20 minutes of operation; this compares with 1200/100 ml in the influent water.

Figure 3-9 shows how both headloss and effluent turbidity vary with time during Run 78 using optimum dosage of Nalco 8102 polymer. As shown in Figure 3-9, 10-hours were required for the effluent turbidity to reach the lowest value of 0.15 NTU, while a turbidity level of 0.4 NTU was reached at 1-hour after backwashing. Breakthrough occurred about 14-hours after the start of the run, as indicated by the steep slope of the turbidity-time curve. Headloss increased continuously to about eight feet of water, which existed when breakthrough occurred.

After 12-hours of filtering during Run 78 Giardia cysts and coliform bacteria were fed into the system (at this point the run was designated as Run 79). Cysts were not detected in the effluent stream. Coliform counts were 8700/100ml in the influent, and 50/100ml in the effluent, giving >99 percent removal. It was not the purpose to have a prolonged run time, as is desired in practice. The purpose of Run 79 was to test the effectiveness of a "well-seated" filter in removing Giardia cysts and coliform bacteria.

3.3 Low-Turbidity Results

The low-turbidity testing phase using raw water from the Cache La Poudre River was comprised of 32 test runs. As with the Horsetooth phase effluent turbidity vs coagulant dose curves were generated for five coagulant combinations. From these curves, "optimum" and "nonoptimum" coagulant dosages were obtained. Evaluations of Giardia cyst and coliform bacteria removals were done in nine tests for coagulant dosages of "none", "optimum", and "nonoptimum".

The WATER BOY was located at the Fort Collins Water Treatment Plant No. 1 for this testing period, which started in November 1983 and continued through the first week of January 1984 as weather permitted. The low-turbidity testing was confined to periods when the raw water turbidity from the Cache La Poudre River was less than 1 NTU, which occurred after September in 1983.

3.3.1 Coagulant Dosage Determination

Table 3-2 shows the results of the 23 effluent turbidity vs coagulant dose tests which used low-turbidity water from the Cache La Poudre River. Five coagulants and coagulant combinations were used in this testing. The selection was based upon practice as determined by the survey of coagulation practice reviewed in Appendix H, and upon the recommendations from lab-scale experiments by Al-Ani (1984). From the data in Table 3-2 effluent turbidity vs coagulant dose plots were generated, shown as Figures 3-10 through Figure 3-14, for Nalco 8102, Nalco 8102 and alum, alum, Magnifloc 572-C, and Magnifloc 572-C and alum, respectively.

Of these five figures, Figures 3-10, 3-13, and 3-14 are typical U-shaped curves; Figure 3-11 and 3-12 are not. The finished water turbidities in Figures 3-10 to 3-13 show only 0 to 25 percent reductions compared to raw water turbidities which ranged from 0.45 to 0.9 NTU.

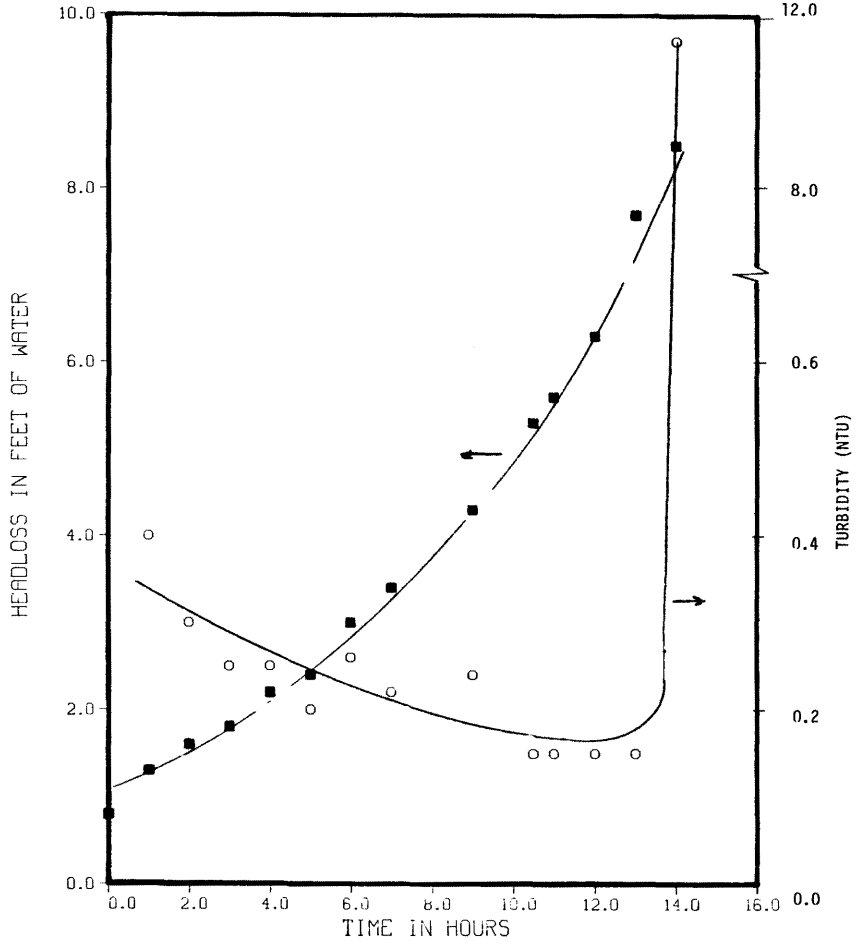

Figure 3-9. Headloss and effluent turbidity vs time for Run 78. Raw water was 7.0 NTU, and 6 °C. Nalco 8102 dose used was 3.5 mg/l

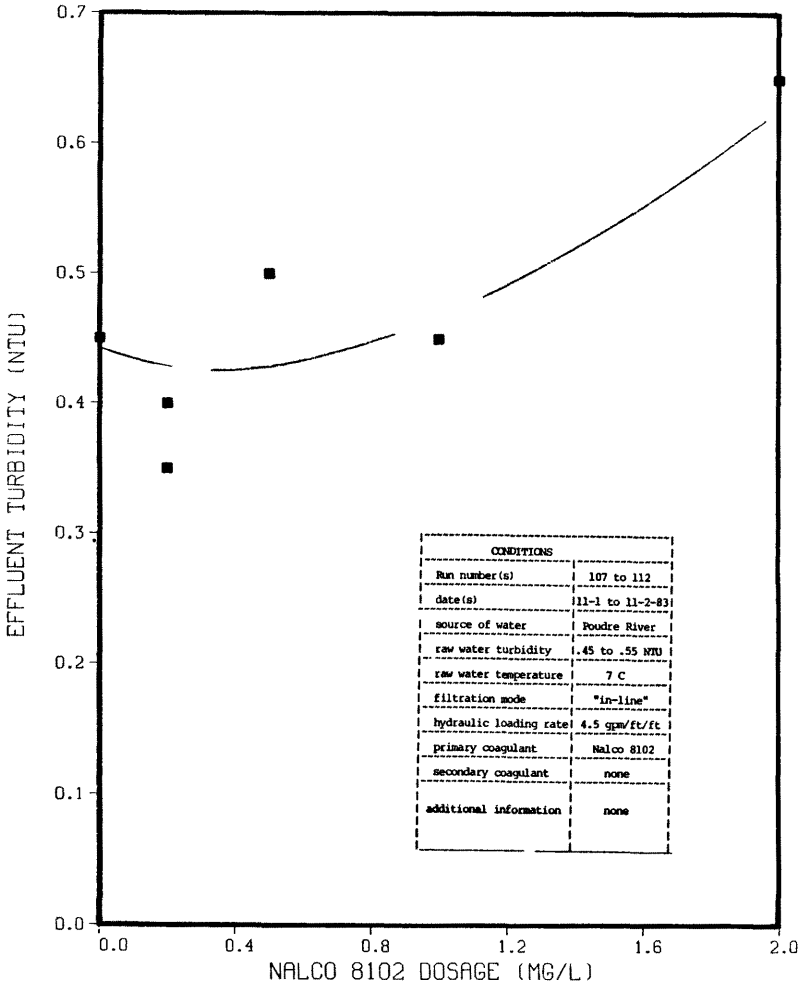

Figure 3-10. Effluent turbidity vs Nalco 8102 dose. Low-turbidity water

Table 3-2. Results of Twenty Three Effluent Turbidity vs Chemical Dose Tests Using Low-Turbidity Raw Water.[1/2/] Data Points for Chemical Dose and Corresponding Effluent Turbidity were Used to Construct Figures 3-10 through 3-14

Run #	Chemical Species[3/]	Coagulants		Turbidity (NTU)	
		Chemical Dose[4/] mg/l	Water Temperature (°C)	Influent	Effluent[5/]
107	None	0	7	0.55	0.45
108	8102	0.2	7	0.55	0.40
109	8102	0.5	7	0.45	0.50
110	8102	1.0	7	0.50	0.45
111	8102	2.0	7	0.45	0.65
112	8102	0.2	7	0.45	0.35
113	Alum/8102	3.0/0.6	7	0.60	0.75
114	Alum/8102	3.0/0.6	7	0.60	0.75
115	Alum/8102	3.0/0.2	7	0.70	0.70
116	Alum/8102	3.0/0.7	7	0.60	0.60
118	Alum	3.0	2	0.65	0.60
119	Alum	0.5	2	0.65	0.55
120	Alum	1.5	2	0.65	0.55
121	Alum	5.5	2	0.65	0.60
122	Alum	1.0	3	0.65	0.60
130	572-C	0.4	1	0.80	0.65
131	572-C	0.8	1	0.80	0.60
132	572-C	2.0	1	0.80	1.60
133	Alum/572-C	1.5/0.7	1	0.80	0.50
134	Alum/572-C	15/2.0	1	0.70	1.00
135	Alum/572-C	4.5/2.0	1	0.70	0.35
136	Alum/572-C	9/2.0	1	0.70	0.35
137	Alum/572-C	30/2.0	1	0.70	3.00

[1/] Abstracted from Table B-1

[2/] Cache La Poudre River water with less than 1 NTU

[3/] Nalco 8102, Magnifloc 572-C

[4/] Alum doses are mg/l as $Al_2(SO_4)_3$ 14 H_2O

[5/] Effluent turbidity after one hour of operation

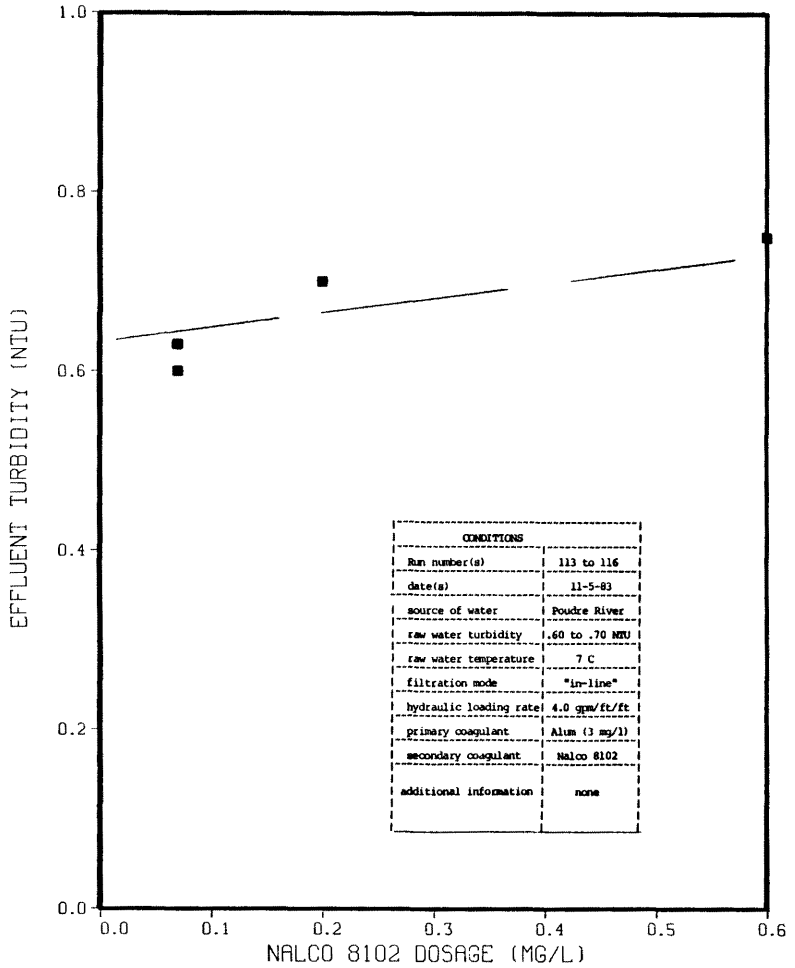

Figure 3-11. Effluent turbidity vs Nalco 8102 dose using 3 mg/l of alum, $Al_2(SO_4)_3 \cdot 14\ H_2O$, for low-turbidity water

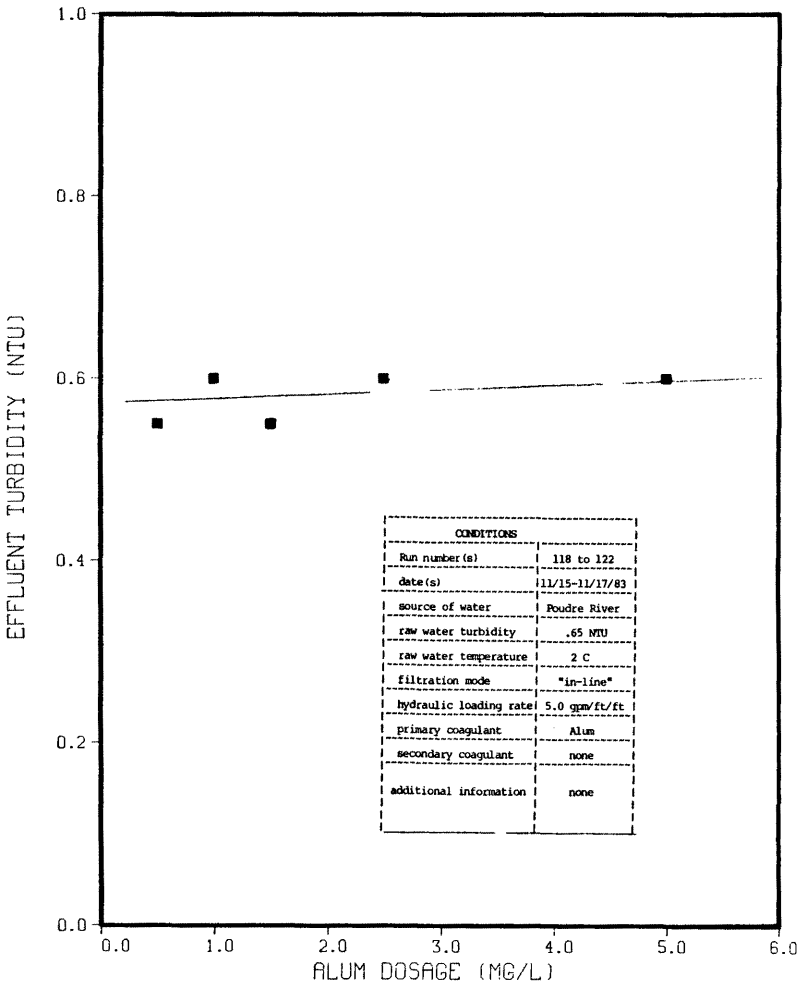

Figure 3-12. Effluent turbidity vs alum dose, $Al_2(SO_4)_3 \cdot 14H_2O$, for low-turbidity water

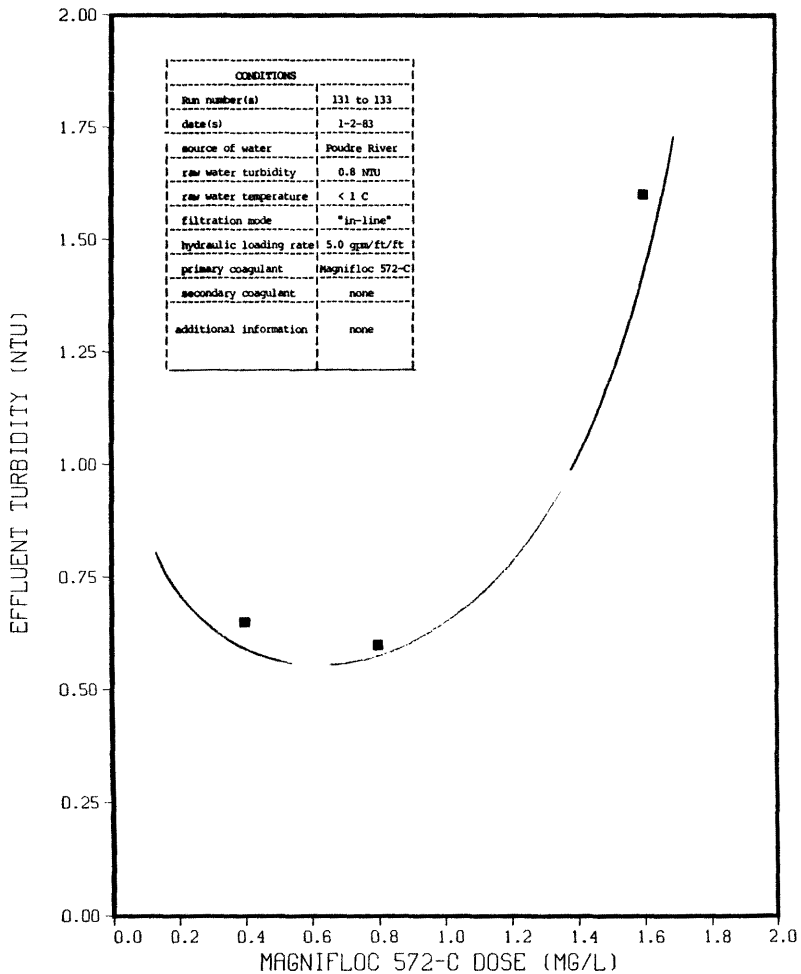

Figure 3-13. Effluent turbidity vs dose of Magnifloc 572-C. Low-turbidity water

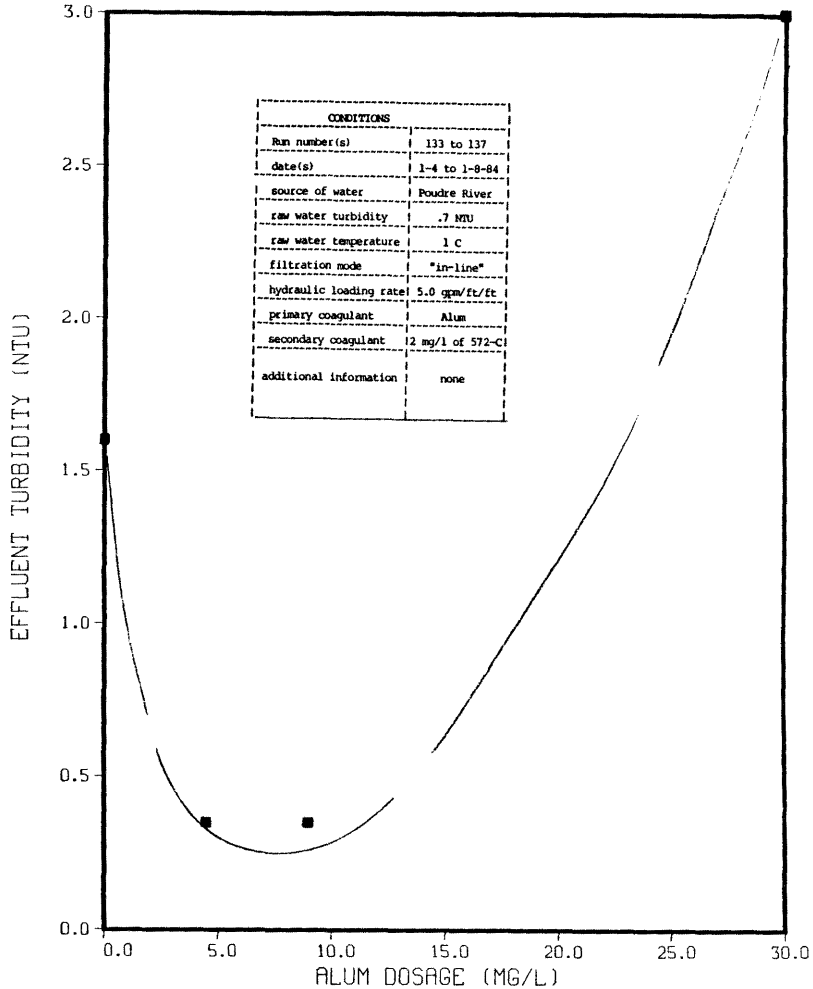

Figure 3-14. Effluent turbidity vs alum dose, $Al_2(SO_4)_3 \cdot 14H_2O$, using 2 mg/l of Magnifloc 572-C for low-turbidity water

Determination of "optimum" dosages are not well defined for these curves, except in Figure 3-13. Figure 3-14 shows, however, the typical U-shaped curve, using alum at different dosages and a fixed dosage of 2.0 mg/l of Magnifloc 572-C, where an "optimum" dosage is well defined. The finished water turbidity was reduced to 0.35 NTU compared to 0.7 NTU for the raw water. Later, in Run 138, during a Giardia test run at "optimum" dosage of alum and Magnifloc 572-C, the turbidity was reduced to 0.20 NTU after two-hours of operation. For the same water and using the same coagulants, the turbidity was reduced to 0.05 to 0.10 NTU for the lab-scale work of Al-Ani (1984).

3.3.2 Effect of Coagulant Dose on Filtration

Evaluations of removals of Giardia cysts, coliform bacteria, and turbidity were performed using coagulant dosages categorized as "none", "optimum", and "nonoptimum". Nine such evaluations were performed, and are described in Table 3-3, for low-turbidity water. In Table 3-3 the coagulant dose is categorized as before as "none", "optimum", and "nonoptimum", even though determination of "optimum" coagulant dosages were not clear for some turbidity-dose curves.

Zero Coagulant Dose Tests. Runs 117 and 129, in Table 3-3 show results obtained for "zero" coagulant dosage tests in which Giardia cysts and coliform bacteria were injected into low-turbidity, low-temperature raw water. These "no chemical" tests were to establish a reference for other tests using coagulants. For the zero or "none" coagulant condition, coliform bacteria removals were 20 and 15 percent, respectively. The Giardia cyst removal of Run 117 was only 30 percent. No Giardia removal data is reported for Run 129 because the cysts were questionable with respect to maintaining identity for analysis. The effluent turbidity was greater than the influent turbidity for each of these "no chemical" runs.

During Run 107, no chemical pretreatment was provided. After one-hour of operation, as shown in Table 3-2, the effluent turbidity was 0.45 NTU. The raw water turbidity was 0.55 NTU.

Optimum Coagulant Dose Tests. Runs 123, 124 and 138 were categorized as "optimum". For Runs 123 and 124 removals of Giardia cysts were 45 and 40 percent, respectively, coliform removals were 20 and 50 percent, while turbidity removal were less than one percent.

For Run 138, however, removals in all three categories were high, i.e 95 percent for Giardia cysts, 98 percent for coliform bacteria, and 42 percent for turbidity. Coagulant chemicals used for Run 138 were 7.0 mg/l of alum, as $Al_2(SO_4)_3$ 14 H_2O, and 2 mg/l of Magnifloc 572-C. These coagulant dosages were found to be effective in previous bench scale and lab-scale testing. For this test the raw water turbidity was 0.7 NTU, and the effluent turbidity was 0.4 NTU, while the water temperature was $<1^{o}C$.

Nonoptimum Coagulant Dose Tests. Runs 125 to 128 were classified as "nonoptimum", even though some of the turbidity-dose curves did not show well defined U-shapes. Results for removals of turbidity, coliform

Table 3-3. Giardia and Coliform Results from Testing Using Low-Turbidity Raw Water1/2/

Run No.	Coagulant Dosage Category11/	Coagulants Used		Water Temperature (°C)	Turbidity			Giardia Cyst 5/7/			Coliforms8/		
		Chemical3/ Species	Chemical Dose4/ (mg/l)		Influent10/ (NTU)	Effluent9/ (NTU)	Percent Removal	Influent5/ cysts/liter	Effluent6/ cysts/liter	Percent Removal	Influent5/ No./100 ml	Effluent6/ No./100ml	Percent Removal
117	None	None	0	2	0.4	0.6	<1	260	180	30	15000	12000	20
129	None	None	0	1	0.6	0.7	<1	**	**	**	3500	3000	15
123	Optimum	8102	0.1	1	0.6	1.1	<1	325	180	45	6900	5700	20
124	Optimum	8102	0.4	1	0.6	0.85	<1	325	100	40	6900	3500	50
138	Optimum	Alum/572-C	7.0/2.0	<1	0.7	0.4	42	1300	70	95	10000	150	>98
125	Nonoptimum	Alum	0.4	1	0.55	1.0	<1	1300	850	35	9000	8500	10
126	Nonoptimum	Alum	5.0	1	0.55	1.0	<1	1300	950	30	9000	6500	30
127	Nonoptimum	Alum/8102	3.0/0.2	1	0.9	1.1	<1	175	100	45	*	*	*
128	Nonoptimum	Alum/8102	3.0/0.4	1	0.9	0.9	<1	175	125	30	*	*	*

1/ Abstracted from Table B-1
2/ Cache La Poudre River water having raw water turbidities less than 1 NTU
3/ Nalco 8102, Magnifloc 572-C
4/ Alum doses are mg/l as $Al_2(SO_4)_3\ 14H_2O$
5/ Detected cyst concentrations, sampling influent stream after mixing by four elbows and before injection of coagulants. Membrane filters used were Nucleopore polycarbonate 5 micrometer pore size, 293 mm diameter. Samples were analyzed by micropipette technique.
6/ Procedures were the same as used for influent sampling and analysis.
7/ Double asterisk indicates cysts were of questionable viability
8/ Single asterisk indicates no data; missed dilution range
9/ Effluent turbidity after one hour of filtration
10/ Influent turbidity prior to contaminant injection
11/ Reference should be made to Figures 3-10 to 3-14 to judge coagulant dosage with respect to turbidity reductions

bacteria, and Giardia cysts were not significantly different than for the "zero" coagulant dosage tests.

3.3.3 Associations Between Dependent Variables

Figure 3-15 is a plot of data taken from Table 3-3 showing percent removal of Giardia cysts plotted against percent removal of coliform bacteria. Figure 3-15 indicates that high removals of Giardia cysts can be expected when high removals of coliform bacteria occur. Again, this is consistent with findings in lab-scale experiments with low-turbidity water. It is consistent also with results for Horsetooth water. Other associations were not made because of limited data for the low-turbidity testing phase.

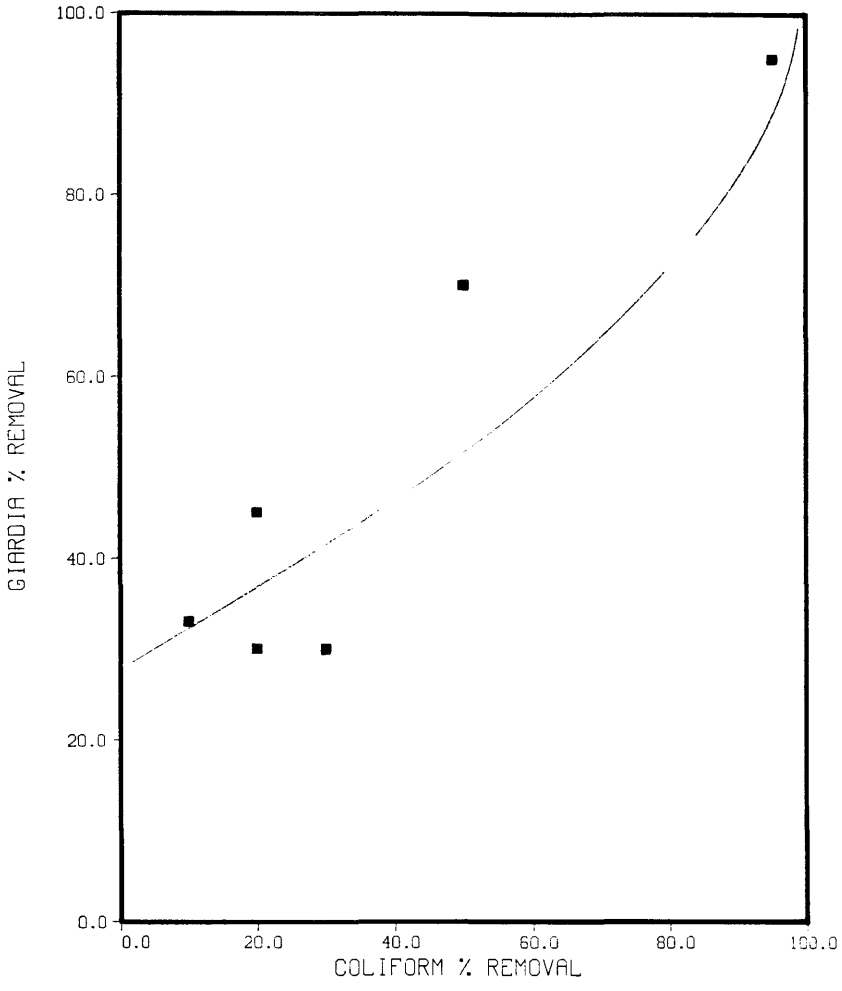

Figure 3-15. Percent removal of Giardia cysts vs percent removal of coliform bacteria for low-turbidity water. Raw water characteristics were: <1°C and <1 NTU

Chapter 4: CONCLUSIONS AND SUMMARY

4.1 Conclusions

The findings of this research illustrate the critical role of coagulant selection and dosage in removal of *Giardia* cysts and coliform bacteria by the rapid rate filtration process. The findings and conclusions are outlined below, grouped by categories of interest.

Filtration Without Coagulation. The results of this research confirm the necessary role of chemical pretreatment in effective filtration of low-turbidity water. Tests with the WATER BOY showed that without chemical pretreatment, i.e. a coagulant dosage of "none", large numbers of *Giardia* cysts and coliform bacteria will pass through a rapid rate filter. For ten such tests without chemicals, removals were 30 percent nominally for both *Giardia* cysts and coliform bacteria, while turbidity removals were only about 10 percent. This was shown for two waters, Horsetooth Reservoir water having turbidity levels of 5 to 10 NTU, and Cache La Poudre River water having turbidity levels of <1 NTU.

Coagulation of Horsetooth Reservoir Water. The results showed that when using Horsetooth Reservoir water all polymers tested, either alone or with alum, were highly effective, e.g. >90 percent removals occurred for *Giardia* cysts and coliform bacteria, and removals were often >99 percent. Removals were equally high for both "nonoptimum" coagulant dosages and for "optimum" coagulant dosages. Thus removals were not highly sensitive to differences in polymers or to dosages of a given polymer.

Coagulation of Cache La Poudre River Water. Results for testing using water from the Cache La Poudre River showed that only one chemical combination tested, Magnifloc 572-C used with alum, was effective in coagulation for filtration of low-turbidity water. For this combination at "optimum" dose removals were >94 percent for both *Giardia* cysts and coliform bacteria. Removals for the "nonoptimum" dosages, or removals with other coagulants, were about the same as for the "none" coagulant dosage condition, e.g. removals of only 30 percent nominally. These findings underline the importance of coagulant selection and dose determination when filtering low-turbidity waters.

Turbidity Removal as a Surrogate. Results showed that percent removals of turbidity were associated with percent removals of *Giardia* cysts and coliform bacteria. These associations were established in testing using waters from both Horsetooth Reservoir and the Cache La Poudre River. Also associations were established between percent removals of coliform bacteria and percent removals of *Giardia* cysts. These associations indicate that coagulants effective in reducing turbidity by more than 80 percent will remove coliform bacteria and *Giardia* cysts at the 90 to 98 percent level.

Pilot Testing. To screen polymers and to ascertain "optimum" polymer-alum dosage combinations, bench scale testing as developed by Choi (1983) and Brink (1984) can be used. Five tests comparing effluent turbidity vs coagulant dose showed similar curves at bench scale, laboratory scale, and field scale. These comparisons help substantiate

the use of bench scale and laboratory scale tests evaluating coagulation effectiveness for full scale operation.

In-Line Filtration. The "in-line" filtration treatment train, i.e. rapid mix with chemical feed followed by filtration, was found to be effective, corroborating the findings by Al-Ani (1984) at the laboratory scale. For the more turbid water during spring runoff, when turbidity levels were 20 to 40 NTU, run times were impractically short, e.g. 2-hours.

4.2 Summary

Coagulant selection and dosage is extremely important in providing effective removals of Giardia cysts and coliform bacteria from cold, low-turbidity Cache La Poudre River water. Removals of Giardia cysts and coliform bacteria are not highly sensitive, however, to coagulant selection and dosage for Horsetooth Reservoir water, which had turbidities of 5 to 10 NTU. Only one coagulant combination, alum and Magnifloc 572-C, was effective in high removals of Giardia cysts and coliform bacteria for low-turbidity water. Other tested coagulants were not effective for low-turbidity waters, but were effective during tests using Horsetooth Reservoir water.

The results of this field scale study generally corroborate results from the bench scale and laboratory scale studies, which helps validate the use of bench scale and laboratory scale pilot plants being used to select coagulants and dosages for water treatment plants. Field scale testing is more difficult because of logistic aspects and because weather conditions limit opportunities for testing. Additional testing is needed, however, to explore further in this area of coagulation-filtration of low-turbidity, low-temperature water.

Further exploration for polymers effective with low-turbidity waters, and more testing using Magnifloc 572-C is needed. The roles of temperature and rapid mix intensity needs to be evaluated, along with theoretical studies of mechanisms of filtration for low-turbidity waters. Such studies will aid in effective coagulation systems.

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APPENDICES

APPENDIX A

DESCRIPTION OF THE WATER BOY PILOT PLANT AND ITS OPERATION

A-1 Description

The WATER BOY is a Neptune Microfloc model WB-27 package water treatment plant capable of satisfying the water needs of a community of 190 people. Its nominal capacity is 1.7 l/s (20 gpm). The plant was purchased by the Drinking Water Research Division of the U.S. Environmental Protection Agency in Cincinnati. The EPA designed a 22 foot trailer to hold the WATER BOY as shown in Figure A-1; thus it became a mobile water treatment plant.

Figure A-2 is the Neptune Microfloc drawing of the WATER BOY showing elevation and plan views. Figure A-3 is the Neptune Microfloc flow diagram for the WATER BOY, illustrating process hydraulics. As shown in Figures A-2 and A-3, the Water Boy is a complete rapid rate filtration water treatment plant consisting of: rapid mix basin, flocculation basin with variable speed paddle wheel, sedimentation consisting of tube settlers at 7.5 degrees, and filtration box. The mixed media has been replaced with dual filtration media as described below.

When the WATER BOY arrived at Colorado State University, in August 1982, after work at Oneida, New York conducted by Clarkson College of Technology, it contained the filtration media shown in Figure A-4. This media was used in experiments here during initial familiarization testing, but was replaced in March 1983 by media obtained locally.

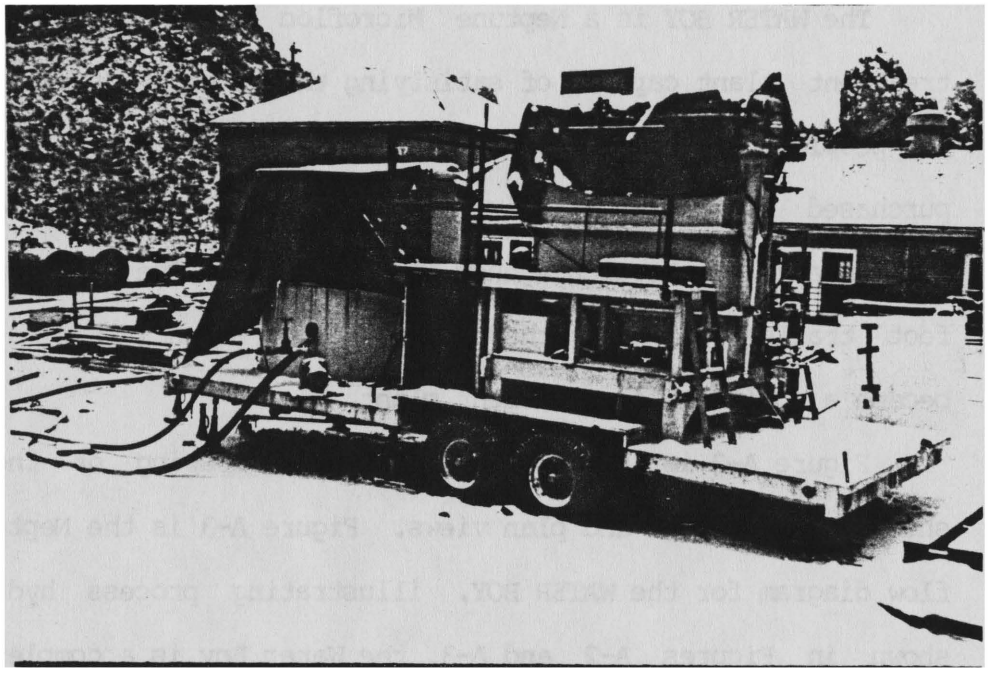

Figure A-1. WATER BOY setup at the Fort Collins Water Treatment Plant No. 1 for low-turbidity testing

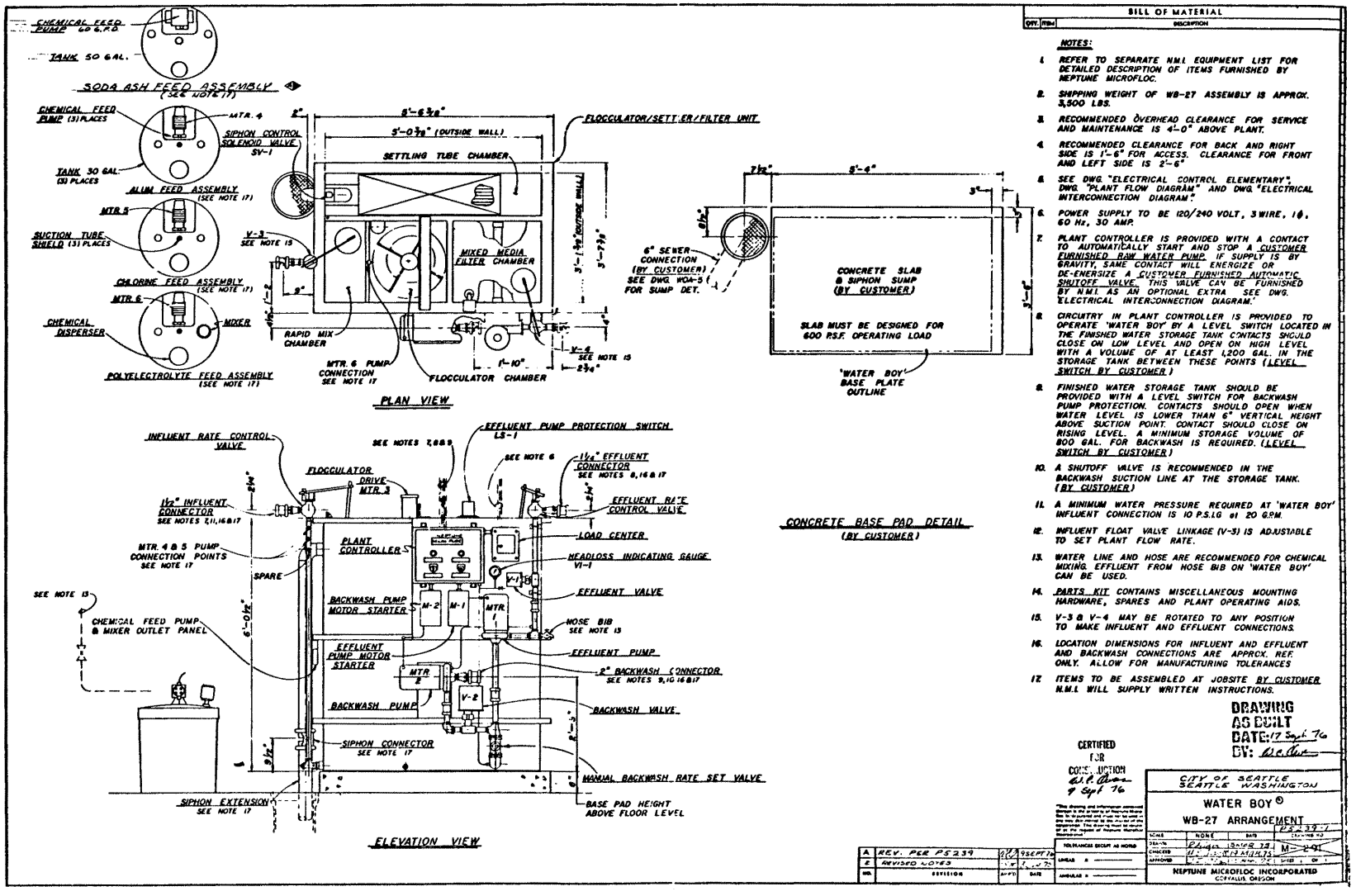

Figure A-2. Neptune Microfloc diagram of the WATER BOY showing elevation and plan views

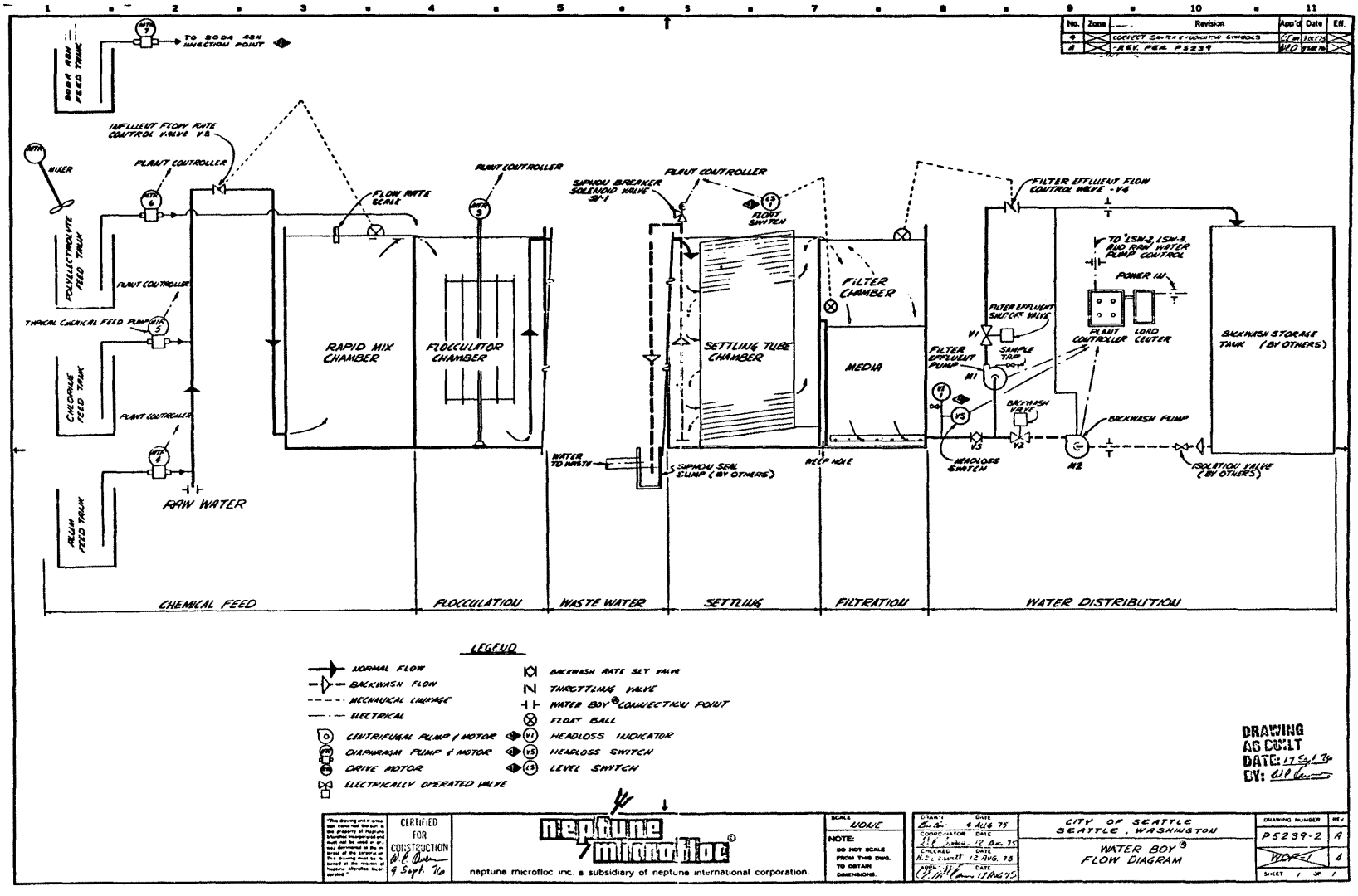

Figure A-3. Neptune Microfloc flow diagram of the WATER BOY showing processes and hydraulics

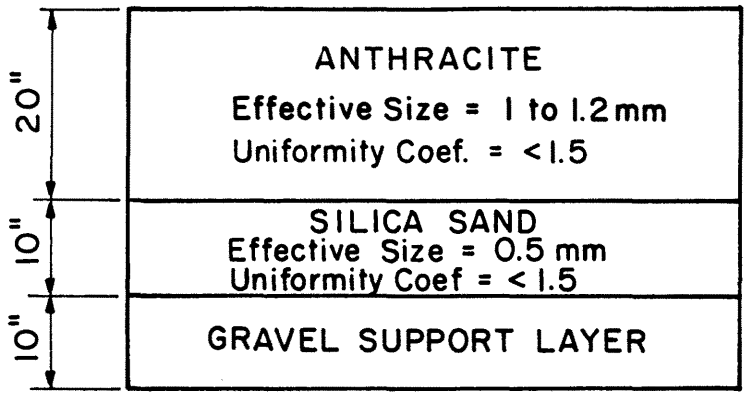

Figure A-4. Filtration media used during Familiarization testing. Media used was packed in New York by Jim Edzwald, Clarkson College of Technology.

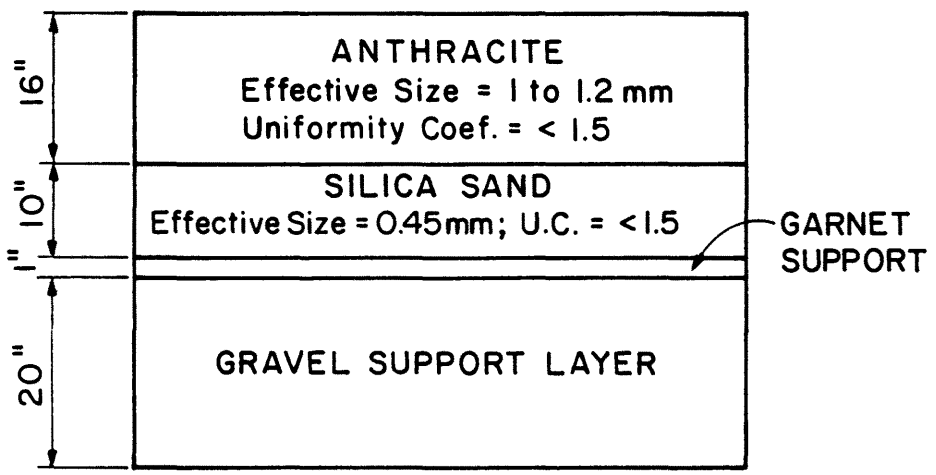

Figure A-5. Filtration media used during Spring Runoff, Horsetooth, and Low-Turbidity testing. Anthracite was obtained from the Fort Collins Water Treatment Plant No. 1, and the sand was obtained from the Fort Collins Treatment Plant No. 2

Figure A-5 shows the filtration media used after March 1983 and which has remained in the WATER BOY for all subsequent testing.

Table A-1 lists the appurtenances which were used with the WATER BOY. All except the flow-through turbidimeters were assembled for the purposes of the present research.

Figure A-6 is a flow schematic of the WATER BOY as set up and used in this research. It shows the chemical feed system, contaminant injection system, and contaminant sampling system. Sampling ports for turbidity, coliform bacteria, and Giardia cysts are shown on both the influent side and on the effluent side.

The contaminant injection port is comprised of a 0.64 cm (1/4 inch) diameter tube placed at the center of the 2.54 cm (1 inch) diameter influent pipe. The contaminants were injected at the center of the pipe. Four elbows were added to the piping after the point of contaminant injection to assure mixing prior to sampling of the contaminants on the influent side. The sampling of contaminants on the influent side was almost the same as the injection. The point of withdrawal was located 30 cm (12 inches) downstream from the last of the four elbows. The withdrawal tube was a 0.95 cm (3/8 inch) tube inserted to the center of the pipe. It was cut at 45^{o} with the open side facing the flow. The purpose of this modification was to obtain a representative sample of contaminant concentration as it is fed to chemical pretreatment. This same modification for sampling was fabricated for the effluent side also. The point of effluent sampling was 122 cm (48 inches) downstream from the filter box. The stream sampled was pumped by positive displacement pump through a 293 mm diameter Nucleopore polycarbonate membrane filter, the device used to

Table A-1. Appurtenances for[1] WATER BOY Pilot Plant

Item	Purpose & Specifications	Manufactor	Model #
Raw Water Pump	Pumps Raw Water into Rapid Mix	Goulds Pumps, Inc.	XSH 15
Contaminant Feed Pump	Meters the contaminant batch into the main flow (0 to 1120 ml/min)	Fluid Metering, Inc	RP-D
Alum Feed Pump	Meters alum solution into main flow (0 to 75 ml/min)	Precision Control	111311-361
Polymer Feed Pump	Meters polymer solution into main flow (0 to 75 ml/min)	Precision Control	111311-361
Sodium Thiosulfate Feed Pump	Feeds $Na_2S_2O_3$ solution into effluent stream for dechlorination (50 to 1000 cc/min)	Cole Parmer	212
Giardia Sampling Pump	Diverts sampling stream from main flow through membrane filter (0 to 8.5 l/min)	Grainger	Rotary Beam Pump 1P771
Giardia Sampling Pump Motor	Drives *Giardia* sampling pump (3/4 hp)	Grainger	27846
Contaminant Batch Mixer	Agitates contaminant batch	Lightnin Mixers	Series 20
Alum Batch Mixer	Mixes alum solution	Wilkens-Anderson Co.	Power Stirrer
Polymer Batch Mixer	Mixes polymer solution	Cole Parmer	4555 H
Rapid Mix Basin Mixer	Disperses chemicals in rapid mix basin (1/4 hp) 1725 rpm	Lightnin Mixers	Mark II
Membrane Filter Holder	Holds 5 μm pore size 293 mm diameter membrane filters made by Nucleopore Corporation	Gelman Sciences	11873
Ratio Turbidimeter	Measures grab samples for turbidity	Hach Chemical Co.	18900-10
Flow-through Turbidimeter	Monitor influent and effluent turbidity	Hach Chemical Co.	1720-A

[1] WATER BOY was Neptune Microfloc Model WB-27 package water treatment plant.

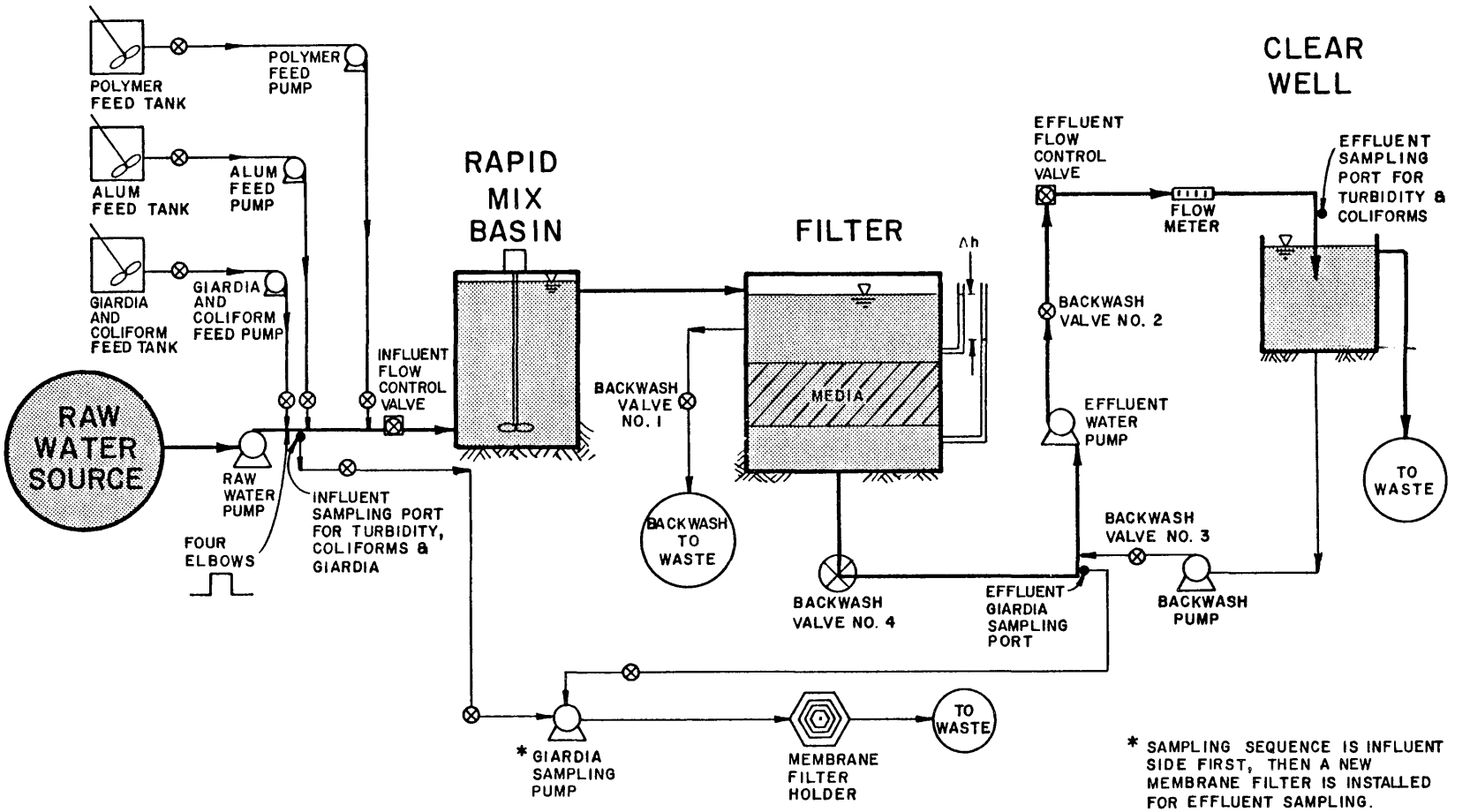

Figure A-6. Schematic diagram of the WATER BOY pilot plant showing chemical feed, contaminant feed, and sampling systems

sample Giardia cysts. Coliform and turbidity samples were obtained in the influent side before connecting the membrane filter. On the effluent side, coliform and turbidity samples were taken from the discharge to the clear well.

A-2 Operation

The operation of the WATER BOY as it was set up and used at Colorado State University is described in the following sections. Instructions are summarized for the following steps: i) start up, ii) filtration, iii) backwashing, v) backwash flow control, v) filtration flow control, vi) chemical feed, vii) contaminant feed and sampling.

A-2.1 Start Up

i) Turn filter switch (on major control box) and backwash pump switch (minor control box) to off positions. The major and minor control boxes are shown in Figure A-7.

ii) Fill the rapid mix basin by turning on the raw water feed pump. Figure A-8 shows the raw water feed pump. Control raw water flow with the influent-flow-control-valve shown in Figure A-9.

iii) Allow the water to overflow from the rapid mix basin into the filter box until the water level in the filter box is 10-12 cm above the filtration media; then turn off the raw water pump.

iv) Gently stir the filtration media (to a maximum depth of 50 cm) with a broom handle, or similar device, to remove the air bound within the filtration media.

v) After the bound air is removed, fill the filter box, by turning back on the raw water pump, to within 5 to 7 cm of the top, i.e. about 10 to 12 cm above the backwash overflow trough; then turn off raw water pump.

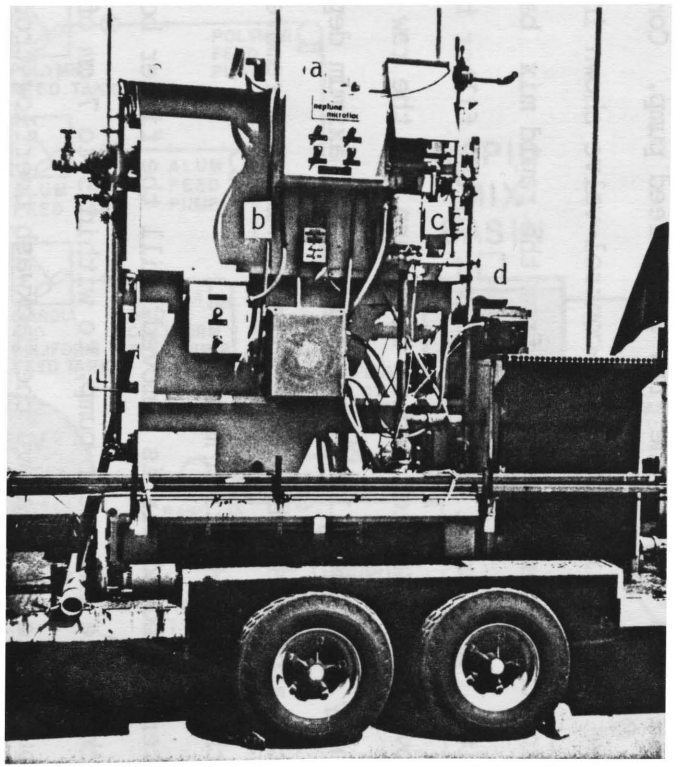

Figure A-7. Side view of WATER BOY: a) major control panel, b) minor control panel, c) effluent-flow pump, d) garden-hose-valve

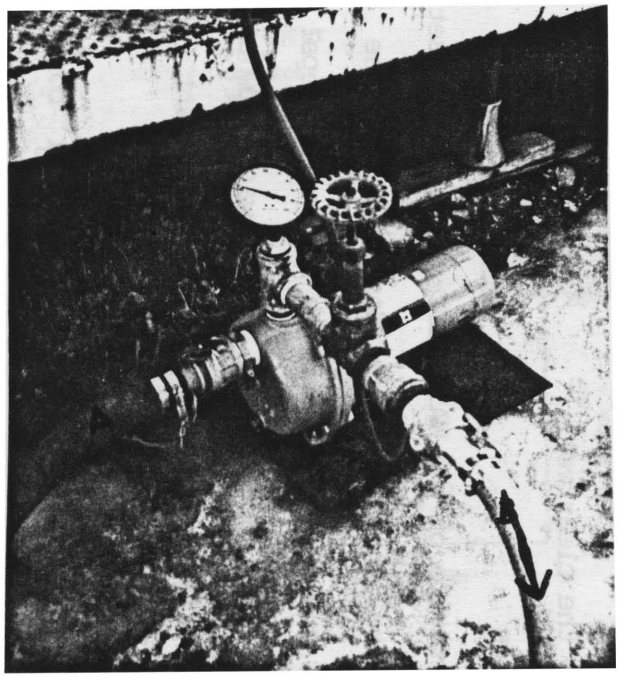

Figure A-8. Raw water pump (1 1/2 hp)

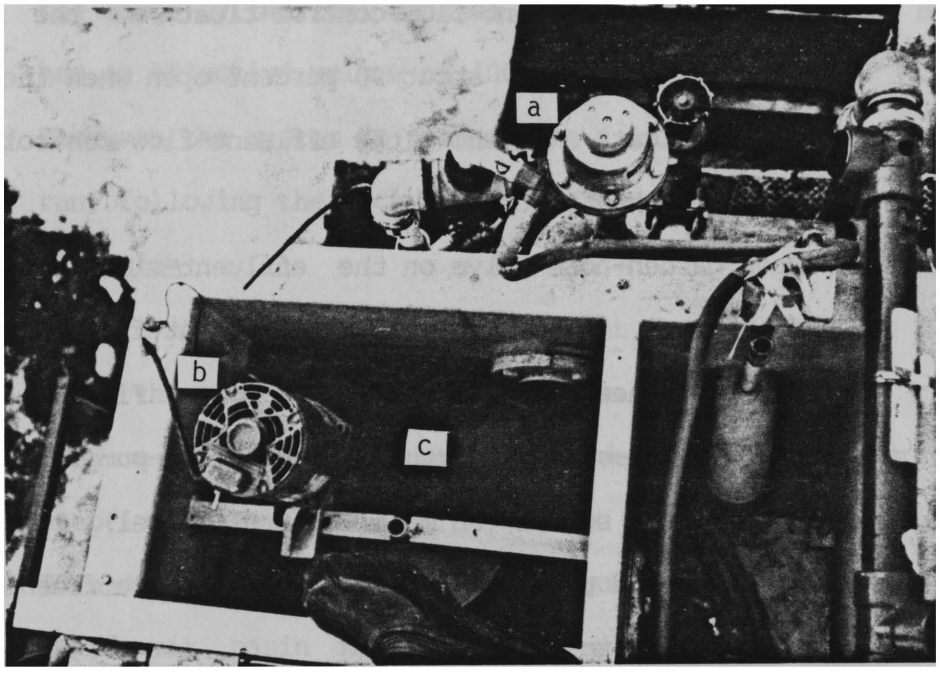

Figure A-9. Top view of rapid mix basin: a) influent-flow-control valve, b) mixer, c) rapid mix basin

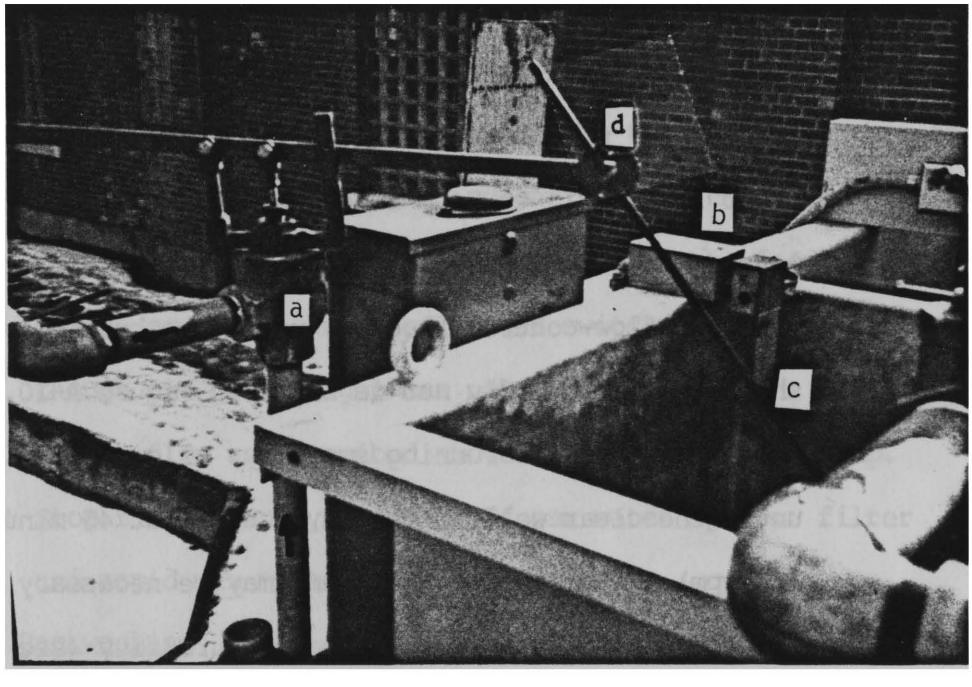

Figure A-10. Effluent flow control. a) effluent-flow-control valve, b) effluent-flow-pump-protector switch, c) shaft connected to effluent-flow-control-float, d) butterfly nut

vi) Install the effluent-flow-control-float so the effluent-flow-control valve is about 90 percent open when the filter box is full. Figure A-10 shows the effluent-flow-control valve and the shaft of the float.

vii) Open garden-hose-valve on the effluent-side of the effluent-flow-pump. This primes the effluent-flow-pump, by using the available head within the filter box. Figure A-7 shows the garden-hose-valve, and the effluent-flow-pump.

viii) Turn filter switch (on main control panel) to manual, green light should turn on. This activates the effluent-flow-pump and opens backwash valve #2.

ix) Turn on raw water pump. The effluent-flow-pump-protector-switch shown in Figure A-10 should be on, i.e. effluent-flow-pump should be on.

x) Adjust influent-flow-control-valve until an equilibrium is estabished within the filter box. Best operation is when the water level is 5 to 8 cm below the top of the filter box. This level can be varied by adjusting the fulcrum length on the effluent-flow-control-float by using the butterfly nut on its shaft. The butterfly nut is shown in Figure A-10.

xi) Once the system is running smoothly, allow it to filter water until the clear well is filled, i.e. about 45 minutes at 1.3 l/s (20 gpm). Chemical pretreatment may be necessary during this 45 minutes depending on the raw water turbidity (see the discussion on chemical feed system below).

xii) Once the clear well is filled, turn-off raw water feed pump and turn-off filter switch on main control panel. The clear well is

the large cylindrical tank on the front of the WATER BOY, and has an effective volume of 4000 liters.

xiii) Backwash the system to prepare the filtration media for a test run, following the backwashing procedures below.

A-2.2 Filtration

i) Prepare chemical feed and contaminant feed systems as described under the appropriate headings below.

ii) Turn-on the raw water pump, then immediately begin step iii) and step iv).

iii) Turn-on rapid mix basin mixer. Figure A-9 shows the 1/4 hp rapid mix basin mixer. This mixer must be plugged into electrical box No. 1 (left hand box as shown in Figure A-11) or an overloading of the circuit breakers will occur.

iv) Turn-on filter switch on main control panel to manual. Once the water level in the filter box raises high enough to activate the effluent-flow-pump-protector-switch, the green light on the main control panel will light indicating that the effluent-flow-pump is on. However, chemical and contaminant feed, and mixing, begin as soon as the filter switch is turned to manual even though the green light has not lit.

v) Adjust flow as described above in step x) of start up.

vi) Stop filtration by turning off raw water pump, filter switch, and rapid mix mixer.

A-2.3 Backwashing

i) Turn-off raw water feed pump, rapid mix mixer, and filter switch. This will automatically close backwash valve No. 2.

ii) Turn on backwash pump using switch on minor control box

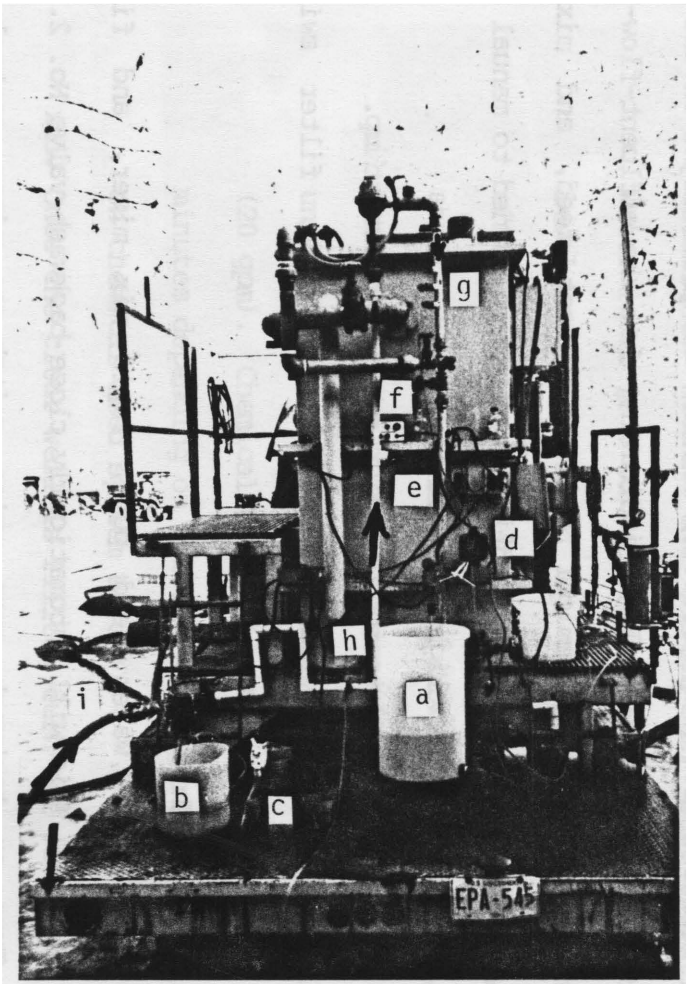

Figure A-11. Chemical feed system: a) polymer tank, b) alum tank, c) alum pump, d) polymer pump, e) electrical boxes, f) speed controller for polymer mixer, g) polymer injection port, h) alum injection port, i) influent raw water

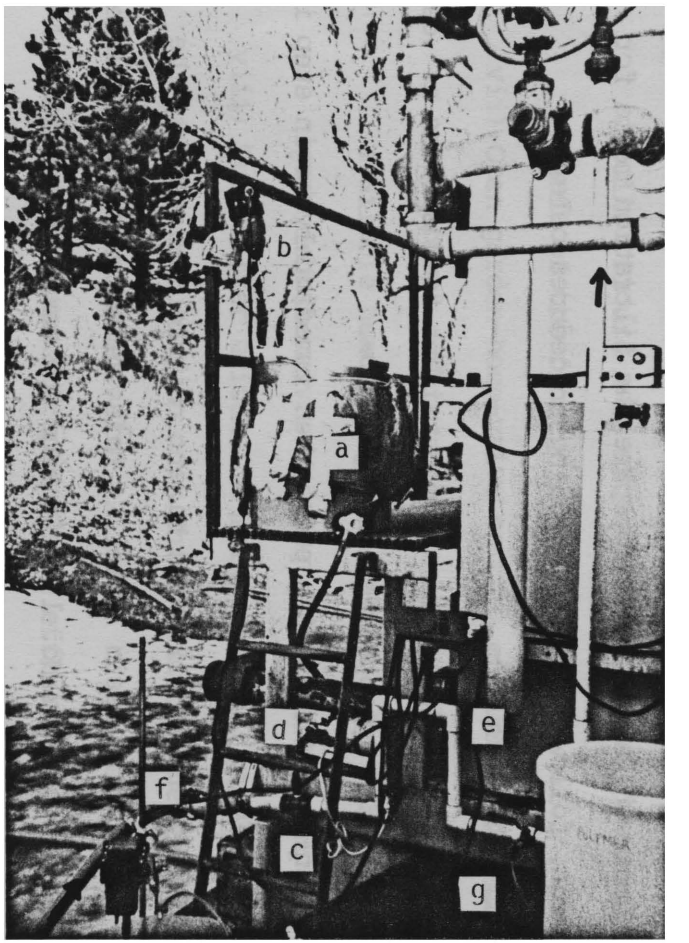

Figure A-12. Contaminant feed system: a) batch tank, b) mixer, c) injection port, d) metering pump, e) four elbows for mixing contminants with raw water, f) raw water influent line, g) influent sampling port for Giardia, coliforms, and turbidity

(directly below major control box). This will automatically open backwash valve No. 1.

iii) Slowly open backwash valve No. 3 (see Figure A-6). This allows the backwash pump to draw water from the clear well and pump it into the bottom of the filter.

iv) Check to insure that the water level in the filter box drops to the top of the overflow weir. If it does not, then either the backwash hose is clogged, possibly with ice, or more head is required between the backwash water discharge, i.e. disposal, point and the top of the overflow weir.

v) Stop the backwash cycle before the water level in the clear well reaches the pipe used by the backwash pump to draw the water from the clear well. This will prevent the backwash pump from pumping air.

vi) To stop the backwash cycle, turn off the backwash pump, and immediately close backwash valve No. 3. Close this valve fast, so that the filtration media "sets" properly.

vii) Filtration can now be resumed.

A-2.4 Backwash Flow Control

i) The backwash rate should be about 3.8 l/s (60 gpm), which is 10.2 mm/s (15 gpm/ft^2), which is 61 cm per minute rise within the filter box.

ii) The backwash rate can be adjusted by thottling backwash valve No. 4.

A-2.5 Filtration Flow Control

i) The influent flow is controlled by the influent-flow-control-valve.

ii) The effluent flow is controlled by the effluent-flow-control-float, which is connected to the effluent-flow-control-valve, which the effluent-flow-pump pumps against.

iii) The effluent-flow-pump is protected by the effluent-flow-pump-protector-switch, which is mounted at the top of the filter box and has two small floats attached to it. This protector switch automatically turns off the effluent-flow-pump when the water level in the filter box gets to low.

A-2.6 Chemical Feed

i) The chemical feed system is shown in Figure A-11.

ii) Both alum and polymer injection ports are injection quills which allow injection of the chemicals directly into the center of the flow stream.

iii) The following sample calculations illustrate how alum dosages were determined. Alum is reported as mg/l of $Al_2(SO_4)_3\ 14H_2O$.

Given:
* Raw water flow rate = 75 l/min
* Alum solution feed rate = 15 ml/min
* Alum solution consists of 5 liters of distilled water and 500 ml of commerical grade liquid alum.
* There is 643 grams of $Al_2(SO_4)_3\ 14H_2O$ in every milliliter of commerical grade liquid alum.

Find: The dosage of alum in mg/l of $Al_2(SO_4)_3\ 14H_2O$ per liter of raw water.

Solution:

$$\frac{643 \text{ mg of } Al_2(SO_4)_3 \cdot 14\ H_2O}{\text{ml of soln}} \times \frac{500 \text{ ml of liquid alum}}{5.5 \text{ l of batch}} \times \frac{0.015 \text{ l of alum soln}}{\text{min}}$$

$$\times \frac{1 \text{ min}}{75 \text{ l raw water}} = \frac{11.5 \text{ mg of } Al_2(SO_4)_3\ 14H_2O}{\text{liter of raw water}}$$

iv) Polymer dosages were calculated as follows:

Given:
* Raw water flow rate = 75 l/min
* Polymer batch feed rate = 70 ml/min
* Polymer batch consists of 20 liters of tap water and 10 ml of polymer
* The specific gravity of the polymer is 1.14

Find: The dosage of polymer is milligrams of polymer per liter of raw water.

Solution:

$$\frac{1\ 140\ \text{mg of polymer}}{\text{ml of polymer}} \times \frac{10\ \text{ml of polymer}}{20\ \text{l of batch}} \times \frac{0.07\ \text{l of batch}}{1\ \text{min}}$$

$$\times \frac{1\ \text{min}}{75\ \text{l of raw water}} = \frac{0.5\ \text{mg of polymer}}{\text{liter of raw water}}$$

A-2.7 Contaminant Feed and Sampling

i) The contaminant feed system is shown in Figure A-12. Notice the four elbows which insure adequate mixing of the contaminants with the raw water prior to influent sampling.

ii) An injection quill, similar to the ones used for chemical feed, was used for injecting the contaminants. The contaminants consisted of raw water, dog feces, and primary effluent from Fort Collins Wastewater Treatment Plant No. 2. These contaminants were mixed in a 50 liter plastic batch tank, shown as a) in Figure A-12. The dog feces served as the *Giardia* cyst source, and the primary effluent was the coliform bacteria source.

iii) Figure A-6 shows the points in the flow scheme where the influent and effluent were sampled for turbidity, coliform bacteria, and *Giardia* cysts.

iv) Figure A-13 shows the *Giardia* sampling pump connected to the

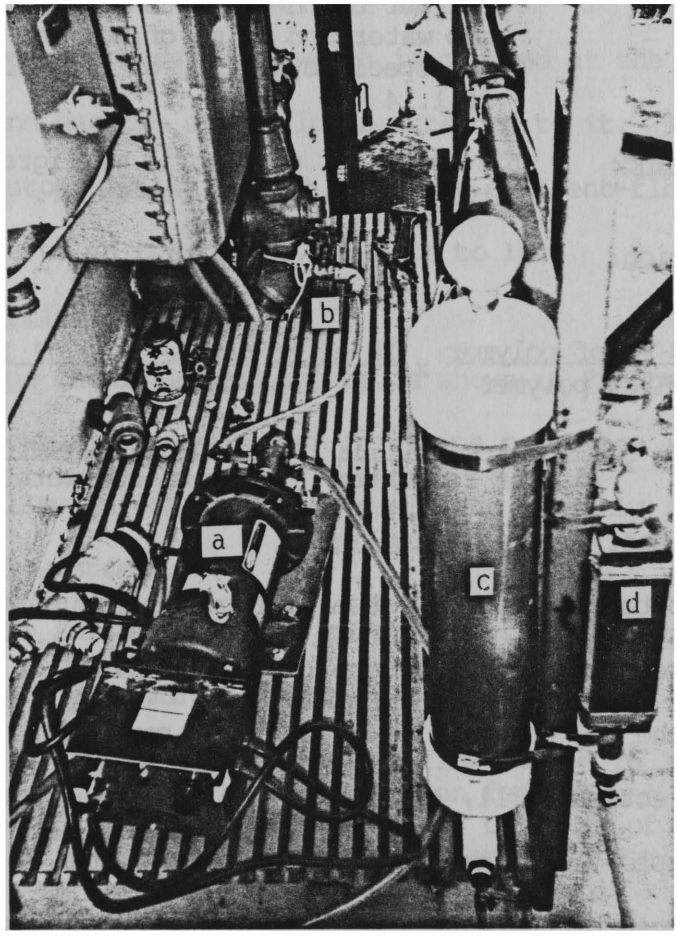

Figure A-13. Portion of apparatus for sampling Giarida cysts in effluent stream: a) Giardia sampling pump, b) effluent sampling port for Giardia, c) dampener to attenuate pressure fluctuations in the samping stream, d) flow meter used to measure sampling flow rate

effluent Giardia sampling port. A representative effluent sample was obtained by placing the effluent sampling port in a 3.8 cm (1.5 inch) elbow, taking the sampling stream from the center of the pipe, and having the velocity of the sampling stream equal to the velocity of the main flow stream.

v) Representative influent sampling was insured by allowing stream-lines direct access to the influent sampling port. This was obtained by having the water velocity in the sampling stream equal to the water velocity in the main flow stream, and by directing the sampling port towards the incoming flow.

APPENDIX B

MASTER DATA TABLE

Table B-1 contains all experimental data from the four WATER BOY testing phases, i.e., Familiarization, Spring Runoff, Horsetooth, and Low-Turbidity. The table has three parts: i) influent water characteristics, shown in Table B-1(a); ii) chemical basin information, shown in Table B-1(b); and iii) filter conditions and effluent water conditions, shown in Table B-1(c).

Table B-1 served as a source from which other tables and graphs were derived. These are shown in Appendices C, D, and E, and in the text.

Table B-1 is intended to be used, for those interested, as a "fold out". The fold out table can be constructed using copies or originals, of Tables B-1(a), B-1(b), and B-1(c), constructed as shown below:

Table B-1(a)	Table B-1(b)	Table B-1(c)
Sheet 1	Sheet 1	Sheet 1
Sheet 2	Sheet 2	Sheet 2
Sheet 3	Sheet 3	Sheet 3

TABLE B-1(a). Master Data Table (Sheet 1)

Test Identification			Influent Water Characteristics				
Run #	Date	Source of Water	Temp. (°C)	Turbidity (NTU)	Coliforms (#/100ml)	Giardia Designed (cyst/liter)	Giardia Detected (cyst/liter)
1	11/9/82	HT	10.0	9.0	2/	1/	1/
2	11/14/82	HT	7.5	9.0	2/	1/	1/
3	12/30/82	HT	6.0	9.5	2/	1/	1/
4	12/31/82	HT	6.0	9.5	2/	1/	1/
5	1/2/83	HT	6.0	9.5	2/	1/	1/
5	1/3/83	HT	6.0	9.5	2/	1/	1/
7	1/4/83	HT	6.0	9.6	2/	1/	1/
8	1/5/83	HT	6.0	9.0	2/	1/	1/
9	1/7/83	HT	5.5	9.0	2/	1/	1/
10	1/8/83	HT	5.5	9.0	2/	1/	1/
11	1/8/83	HT	5.5	8.0	2/	1/	1/
12	1/8/83	HT	5.5	8.0	2/	1/	1/
13	1/9/83	HT	5.5	8.5	2/	1/	1/
14	1/9/83	HT	5.5	8.5	2/	1/	1/
15	1/20/83	HT	5.0	9.0	2/	1/	1/
16	1/20/83	HT	5.0	9.0	2/	1/	1/
17	1/2/83	HT	5.0	9.0	2/	1/	1/
18	1/21/83	HT	5.0	9.0	2/	1/	1/
19	1/23/83	HT	5.0	9.5	2/	1/	1/
20	2/2/83	HT	5.0	9.0	2/	1/	1/
21	2/2/83	HT	5.0	9.0	2/	1/	1/
22	2/9/83	HT	5.0	9.0	2/	1/	1/
23	4/23/83	PR	8.0	27.0	2/	1/	1/
24	4/23/83	PR	8.0	27.0	2/	1/	1/
25	4/23/83	PR	8.0	27.0	2/	1/	1/
26	4/23/83	PR	8.0	27.0	2/	1/	1/
27a	4/26/83	PR	9.0	30.0	2/	1/	1/
27b	4/26/83	PR	9.0	30.0	2/	1/	1/
28a	4/26/83	PR	9.0	30.0	2/	1/	1/
28b	4/26/83	PR	9.0	30.0	2/	1/	1/
29	5/25/83	PR	9.0	44.0	2/	1/	1/
30	5/25/83	PR	9.0	44.0	2/	1/	1/
31	5/25/83	PR	9.0	44.0	2/	1/	1/
32	5/25/83	PR	11.0	35.0	2/	1/	1/
33	5/26/83	PR	10.0	32.0	2/	1/	1/
34	5/26/84	PR	10.0	27.0	2/	1/	1/
35	5/29/83	PR	7.5	34.0	2/	1/	1/
36	5/29/83	PR	7.5	35.0	2/	1/	1/
37	5/29/83	PR	7.5	35.0	2/	1/	1/
38	5/31/83	PR	7.0	16.0	2/	1/	1/
39	6/1/83	PR	7.0	17.0	2/	1/	1/
40	6/1/83	PR	8.0	17.0	2/	1/	1/
41	6/1/83	PR	8.0	12.0	2/	1/	1/
42	6/1/83	PR	8.0	12.0	2/	1/	1/
43	7/3/83	HT	10.0	7.0	2/	1/	1/
44	7/3/83	HT	10.0	7.0	2/	1/	1/
45	7/4/83	HT	10.0	7.0	2/	1/	1/
46	7/4/83	HT	10.0	7.0	2/	1/	1/
47	7/4/83	HT	10.0	7.0	2/	1/	1/
48	7/5/83	HT	10.0	7.0	2/	1/	1/
49	7/12/83	HT	10.0	7.0	2/	135	10
50	7/12/83	HT	10.0	7.0	2/	135	130
51	7/13/83	HT	10.0	7.0	300	220	110
52	7/14/83	HT	10.0	7.0	220	220	30

1/ No Giardia cysts or coliform bacteria injected
2/ Coliform bacteria were not monitored
3/ Cysts were of questionable viability
4/ No Giardia injected, therefore no Giardia sampling
5/ No effluent turbidity sample
6/ Alum dosages are in mg/l as $Al_{2(SO_4)_3 \cdot 14H_2O}$

cut line

TABLE B-1(a). continued (Sheet 2)

Test Identification		Influent Water Characteristics					
Run #	Date	Source of Water	Temp. (°C)	Turbidity (NTU)	Coliforms (#/100ml)	Giardia Designed (cyst/liter)	Giardia Detected (cyst/liter)
53	7/13/83	HT	11.0	7.0	2/	1/	1/
54	7/14/83	HT	10.0	7.0	2/	1/	1/
55	7/14/83	HT	10.0	7.0	2/	1/	1/
56	7/14/83	HT	10.0	7.0	2/	1/	1/
57	7/15/83	HT	10.0	7.0	2/	245	25
58	7/15/83	HT	10.0	7.0	2/	245	45
59	7/18/83	HT	12.0	7.0	1200	210	25
60	7/19/83	HT	12.0	7.0	13,000	150	50
61	7/19/83	HT	12.0	7.0	23,000	150	16
62	7/19/83	HT	12.0	7.0	2/	800	60
63	7/25/83	HT	12.0	7.0	2/	1/	1/
64	7/25/83	HT	12.0	7.0	2/	1/	1/
65	7/25/83	HT	11.0	7.0	2/	1/	1/
66	7/25/83	HT	11.0	7.0	2/	1/	1/
67	8/3/83	HT	12.0	7.0	2/	1/	1/
68	8/3/83	HT	12.0	7.0	2/	1/	1/
69	8/3/83	HT	12.0	7.0	2/	1/	1/
70	8/4/83	HT	12.0	7.0	2/	1/	1/
71	8/11/83	HT	12.0	7.0	2/	1/	1/
72	8/12/83	HT	12.0	7.0	2/	1/	1/
73	8/12/83	HT	11.0	7.0	3600	700	3/
74	8/12/83	HT	11.0	7.0	1500	700	3/
75	8/14/83	HT	13.0	7.0	3600	525	3/
76	8/14/83	HT	13.0	7.0	2700	525	3/
77	8/14/83	HT	13.0	7.0	2/	1/	1/
78	8/15/83	HT	12.0	7.0	2/	1/	1/
79	8/15/83	HT	12.0	7.0	8700	550	35
80	8/16/83	HT	13.0	7.0	2/	1/	1/
81	8/16/83	HT	13.0	7.0	2/	1/	1/
82	8/16/83	HT	13.0	7.0	2/	1/	1/
83	8/16/83	HT	13.0	7.0	2/	1/	1/
84	8/23/83	HT	12.0	7.0	2/	1/	1/
85	8/23/83	HT	12.0	7.0	2/	1/	1/
86	8/23/83	HT	12.0	7.0	2/	1/	1/
87	8/23/83	HT	12.0	7.0	2/	1/	1/
88	8/23/83	HT	12.0	7.0	2/	1/	1/
89	8/23/83	HT	12.0	7.0	2/	1/	1/
90	8/24/83	HT	12.0	7.0	16,000	550	250
91	8/24/83	HT	12.0	7.0	16,000	550	350
92	8/24/83	HT	12.0	7.0	30,000	1000	800
93	8/27/83	HT	12.0	7.0	2/	1/	1/
94	8/28/83	HT	12.0	7.0	2/	1/	1/
95	8/28/83	HT	12.0	7.0	2/	1/	1/
96	8/28/83	HT	12.0	7.0	2/	1/	1/
97	8/28/83	HT	12.0	7.0	2/	1/	1/
98	8/28/83	HT	12.0	7.0	20,000	2400	2000
99	8/28/83	HT	12.0	7.0	15,000	2400	1700
100	8/29/83	HT	12.0	7.0	2/	1/	1/
101	8/30/83	HT	12.0	7.0	2/	1/	1/
102	8/30/83	HT	12.0	7.0	2/	1/	1/
103	8/30/83	HT	12.0	7.0	2/	1/	1/
104	8/31/83	HT	12.0	7.0	2/	1/	1/
105	8/31/83	HT	12.0	7.0	1200	450	200
106	8/31/83	HT	12.0	7.0	2500	1000	75

1/ No Giardia cysts or coliform bacteria injected
2/ Coliform bacteria were not monitored
3/ Cysts were of questionable viability
4/ No Giardia injected, therefore no Giardia sampling
5/ No effluent turbidity sample
6/ Alum dosages are in mg/l as $Al_2(SO_4)_3 \cdot 14H_2O$

TABLE B-1(a). continued (Sheet 3)

Test Identification			Influent Water Characteristics				
Run #	Date	Source of Water	Temp. (°C)	Turbidity (NTU)	Coliforms (#/100ml)	Giardia Designed (cyst/liter)	Giardia Detected (cyst/liter)
107	11/1/83	PR	7.0	.60	2/	1/	1/
108	11/1/83	PR	7.0	.55	2/	1/	1/
109	11/1/83	PR	7.0	.45	2/	1/	1/
110	11/2/83	PR	7.0	.50	2/	1/	1/
111	11/2/83	PR	7.0	.45	2/	1/	1/
112	11/2/83	PR	7.0	.45	2/	1/	1/
113	11/5/83	PR	7.0	.60	2/	1/	1/
114	11/5/83	PR	7.0	.60	2/	1/	1/
115	11/5/83	PR	7.0	.70	2/	1/	1/
116	11/5/83	PR	7.0	.60	2/	1/	1/
117	11/10/83	PR	2.0	.40	15000	1500	260
118	11/15/83	PR	2.0	.65	2/	1/	1/
119	11/15/83	PR	2.0	.65	2/	1/	1/
120	11/15/83	PR	2.0	.65	2/	1/	1/
121	11/15/83	PR	2.0	.65	2/	1/	1/
122	11/17/83	PR	3.0	.65	2/	1/	1/
123	12/3/83	PR	1.0	.60	6900	1400	325
124	12/3/83	PR	1.0	.60	6900	1400	325
125	12/6/83	PR	1.0	.55	9000	1300	1300
126	12/6/83	PR	1.0	.55	9000	1300	1300
127	12/10/83	PR	1.0	.90	2/	400	175
128	12/10/83	PR	1.0	.90	2/	400	175
129	12/15/83	PR	1.0	.60	3500	1/	1/
130	1/4/84	PR	1.0	.80	2/	1/	1/
131	1/4/84	PR	1.0	.80	2/	1/	1/
132	1/4/84	PR	1.0	.80	2/	1/	1/
133	1/4/84	PR	1.0	.80	2/	1/	1/
134	1/6/84	PR	1.0	.70	2/	1/	1/
135	1/6/84	PR	1.0	.70	2/	1/	1/
136	1/6/84	PR	1.0	.70	2/	1/	1/
137	1/8/84	PR	1.0	.70	2/	1/	1/
138	1/8/84	PR	1.0	.70	10000	2600	1300

1/ No Giardia cysts or coliform bacteria injected
2/ Coliform bacteria were not monitored
3/ Cysts were of questionable viability
4/ No Giardia injected, therefore no Giardia sampling
5/ No effluent turbidity sample
6/ Alum dosages are in mg/l as $Al_2(SO_4)_3 \cdot 14H_2O$

TABLE B-1(b). Master Data Table (Sheet 1)

Run #	Chemical Basin Information					
	Alum Dosage6/ (mg/l)	Polymer Dosage (mg/l)	Type of Polymer	G(sec^{-1})	T(sec)	GT
1	0	1.0	572C	750	202	151,500
2	0	1.0	573C	750	222	166,500
3	0	0.5	573C	714	228	162,700
4	0	0.5	572C	714	212	151,400
5	0	1.5	573C	714	221	157,800
5	0	1.5	572C	714	212	151,400
7	0	4.0	573C	714	204	145,700
8	0	9.0	573C	714	228	163,000
9	0	7.0	8181	702	221	155,100
10	0	4.0	8102	702	217	152,300
11	0	8.0	8102	702	207	145,300
12	0	11.0	8102	702	203	142,500
13	0	1.0	8102	702	205	143,900
14	0	6.5	572C	702	203	142,500
15	0	1.5	572C	691	280	193,500
16	0	4.5	572C	691	256	176,900
17	0	5.5	572C	691	259	178,900
18	0	2.5	572C	691	228	157,500
19	0	2.5	572C	691	242	167,200
20	0	3.0	573C	691	217	150,000
21	0	7.0	573C	691	219	151,300
22	0	2.0	573C	691	223	154,100
23	0	1.5	572C	720	202	145,400
24	0	4.0	572C	720	202	145,400
25	0	8.5	572C	720	202	145,400
26	0	30	572C	720	202	145,400
27a	0	4.0	572C	726	207	150,300
27b	0	9.0	572C	726	207	150,300
28a	0	17.0	572C	726	207	150,300
28b	0	35.0	572C	726	207	150,300
29	0	10.5	572C	726	238	172,800
30	0	8.0	572C	726	238	172,800
31	0	5.0	572C	726	238	172,800
32	0	21.0	572C	767	238	182,500
33	0	6.5	572C	750	217	162,750
34	0	0	none	750	217	162,750
35	0	9.0	572C	774	238	184,200
36	0	0	none	774	240	185,800
37	0	12.5	572C	774	238	184,200
38	0	7.0	572C	782	248	194,000
39	30	0	none	782	269	210,400
40	18	0	none	720	311	223,900
41	12	0	none	720	230	165,600
42	25	0	none	720	238	171,400
43	0	3.0	573C	750	185	137,700
44	0	2.0	573C	750	180	134,700
45	0	1.0	573C	750	175	131,300
46	0	4.5	573C	750	175	131,300
47	0	6.5	573C	750	170	127,500
48	0	2.5	572C	750	180	135,000
49	0	2.5	573C	750	175	131,300
50	0	0	none	750	180	135,000
51	0	8.0	573C	750	180	135,000
52	0	2.5	8102	750	180	135,000

cut line

1/ No Giardia cysts or coliform bacteria injected
2/ Coliform bacteria were not monitored
3/ Cysts were of questionable viability
4/ No Giardia injected, therefore no Giardia sampling
5/ No effluent turbidity sample
6/ Alum dosages are in mg/l as $Al_2(SO_4)_3 \cdot 14H_2O$

Table B-1(b). continued (Sheet 2)

Run #	Chemical Basin Information: Alum Dose6/ (mg/l)	Polymer Dosage (mg/l)	Type of Polymer	G(sec^{-1})	T(sec)	GT
53	0	2.0	8102	755	170	128,400
54	0	0.8	8102	750	180	135,000
55	0	5.0	8102	750	170	127,000
56	0	7.5	8102	750	170	127,000
57	0	0	none	750	180	135,000
58	0	5.5	8102	750	180	135,000
59	0	11.0	8102	760	180	136,800
60	0	0	none	760	180	136,000
61	0	0	none	760	180	136,000
62	0	0	none	760	180	136,000
63	0	1.0	572C	760	180	136,000
64	0	2.5	572C	760	180	136,800
65	0	5.5	572C	755	180	135,900
66	0	11.0	572C	755	180	135,900
67	4	0	none	760	180	136,800
68	12	0	none	760	180	136,800
69	18	0	none	760	180	136,800
70	25	0	none	760	180	136,800
71	0	4.0	572C	760	180	136,800
72	0	2.5	572C	760	180	136,800
73	0	2.5	572C	755	180	135,900
74	0	0	none	755	180	135,900
75	0	1.0	572C	765	180	137,700
76	30	0	none	765	180	137,700
77	30	0	none	765	180	137,700
78	0	3.5	8102	760	180	136,800
79	0	3.5	8102	760	180	136,800
80	0	1.0	8102	765	210	160,700
81	0	4.0	8102	765	210	160,700
82	0	6.0	8102	765	210	160,700
83	0	10.0	8102	765	210	160,700
84	0	3.0	8102	760	210	159,600
85	0	5.0	8102	760	210	159,600
86	0	7.0	8102	760	210	159,600
87	0	15.0	8102	760	210	159,600
88	0	0	8102	760	210	159,600
89	0	4.0	8102	760	180	136,800
90	0	4.0	8102	760	180	136,800
91	0	1.0	8102	760	180	136,800
92	18	0	none	760	180	136,800
93	16	0	none	760	180	136,800
94	20	0	none	760	180	136,800
95	30	0	none	760	180	136,800
96	25	0	none	760	180	136,800
97	10	0	none	760	180	136,800
98	20	0	none	760	180	136,800
99	0	0	none	760	180	136,800
100	0	4.0	8102	760	180	136,800
101	0	4.0	8102	760	180	136,800
102	20	2.0	8102	760	180	136,800
103	20	1.0	8102	760	180	136,800
104	20	4.0	8102	760	180	136,800
105	20	4.0	8102	760	180	136,800
106	20	4.0	8102	760	180	136,800

cut line

1/ No Giardia cysts or coliform bacteria injected
2/ Coliform bacteria were not monitored
3/ Cysts were of questionable viability
4/ No Giardia injected, therefore no Giardia sampling
5/ No effluent turbidity sample
6/ Alum dosages are in mg/l as $Al_2(SO_4)_3 \cdot 14H_2O$

TABLE B-1(b). continued (Sheet 3)

Run #	Chemical Basin Information: Alum Dosage6/ (mg/l)	Polymer Dosage (mg/l)	Type of Polymer	G(sec^{-1})	T(sec)	GT
107	0	0	none	782	202	158,000
108	0	0.2	8102	782	235	184,000
109	0	0.5	8102	782	235	184,000
110	0	1.0	8102	782	220	172,000
111	0	2.0	8102	782	220	172,000
112	0	0.2	8102	782	220	172,000
113	3.0	0.6	8102	782	252	197,000
114	3.0	0.6	8102	782	252	197,000
115	3.0	0.2	8102	782	252	197,000
116	3.0	0.07	8102	782	252	197,000
117	0	0	none	645	224	144,000
118	3.0	0	none	645	202	130,000
119	0.5	0	none	645	202	130,000
120	1.5	0	none	645	202	130,000
121	5.5	0	none	645	202	130,000
122	1.0	0	none	661	202	133,000
123	0	0.1	8102	630	224	141,000
124	0	0.4	8102	630	224	141,000
125	0.40	0	none	630	235	148,000
126	5.0	0	none	630	235	148,000
127	3.0	0.2	8102	630	202	127,000
128	3.0	0.4	8102	630	202	127,000
129	0	0	none	630	202	127,000
130	0	0.4	572-C	630	202	127,000
131	0	0.8	572-C	630	202	127,000
132	0	2.0	572-C	630	202	127,000
133	1.5	0.7	572-C	630	202	127,000
134	15	2.0	572-C	630	202	127,000
135	4.5	2.0	572-C	630	202	127,000
136	9.0	2.0	572-C	630	202	127,000
137	30	2.0	572-C	630	202	127,000
138	7.0	2.0	572-C	630	202	127,000

cut line

1/ No Giardia cysts or coliform bacteria injected
2/ Coliform bacteria were not monitored
3/ Cysts were of questionable viability
4/ No Giardia injected, therefore no Giardia sampling
5/ No effluent turbidity sample
6/ Alum dosages are in mg/l as $Al_2(SO_4)_3 \cdot 14H_2O$

TABLE B-1(c). Master Data Table (Sheet 1)

	Filter Conditions			Effluent Water Conditions			
Run #	Type of Filtration	Length of Run (hr)	Flow Rate (gpm/ft^2)	Turbidity (NTU)	Giardia (cyst/liter)	Water Sampled (l)	Coliforms (#/100ml)
1	in-line	9.0	5.0	0.8	1/	4/	2/
2	in-line	8.3	4.6	0.3	1/	4/	2/
3	in-line	6.0	4.4	1.2	1/	4/	2/
4	in-line	5.0	4.8	1.9	1/	4/	2/
5	in-line	4.0	4.6	0.2	1/	4/	2/
5	in-line	4.0	4.8	0.2	1/	4/	2/
7	in-line	5.0	5.0	0.15	1/	4/	2/
8	in-line	2.5	4.4	3.0	1/	4/	2/
9	in-line	2.5	4.6	3.5	1/	4/	2/
10	in-line	3.0	4.7	0.1	1/	4/	2/
11	in-line	4.0	4.9	0.15	1/	4/	2/
12	in-line	3.0	5.0	0.5	1/	4/	2/
13	in-line	3.0	4.9	0.3	1/	4/	2/
14	in-line	3.0	5.0	0.4	1/	4/	2/
15	in-line	1.5	3.6	0.4	1/	4/	2/
16	in-line	1.5	4.0	0.3	1/	4/	2/
17	in-line	1.1	3.9	0.4	1/	4/	2/
18	in-line	2.0	4.4	0.45	1/	4/	2/
19	in-line	2.5	4.2	0.30	1/	4/	2/
20	in-line	1.0	4.7	0.45	1/	4/	2/
21	in-line	0.75	4.6	2.0	1/	4/	2/
22	in-line	5.0	4.1	0.2	1/	4/	2/
23	in-line	0.75	5.0	1.5	1/	4/	2/
24	in-line	0.75	5.0	8.5	1/	4/	2/
25	in-line	0.75	5.0	1.0	1/	4/	2/
26	in-line	0.75	5.0	3.0	1/	4/	2/
27a	in-line	0.80	4.9	3.0	1/	4/	2/
27b	in-line	0.80	4.9	1.5	1/	4/	2/
28a	in-line	0.80	4.9	1.5	1/	4/	2/
28b	in-line	0.80	4.9	6.5	1/	4/	2/
29	in-line	0.80	4.3	2.0	1/	4/	2/
30	in-line	0.80	4.3	1.5	1/	4/	2/
31	in-line	0.80	4.3	2.5	1/	4/	2/
32	in-line	0.80	4.3	3.0	1/	4/	2/
33	in-line	1.0	4.7	1.0	1/	4/	2/
34	in-line	1.0	4.7	10.0	1/	4/	2/
35	in-line	1.0	4.3	1.50	1/	4/	2/
36	in-line	1.0	4.2	1.0	1/	4/	2/
37	in-line	1.2	4.3	1.3	1/	4/	2/
38	in-line	2.8	4.1	1.1	1/	4/	2/
39	in-line	1.0	3.8	4.0	1/	4/	2/
40	in-line	0.8	3.3	12.5	1/	4/	2/
41	in-line	0.7	4.4	10.5	1/	4/	2/
42	in-line	0.5	4.3	10.0	1/	4/	2/
43	in-line	3.0	5.5	0.3	1/	4/	2/
44	in-line	1.0	5.6	0.5	1/	4/	2/
45	in-line	1.0	5.8	1.0	1/	4/	2/
46	in-line	1.0	5.7	0.8	1/	4/	2/
47	in-line	1.0	5.8	2.0	1/	4/	2/
48	in-line	6.0	5.6	0.2	1/	4/	2/
49	in-line	2.0	5.7	0.5	zero	150	2/
50	in-line	1.3	5.6	5/	zero	110	2/
51	in-line	1.3	5.6	5/	zero	110	<1
52	in-line	1.4	5.6	5/	zero	110	10

cut line

1/ No Giardia cysts or coliform bacteria injected
2/ Coliform bacteria were not monitored
3/ Cysts were of questionable viability
4/ No Giardia injected, therefore no Giardia sampling
5/ No effluent turbidity sample
6/ Alum dosages are in mg/l as $Al_2(SO_4)_3 \cdot 14H_2O$

TABLE B-1(c). continued (Sheet 2)

	Filter Conditions			Effluent Water Conditions			
Run #	Type of Filtration	Length of Run (hr)	Flow Rate (gpm/ft^2)	Turbidity (NTU)	Giardia (cyst/liter)	Water Sampled (l)	Coliforms (#/100ml)
53	in-line	1.0	5.8	0.6	1/	4/	2/
54	in-line	1.0	5.6	1.5	1/	4/	2/
55	in-line	1.0	5.9	0.45	1/	4/	2/
56	in-line	1.0	6.0	0.55	1/	4/	2/
57	in-line	1.4	5.6	6.0	30	150	2/
58	in-line	1.4	5.6	0.4	zero	190	2/
59	in-line	1.4	5.6	1.0	zero	150	20
60	in-line	1.4	5.6	6.0	8	150	>1000
61	in-line	1.4	5.6	6.2	16	150	>1000
62	in-line	1.4	5.6	6.1	235	150	1/
63	in-line	1.0	5.6	0.7	1/	4/	2/
64	in-line	1.0	5.6	0.55	1/	4/	2/
65	in-line	1.0	5.6	0.6	1/	4/	2/
66	in-line	1.0	5.6	2.3	1/	4/	2/
67	in-line	1.0	5.6	6.3	1/	4/	2/
68	in-line	1.0	5.6	2.3	1/	4/	2/
69	in-line	1.0	5.6	1.3	1/	4/	2/
70	in-line	1.0	5.6	1.6	1/	4/	2/
71	in-line	10.5	5.6	0.5	1/	4/	2/
72	in-line	1.0	5.6	0.6	1/	4/	2/
73	in-line	2.0	5.6	0.5	3/	3/	100
74	in-line	2.0	5.6	6.4	3/	3/	1000
75	in-line	2.0	5.6	1.7	3/	3/	680
76	in-line	4.0	5.6	0.2	3/	3/	100
77	in-line	1.0	5.6	1.8	1/	4/	2/
78	in-line	14.0	5.6	0.15	1/	4/	2/
79	in-line	1.5	5.6	0.15	zero	150	50
80	in-line	1.0	4.8	1.4	1/	4/	2/
81	in-line	1.0	4.8	0.4	1/	4/	2/
82	in-line	1.0	4.8	0.5	1/	4/	2/
83	in-line	1.0	4.8	0.6	1/	4/	2/
84	in-line	1.0	4.8	0.4	1/	4/	2/
85	in-line	1.0	4.8	0.4	-	4/	2/
86	in-line	1.0	4.8	1/	4/	2/	
87	in-line	3.0	4.8	0.8	1/	4/	2/
88	in-line	1.0	4.8	5.8	1/	4/	2/
89	in-line	2.0	5.6	0.3	1/	4/	2/
90	in-line	1.8	5.6	0.4	zero	150	70
91	in-line	1.8	5.6	1.2	zero	150	580
92	in-line	1.8	5.6	1.7	25	150	570
93	in-line	1.0	5.6	1.3	1/	4/	2/
94	in-line	1.0	5.6	1.3	1/	4/	2/
95	in-line	1.0	5.6	2.1	1/	4/	2/
96	in-line	1.0	5.6	1.8	1/	4/	2/
97	in-line	1.0	5.6	8.4	1/	4/	2/
98	in-line	1.8	5.6	1.1	125	150	330
99	in-line	1.8	5.6	6.8	1000	150	11,000
100	in-line	1.0	5.6	0.5	1/	4/	2/
101	in-line	1.0	5.6	0.4	1/	4/	2/
102	in-line	1.0	5.6	0.65	1/	4/	2/
103	in-line	1.0	5.6	1.1	1/	4/	2/
104	in-line	1.0	5.6	0.75	1/	4/	2/
105	in-line	1.8	5.6	0.8	zero	150	30
106	in-line	1.8	5.6	0.7	5	150	100

cut line

1/ No Giardia cysts or coliform bacteria injected
2/ Coliform bacteria were not monitored
3/ Cysts were of questionable viability
4/ No Giardia injected, therefore no Giardia sampling
5/ No effluent turbidity sample
6/ Alum dosages are in mg/l as $Al_2(SO_4)_3 \cdot 14H_2O$

TABLE B-1(c). continued (Sheet 3)

	Filter Conditions			Effluent Water Conditions			
Run #	Type of Filtration	Length of Run (hr)	Flow Rate (gpm/ft^2)	Turbidity (NTU)	Giardia (cyst/liter)	Water Sampled (l)	Coliforms (#/100ml)
107	in-line	1.0	5.0	0.45	1/	4/	2/
108	in-line	1.0	4.3	0.40	1/	4/	2/
109	in-line	1.0	4.3	0.50	1/	4/	2/
110	in-line	1.0	4.6	0.45	1/	4/	2/
111	in-line	1.2	4.6	0.65	1/	4/	2/
112	in-line	1.0	4.6	0.35	1/	4/	2/
113	in-line	0.7	4.0	0.75	1/	4/	2/
114	in-line	1.0	4.0	0.75	1/	4/	2/
115	in-line	1.0	4.0	0.70	1/	4/	2/
116	in-line	1.0	4.0	0.60	1/	4/	2/
117	in-line	1.0	4.5	0.60	180	22	12000
118	in-line	1.0	5.0	0.60	1/	4/	2/
119	in-line	1.0	5.0	0.55	1/	4/	2/
120	in-line	1.0	5.0	0.55	1/	4/	2/
121	in-line	1.0	5.0	0.60	1/	4/	2/
122	in-line	1.0	5.0	0.60	1/	4/	2/
123	in-line	1.8	4.5	1.1	180	22	5700
124	in-line	1.8	4.5	0.85	100	22	3500
125	in-line	1.8	4.3	1.0	850	22	8500
126	in-line	1.8	4.3	1.0	950	22	6500
127	in-line	1.8	5.0	1.1	100	22	2/
128	in-line	1.8	5.0	0.90	125	22	2/
129	in-line	1.0	5.0	0.70	1/	4/	3000
130	in-line	1.0	5.0	0.65	1/	4/	2/
131	in-line	1.0	5.0	0.60	1/	4/	2/
132	in-line	1.0	5.0	0.80	1/	4/	2/
133	in-line	1.0	5.0	0.50	1/	4/	2/
134	in-line	1.0	5.0	1.0	1/	4/	2/
135	in-line	1.0	5.0	0.35	1/	4/	2/
136	in-line	1.0	5.0	0.35	1/	4/	2/
137	in-line	1.0	5.0	3.0	1/	4/	2/
138	in-line	1.8	5.0	0.40	70	22	150

cut line

1/ No Giardia cysts or coliform bacteria injected
2/ Coliform bacteria were not monitored
3/ Cysts were of questionable viability
4/ No Giardia injected, therefore no Giardia sampling
5/ No effluent turbidity sample
6/ Alum dosages are in mg/l as $Al_2(SO_4)_3 \cdot 14H_2O$

APPENDIX C

RESULTS FROM SPRING RUNOFF TESTING

This appendix material summarizes results obtained in April and May 1983 during spring runoff of the Cache La Poudre River, when turbidity levels ranged from 12 to 44 NTU. The results are contained in this appendix to illustrate the contrast in treating high turbidity water compared with the low turbidity water, the focus of the research. The results indicate that although "in-line" filtration can produce water of 1 NTU, run times were only about two hours. Since run times of only two hours are not economical, the "in-line" mode is not feasible for treating high turbidity waters. The question was explored because of its significance if found feasible for high turbidity waters as well as waters having low turbidity.

C. SPRING RUNOFF RESULTS

During spring runoff, turbidity levels of the Cache La Poudre River ranged between 12 and 44 NTU, changing as much as 10 NTU in one hour, and water temperatures ranged between 7 and 10°C. Since the WATER BOY was set up on the river when spring runoff began in late April 1983, it was decided to take advantage of these different conditions and conduct turbidity testing. The idea was to ascertain whether the "in-line" mode of filtration was effective for high turbidity waters.

There were 22 effluent turbidity vs chemical dose test runs using Cache La Poudre River water during spring runoff. Table C-1 summarizes the spring runoff results according to coagulant dose category, as defined in Section 3.2 and as used in Table 3-1. Testing was not done using Giardia cysts and coliform bacteria because of the limited scope of this phase. Eighteen test runs were conducted using Magnifloc 572-C polymer as sole coagulant, and four tests used alum as the sole coagulant. The alum test runs, Runs 39 to 42, were deemed invalid due to excessive dilution of the alum feed solution. The 18 effluent turbidity vs chemical dose tests, using Magnifloc 572-C as the sole coagulant involved two comparisons between the bench scale, laboratory scale, and field scale pilot plants (reported in Appendix D). Three headloss and effluent turbidity vs time curves were developed.

C.1 Effect of Coagulant Dose on Filtration

Figure C-1 shows the effluent turbidity vs chemical dose curve developed using Magnifloc 572-C and water from the Cache La Poudre River during spring runoff. From this curve, the optimum dosage range for Magnifloc 572-C was estimated to be between 6 and 20 mg/l. This optimum dosage range is defined by turbidity removal, as shown in Figure C-1.

Table C-1. Spring Runoff Results[1/3/]

Run No.	Coagulant Dosage Category[2/]	Dose of Magnifloc 572-C mg/l	Turbidity (NTU)		
			Influent	Effluent[4/]	Percent Removal
34	none	0	23	10	57
36	none	0	35	11	69
25	optimum	8.5	27	1.0	96
27b	optimum	9.0	30	1.5	95
28a	optimum	17.0	30	1.5	95
29	optimum	10.5	44	2.0	95
30	optimum	8.0	44	1.5	97
33	optimum	6.5	23	1.0	96
35	optimum	9.0	34	1.5	96
37	optimum	12.5	35	1.3	96
38	optimum	7.0	16	1.1	93
23	nonoptimum	1.5	27	15	44
24	nonoptimum	4.0	27	8.5	69
26	nonoptimum	30	27	3.0	89
27a	nonoptimum	4.0	27	3.0	89
28b	nonoptimum	35	30	6.5	78
31	nonoptimum	5.0	44	2.5	94
32	nonoptimum	21	35	3.0	91

1/ Abstracted from Table B-1

2/ Based upon results in Figure C-1

3/ No Giardia cysts or coliform bacteria were injected during the spring runoff testing phase

4/ Effluent turbidity after 60 minutes of operation

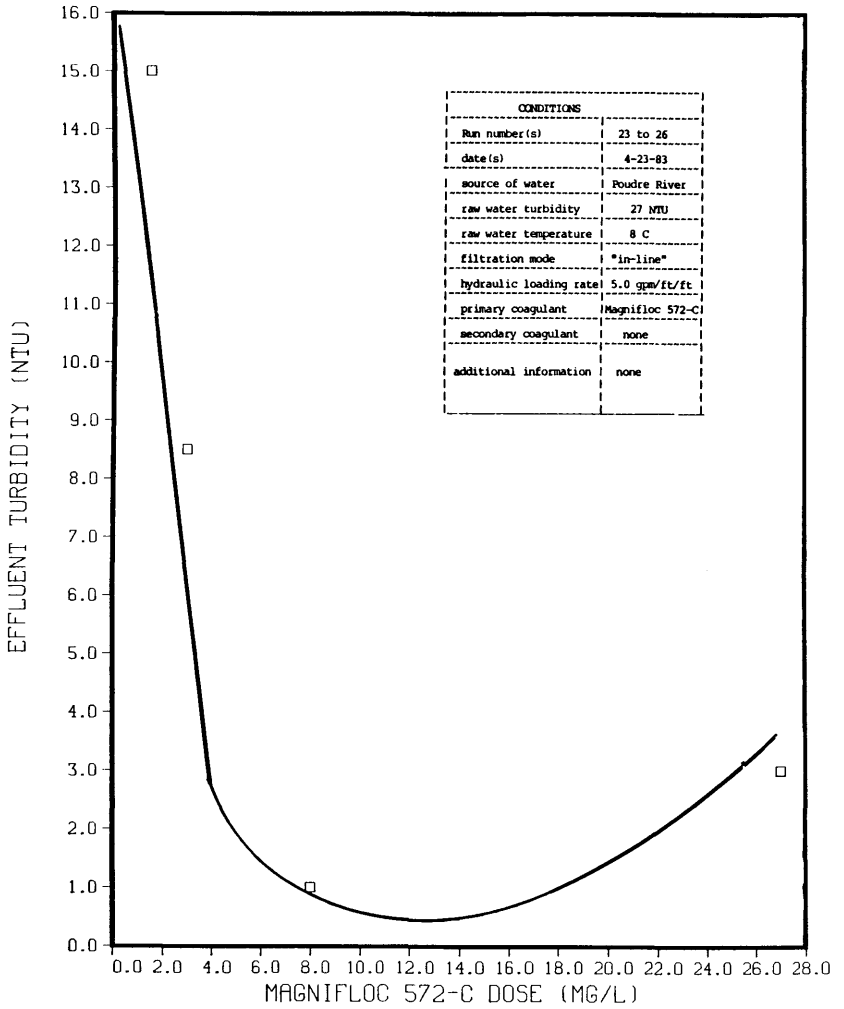

Figure C-1. Effluent turbidity vs Magnifloc 572-C dose. Horsetooth water

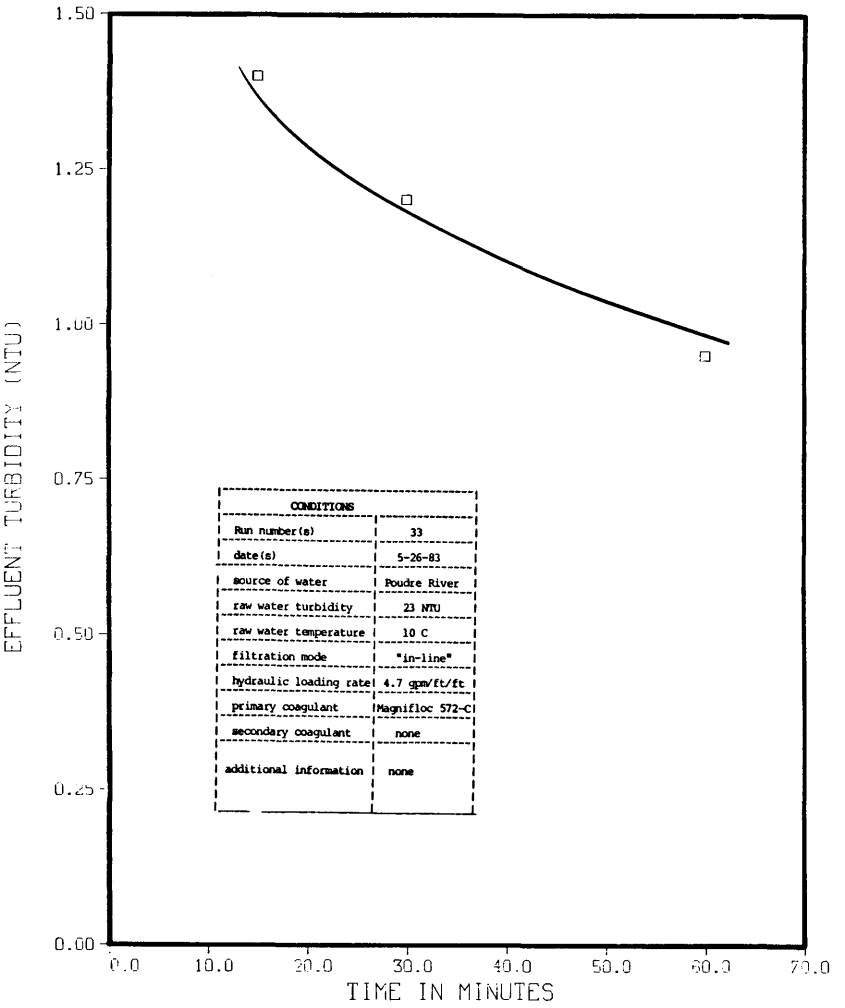

Figure C-2. Effluent turbidity vs time for spring runoff water using 6.5 mg/l of

The curve shown in Figure C-1 is unique for the particular ambient water conditions tested. Results, shown in Table C-1, are summarized in the following sections.

Zero Coagulant Dose Tests. Runs 34 and 36 had zero coagulant dose. Raw water turbidities were 23 NTU and 35 NTU, respectively. These are the first two runs listed in Table C-1. After one-hour of operation, the effluent turbidity for these no chemical runs were 10 NTU, for Run 34; and 11 NTU for Run 36.

Optimum Coagulant Dose Test. The optimum dose range was determined to be 6 to 20 mg/l of Magnifloc 572-C for 27 NTU spring runoff water. Runs 25, 27b, 28a, 29, 30, 33, 35, 37, and 38, had coagulation dosages within this 6 to 20 mg/l optimum dose range. Turbidity removals for these nine optimum dose runs ranged between 93 and 97 percent.

Nonoptimum Coagulant Dose Tests. Runs 23, 24, 26, 27a, 28b, 31, and 32, all had nonoptimum coagulant dosages, as determined with 27 NTU raw water. None of these nonoptimum dose runs had effluent turbidity below 3 NTU. Turbidity removals ranged between 44 and 94 percent.

C.2 Effect of Time on Filtration

Five effluent turbidity and headloss vs time runs were conducted using spring runoff water from the Cache La Poudre River. These were Runs 33, 35, 36, 37, and 38.

The results of Run 33 is shown in Figure C-2, which shows how effluent turbidity varies with time immediately following backwashing for raw water having 23 NTU. Effluent turbidity readings declined steadily to 1.4 NTU, 1.2 NTU, and 0.9 NTU, at 10 minutes, 30 minutes, and 60 minutes, respectively. Figure C-3 shows the results of Run 35, which was similar to Run 33, but with 34 NTU water. Both Figures C-2

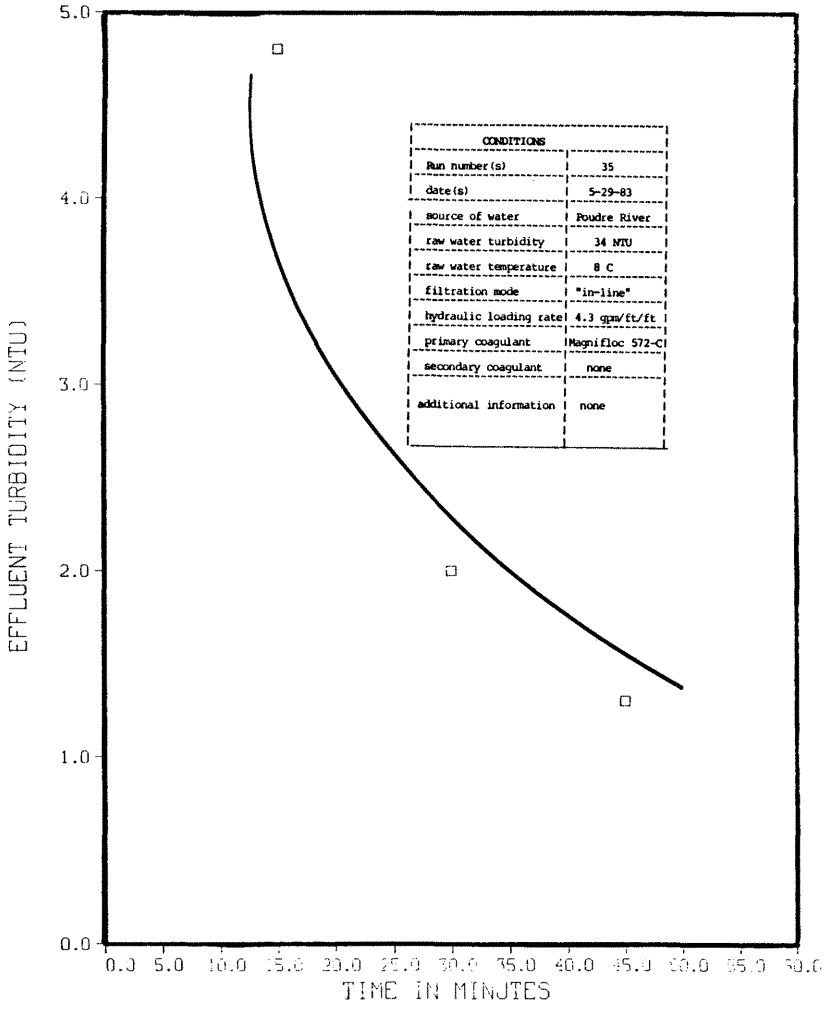

Figure C-3. Effluent turbidity vs time for spring runoff water using 9.0 mg/l of Magnifloc 572-C

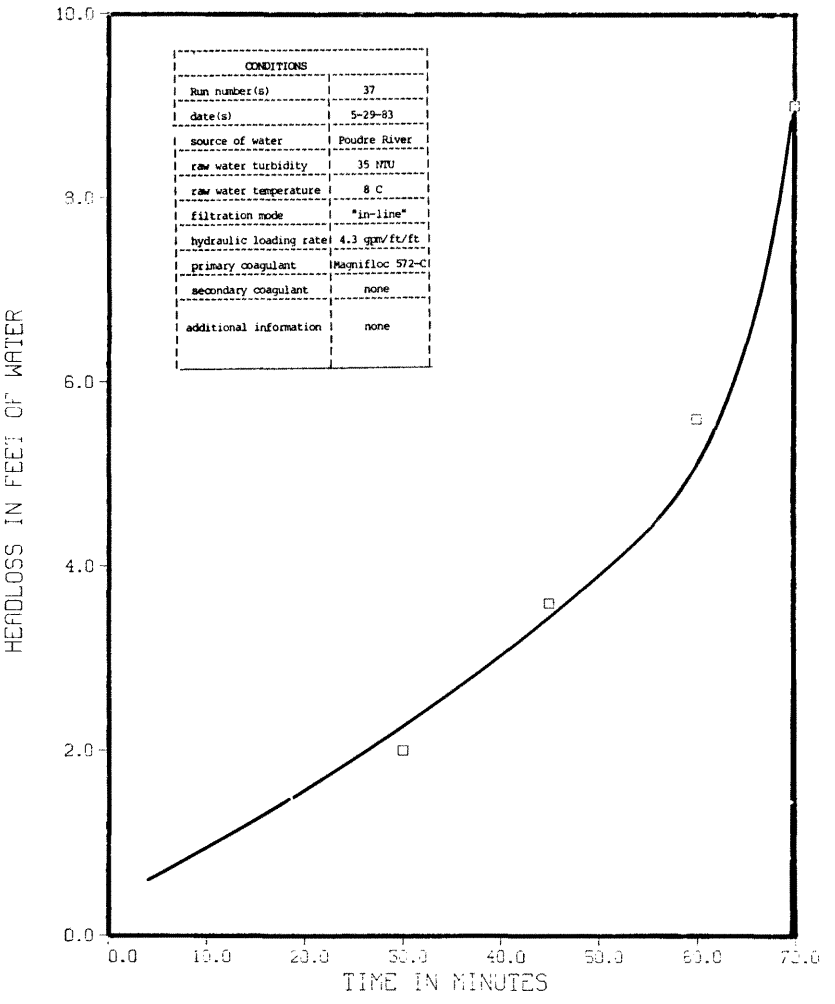

Figure C-4. Headloss vs time without coagulation. Spring runoff water; raw water was 35 NTU

and C-3 illustrate the need for "filtering to waste". A period of about 30 minutes duration appears adequate based upon the curves shown.

Figure C-4 shows how headloss varies with time without chemicals for the "in-line" mode of filtration, and using raw water having turbidity of 35 NTU. Figure C-5 and C-6 show headloss and effluent turbidity vs time relations using an optimum dose of Magnifloc 572-C, "in-line" filtration, and raw water turbidity of 16 and 35 NTU respectively.

Figures C-4, C-5, and C-6 are the results of Runs 36, 38, and 37, respectively. The length of run for these three runs, before backwashing was required, were approximately 60 min, 160 min, 60 min, respectively. These short runs show that "in-line" filtration is not a suitable treatment mode during spring runoff. Conventional treatment would allow flocculation which would permit sedimentation, thus reducing the turbidity load on the filters.

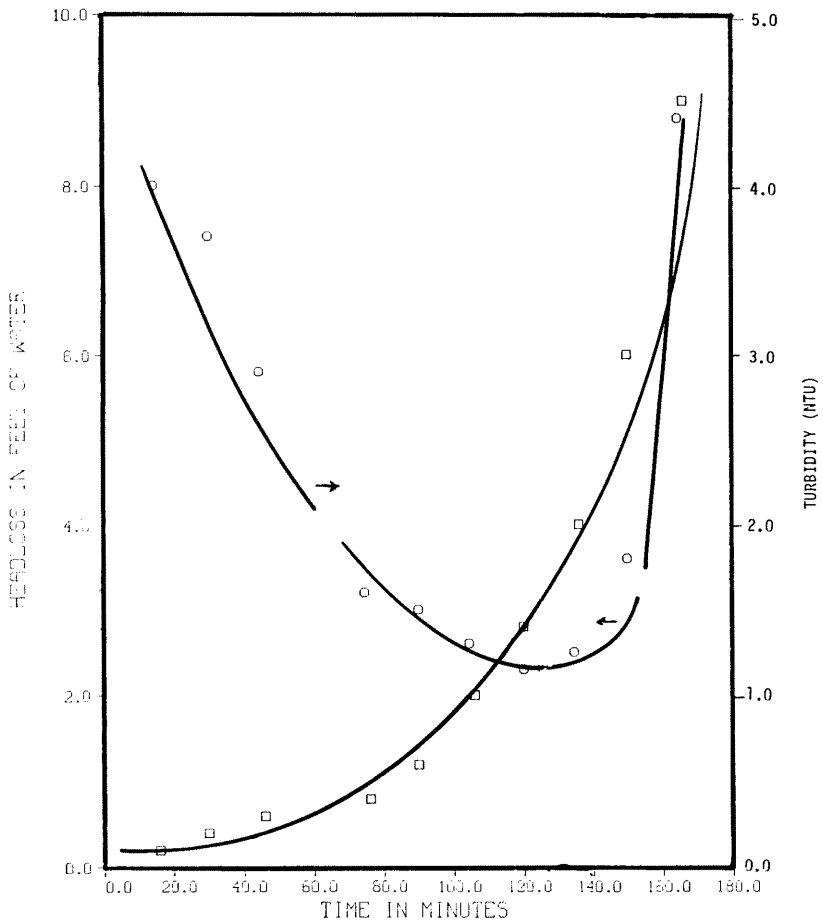

Figure C-5. Headloss and effluent turbidity vs time. Spring runoff water using 7 mg/l of Magnifloc 572-C; raw water was 16 NTU

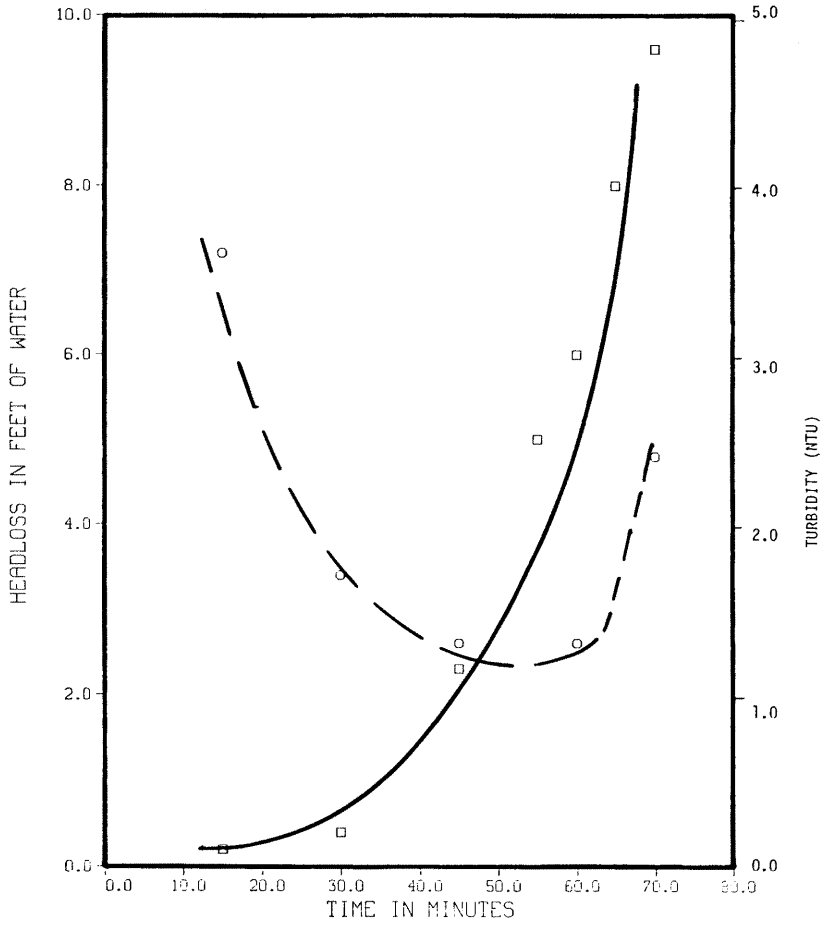

Figure C-6. Headloss and effluent turbidity vs time during spring runoff using 12.5 mg/l of Magnifloc 572-C; raw water was 35 NTU

APPENDIX D

COMPARISONS OF THE BENCH, LABORATORY, AND FIELD SCALE PILOT PLANTS

In order to ascertain the use of bench scale and laboratory scale pilot plants to estimate coagulant dosages for the field scale pilot plant, five sets of tests were made. The tests were done in parallel using the same water, same filtration media, same coagulants, etc. Included were two sets of comparisons with Horsetooth Reservoir water, two sets with Cache La Poudre River water during spring runoff, and one set using low-turbidity water, i.e. 0.7 NTU water from the Cache La Poudre River.

The basis for the comparisons were effluent turbidity vs chemical dose curves generated by each of the three pilot plants, using the same water, same coagulants, and same filtration conditions. Figures D-1 to D-5 show the results of the five sets of tests comparing the three pilot plants.

Figures D-1 and D-2 show the results of the two comparisons made using Horsetooth Reservoir water. These two comparisons used Nalco 8102 polymer as the sole coagulant. Although the curves of Figures D-1 and D-2 do not lie directly on top of each other, all three systems do yield approximately the same range for the optimum dose of chemicals, and do seem to follow the same trends. At a "zero" coagulant dose, on Figure D-1, all three systems yield about the same value for effluent turbidity: 6.5 NTU for the bench scale, 6.0 NTU for the laboratory scale,

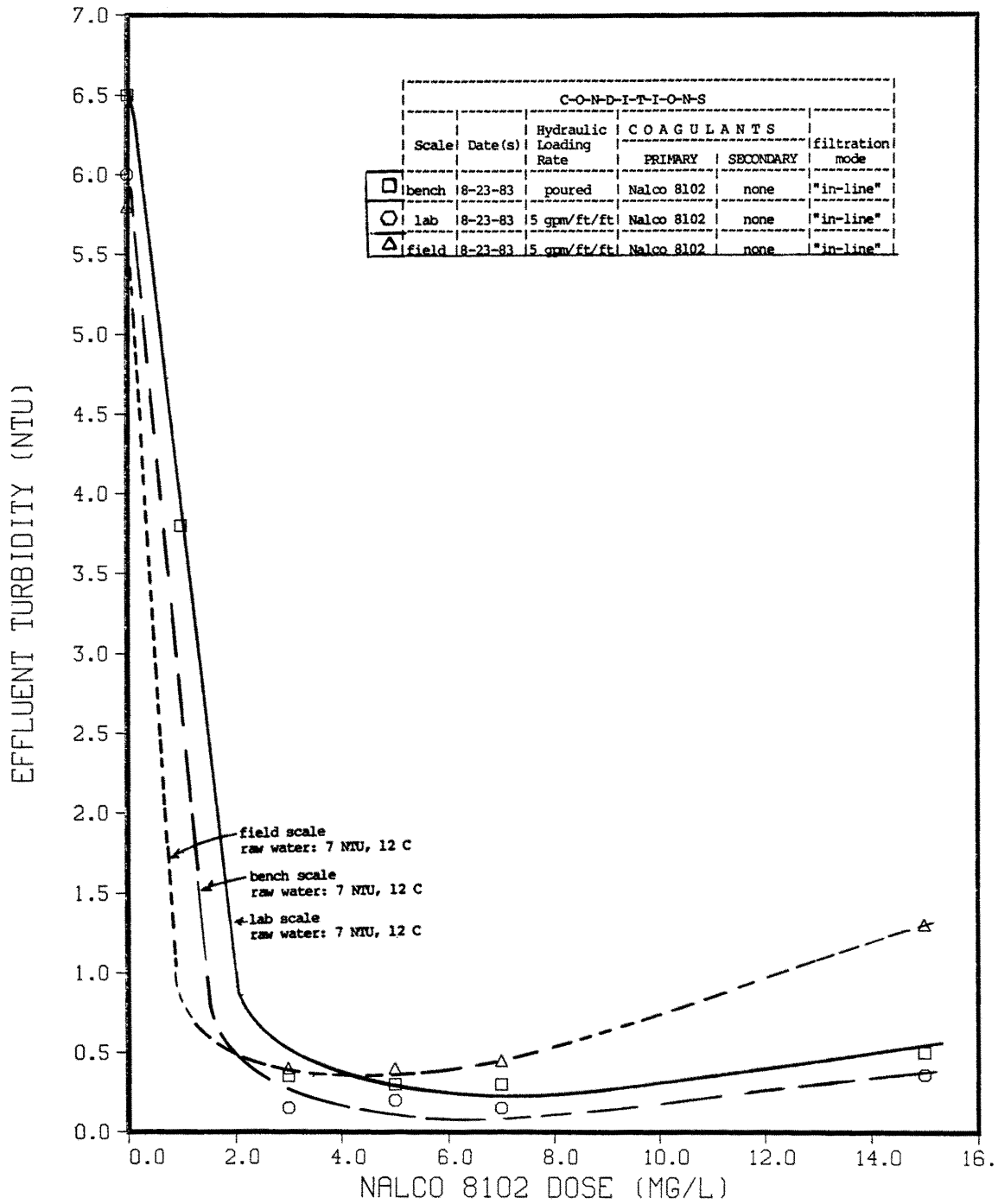

Figure D-1. Horsetooth comparison, conducted August 23, 1983

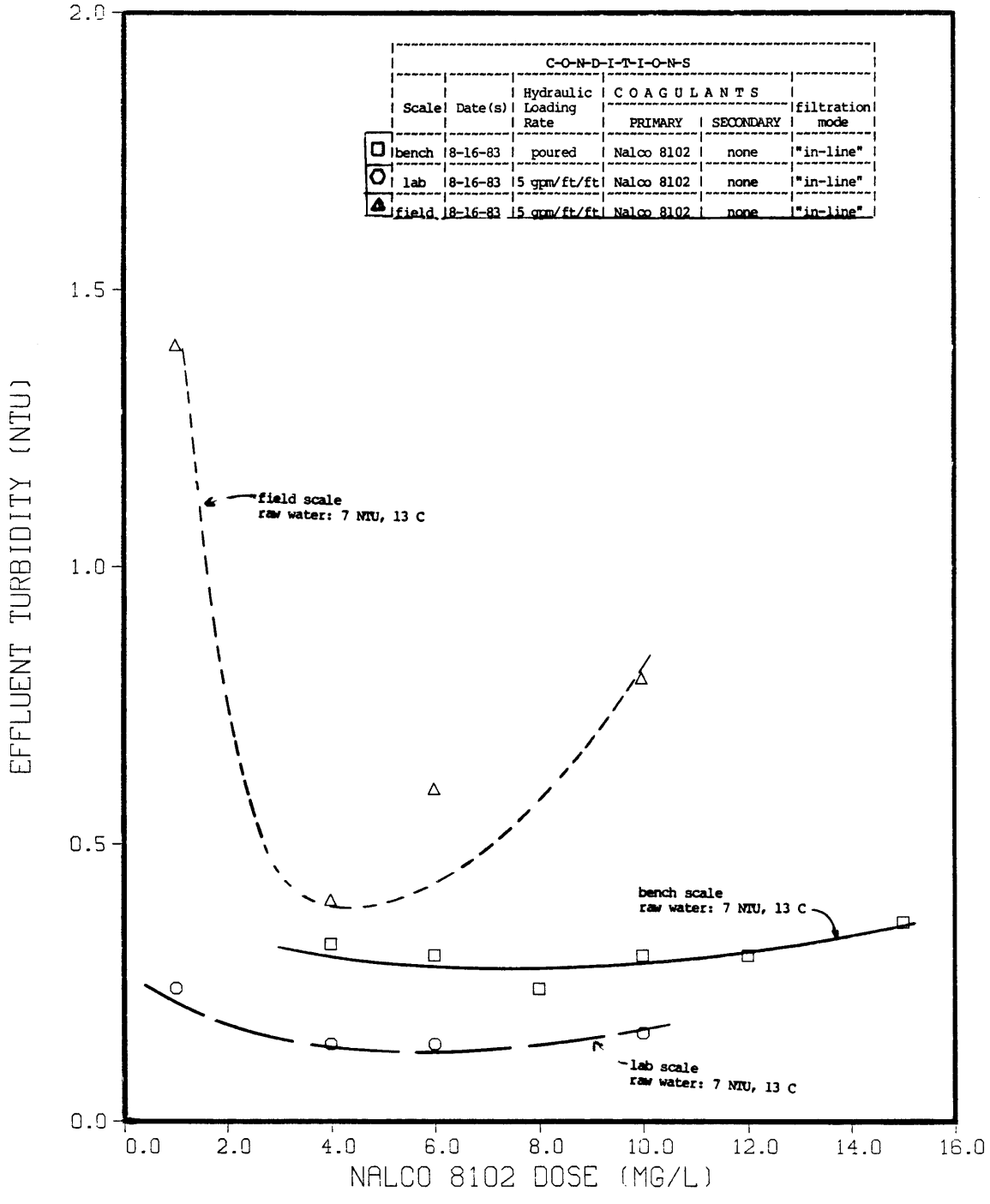

Figure D-2. Horsetooth comparison, conducted August 16, 1983

and 5.8 NTU for the field scale. The raw water turbidity was 7.0 NTU for all three of the pilot plants during the comparison shown in Figure D-1. Although the three curves in Figure D-2 show more space between them than those in Figure D-1, the ordinate scale is much larger. The difference in the optimum dose is only between 0.2 NTU and 0.4 NTU, about the same as shown in Figure D-1.

Figures D-3 and D-4 show the effluent turbidity vs coagulant dose curves developed for the three systems during spring runoff testing. During these comparisons, Magnifloc 572-C was used as the sole coagulant for each pilot plant. Turbidity levels at optimum dosages ranged between 0.5 NTU and 1.5 NTU in Figure D-3 and between 0.2 NTU and 1.8 NTU in Figure D-4. The water conditions were quite variable during spring runoff and changed substantially between the beginning and the end of the WATER BOY tests. The water for the bench scale and lab-scale pilot plants was pumped from the river to a tank trailer at times which differed from when the WATER BOY was in operation by about two-hours. The tank trailer was then hauled back to the Enginnering Research Center as a source of water for the bench scale and lab-scale pilot plants. The differences in raw water temperatures and turbidities for the three systems, shown in Figure D-3 and D-4, should be noted.

Figure D-5 shows the three effluent turbidity vs coagulant dose curves developed by the three systems using low-turbidity Cache La Poudre River water. During this comparison, each pilot plant used 2 mg/l of Magnifloc 572-C as the secondary coagulant. The primary coagulant was alum, and was varied for each point of the curve; as shown in Figure D-5. The raw water for each plant was 0.7 NTU. For these tests the raw water characteristics of the Cache La Poudre River were

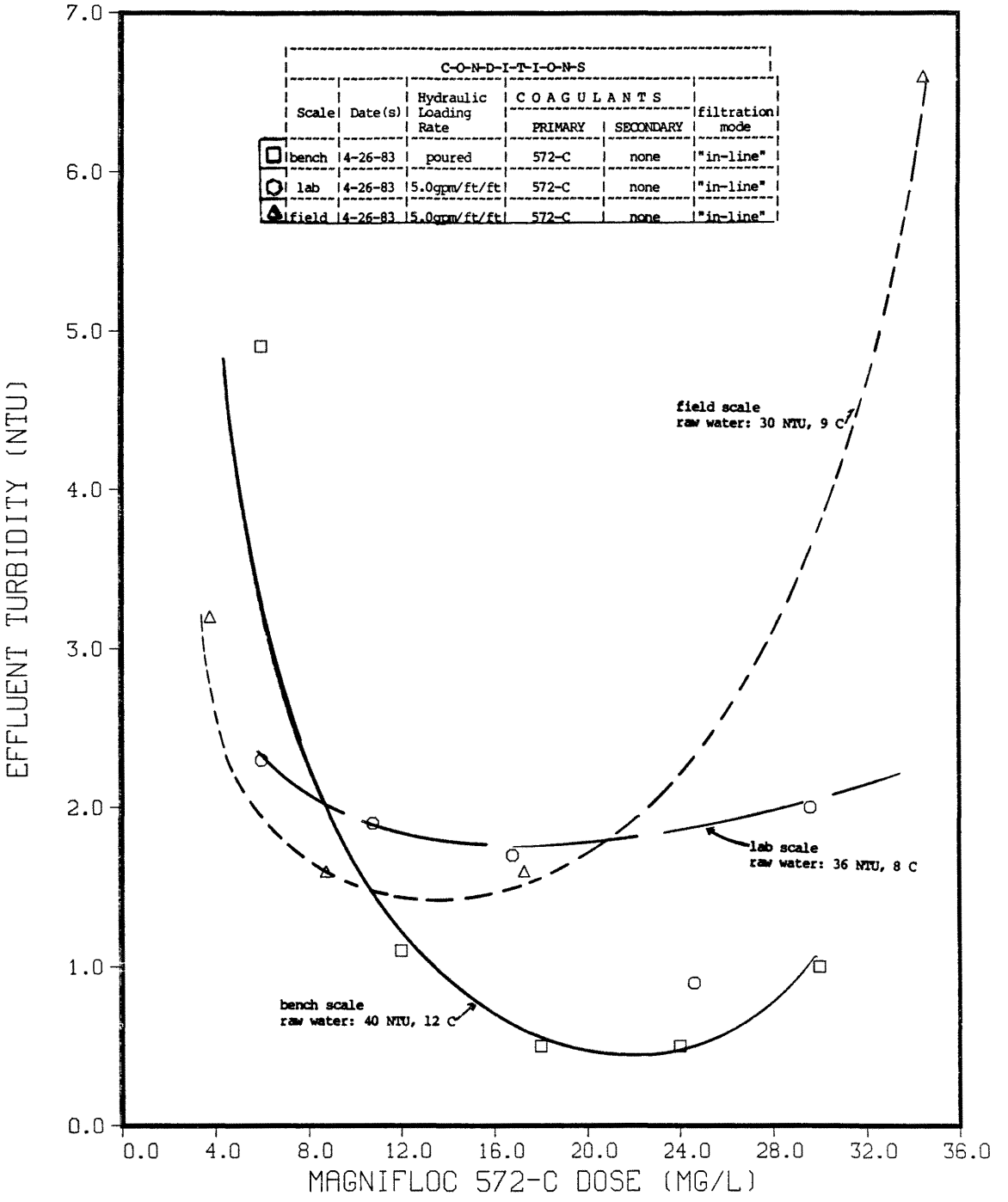

Figure D-3. Horsetooth comparison, conducted April 26, 1983

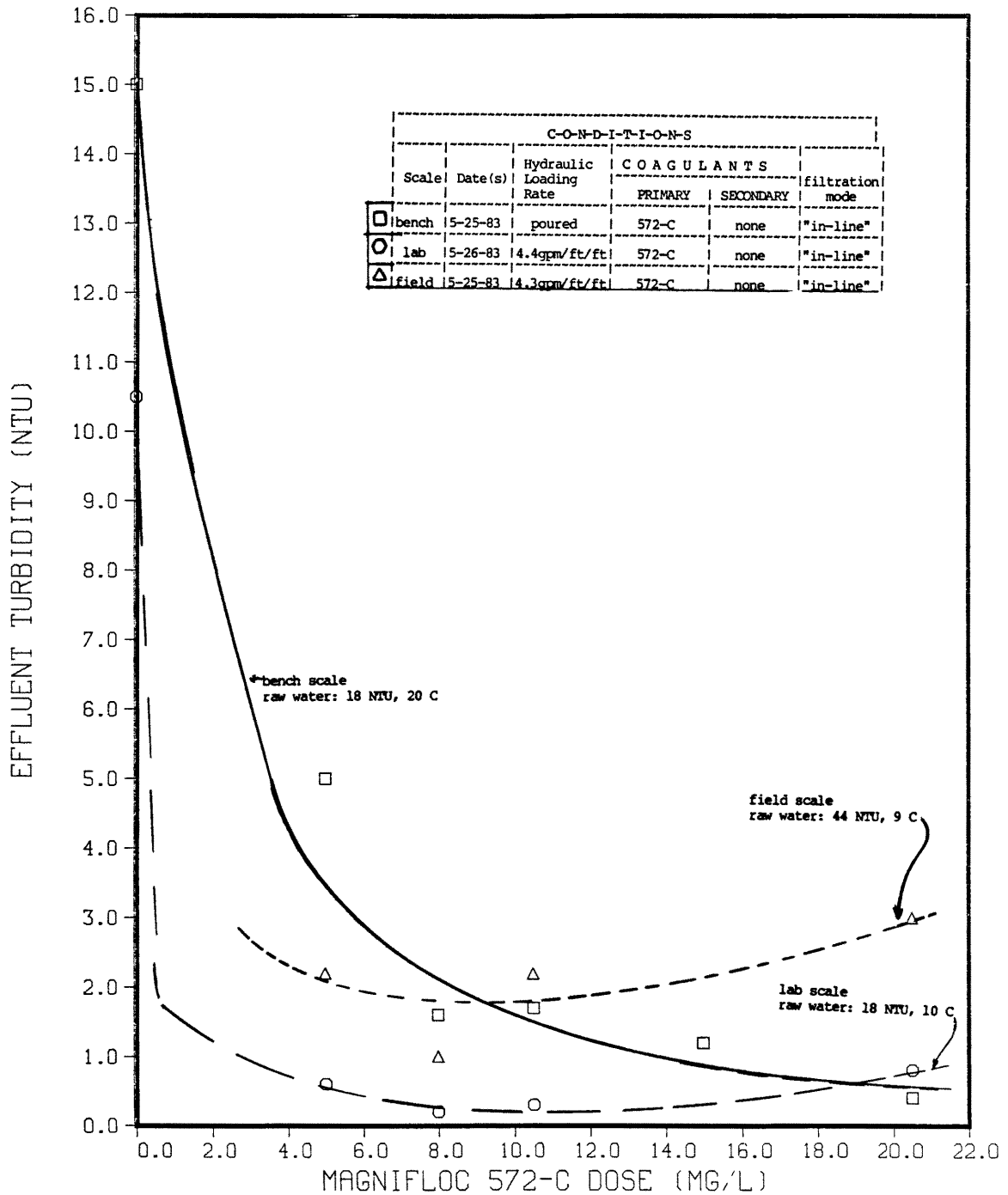

Figure D-4. Horsetooth comparison, conducted May 25, 1983

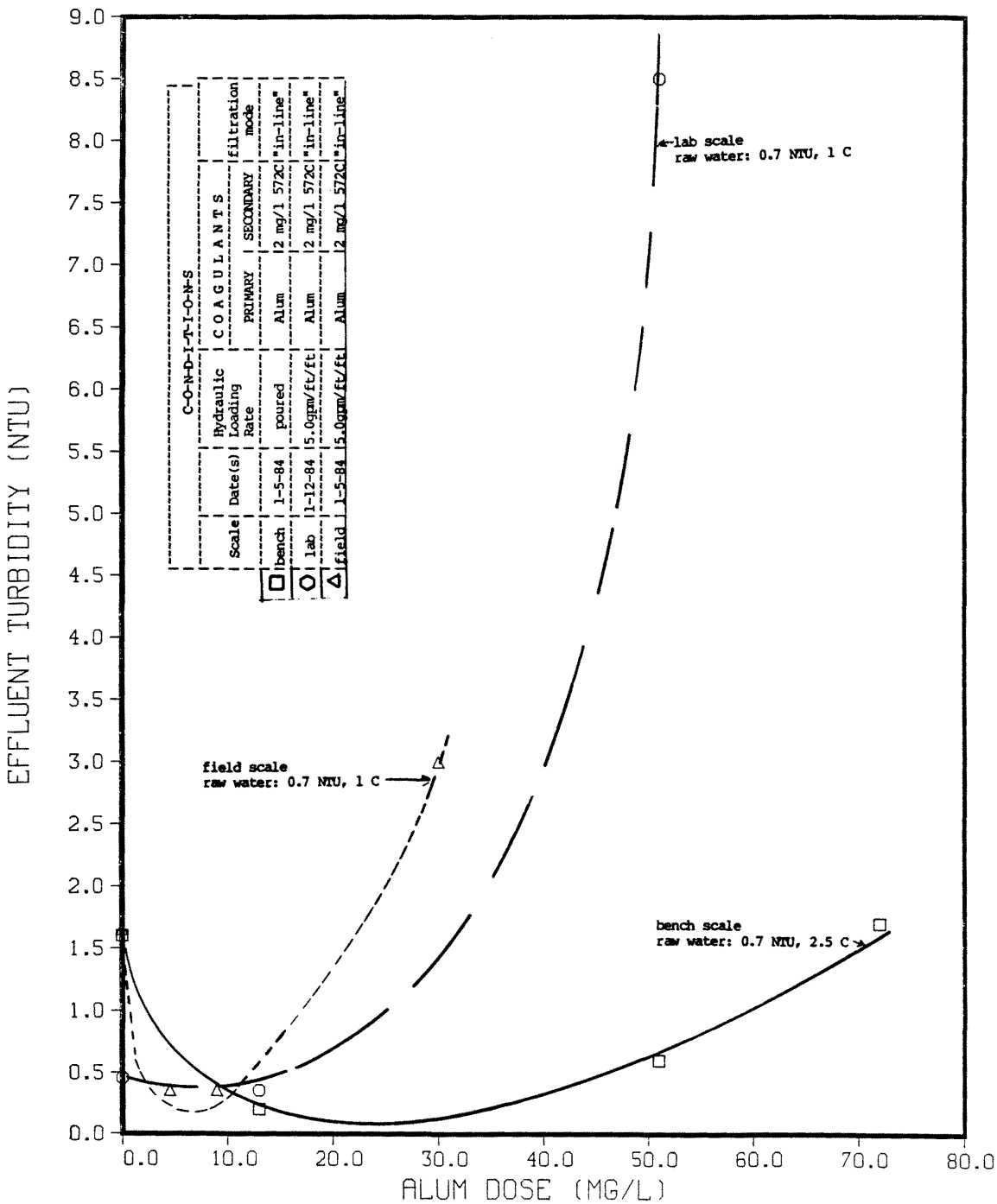

Figure D-5. Low-Turbidity comparison, conducted January 5, 1983

constant over a day period. The three curves show a convergence near the optimum alum dosage range, but show divergence at higher alum dosages. The temperature differences, it should be noted, could account for the divergences of the curves, as the bench scale tests were conducted at 2.5°C, the lab-scale tests at about 1°C, and the WATER BOY tests at <1°C (almost at 0°C). This almost freezing condition during operation of the WATER BOY was felt to have significant influence. Also, it should be noted, the WATER BOY treated the water immediately as it came from the river, but in operation of the lab-scale pilot plant the water was stored for about one week before use at the Engineering Research Center. During this time the water warmed to room temperature, but was cooled to 1°C before testing.

APPENDIX E

RESULTS FROM FAMILIARIZATION TESTING

The following twelve figures, Figures E-1 to E-12, show turbidity vs time relationships developed during the familiarization testing period in which Horsetooth water was used. From these curves, the "stabilized" turbidity was defined as the effluent turbidity at one-hour. The purposes of the familiarization phase were to become familar with the pilot plant, and to size and calibrate chemical feed tanks, pumps, etc.

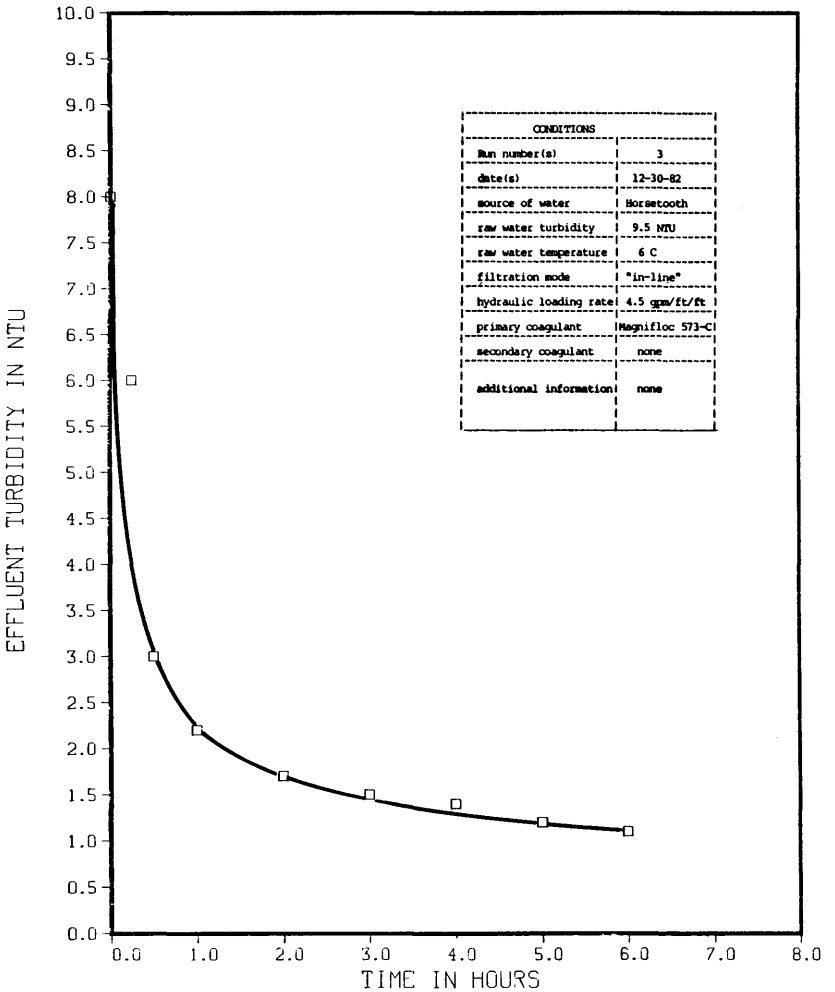

Figure E-1. Effluent-turbidity vs time using 0.5 mg/l of Magnifloc 573-C. Familiarization testing

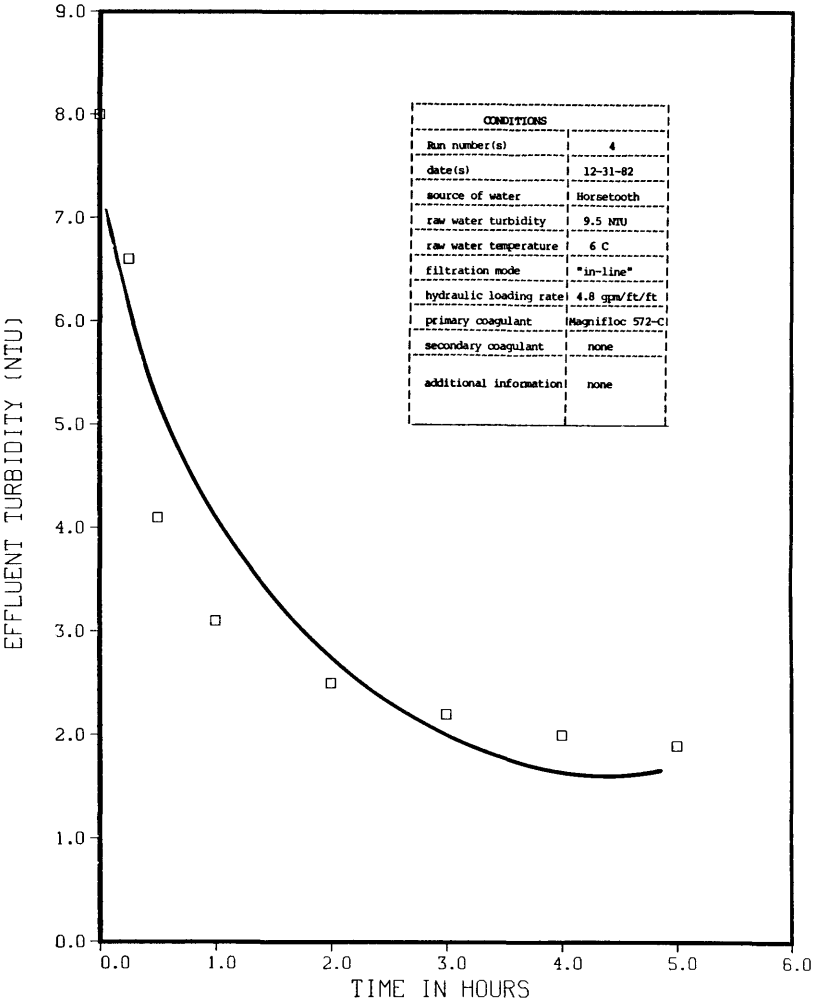

Figure E-2. Effluent-turbidity vs time using 0.5 mg/l of Magnifloc 572-C. Familiarization testing

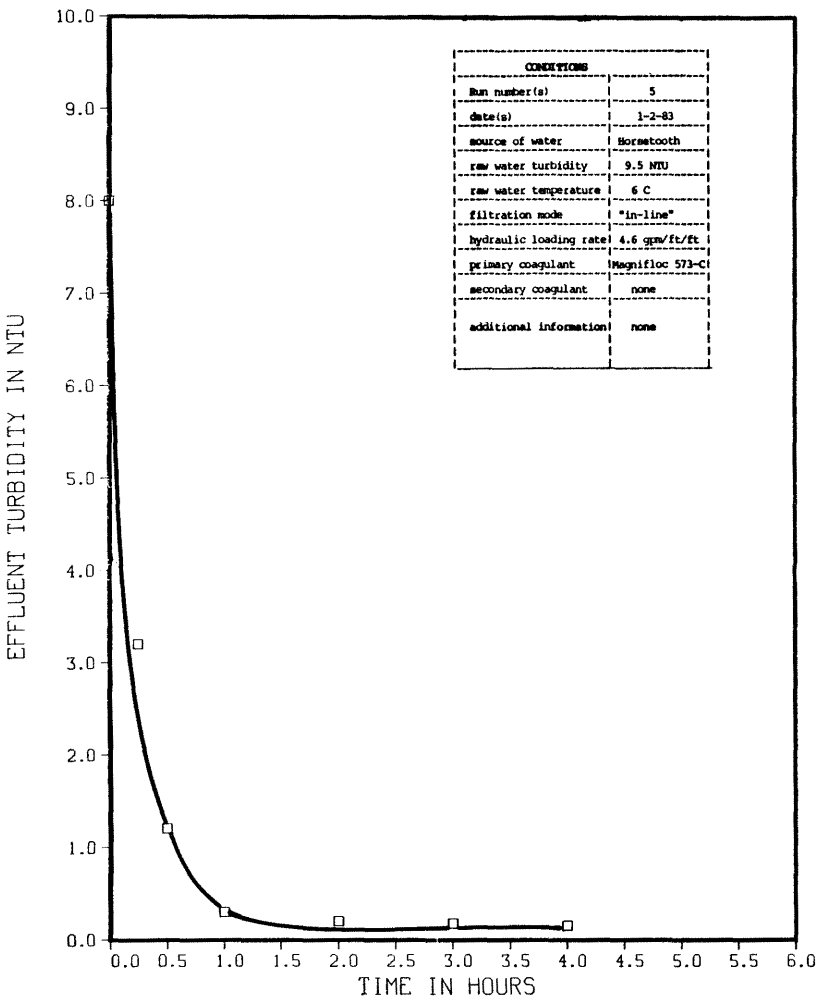

Figure E-3. Effluent-turbidity vs time using 1.5 mg/l of Magnifloc 573-C. Familiarization testing

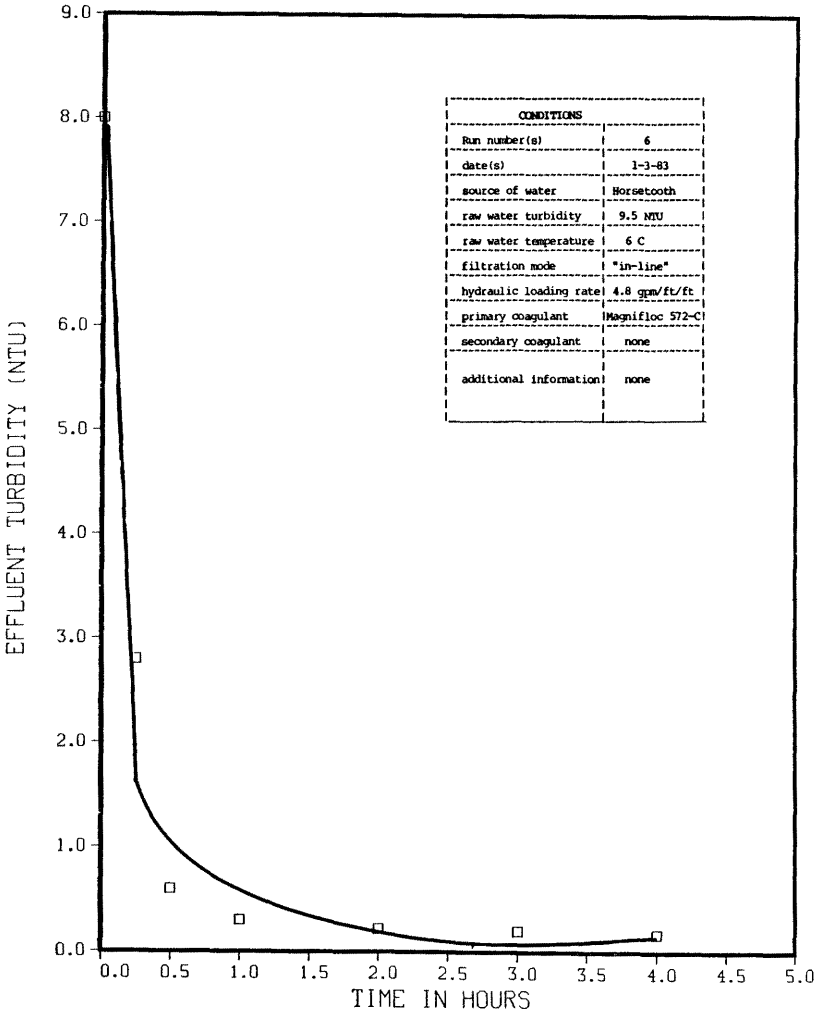

Figure E-4. Effluent-turbidity vs time using 1.5 mg/l of Magnifloc 572-C. Familiarization testing

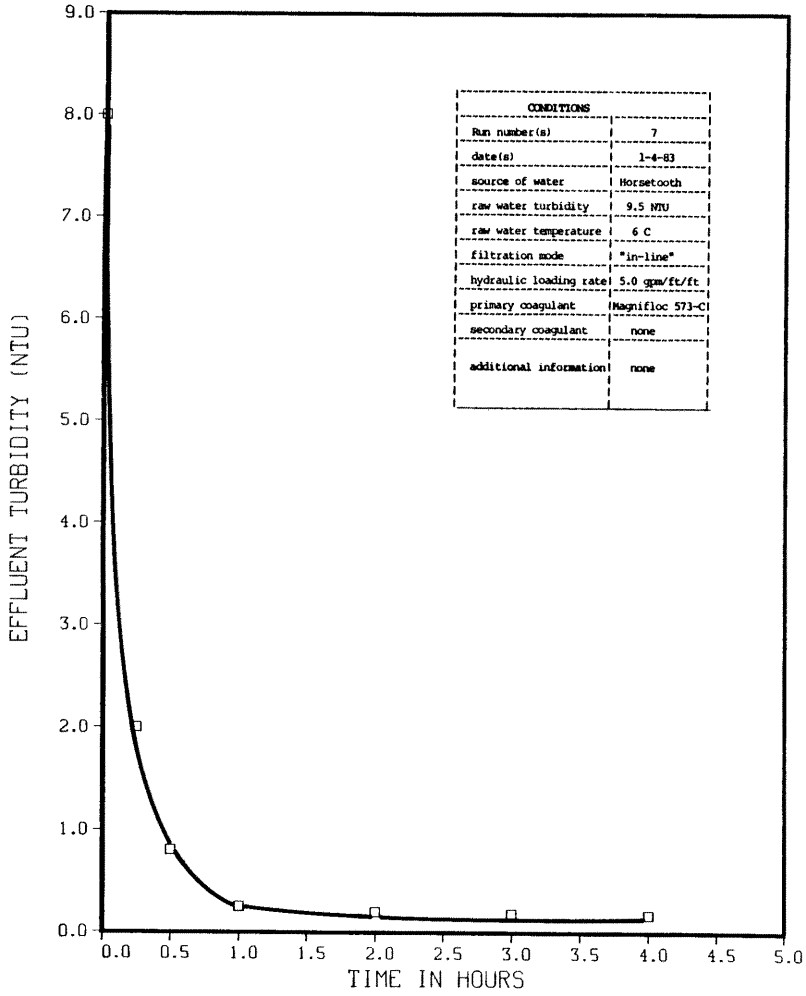

Figure E-5. Effluent-turbidity vs time using 3.8 mg/l of Magnifloc 573-C. Familiarization testing

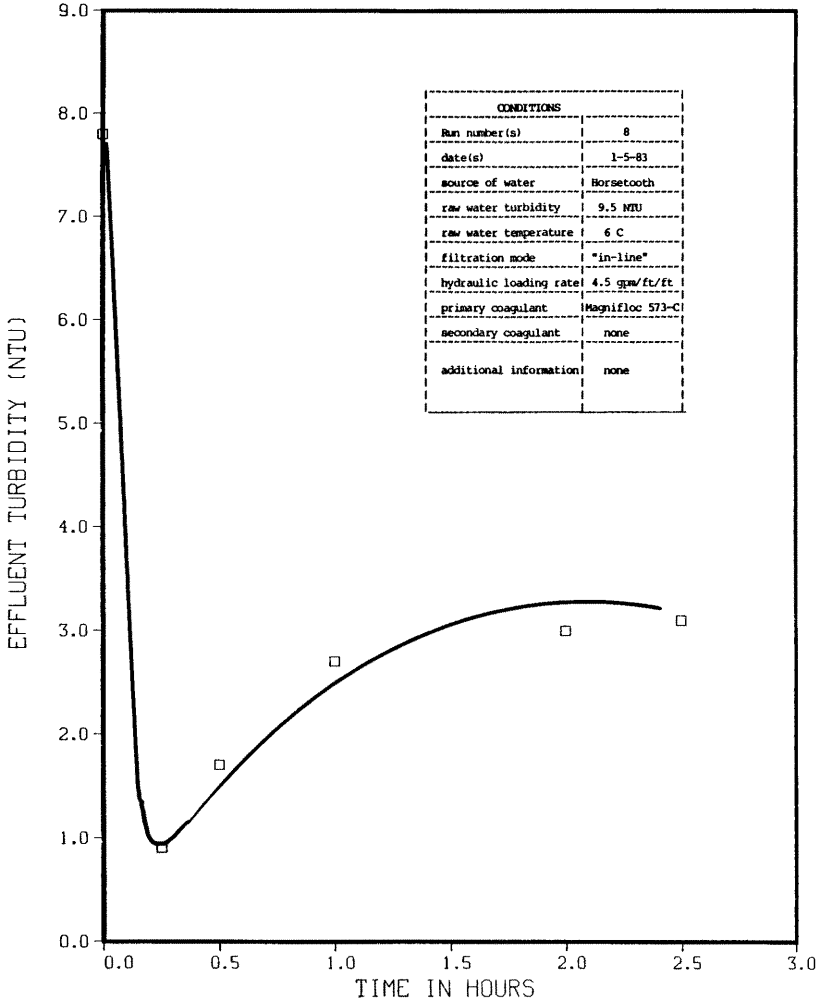

Figure E-6. Effluent-turbidity vs time using 8.8 mg/l of Magnifloc 573-C. Familiarization testing

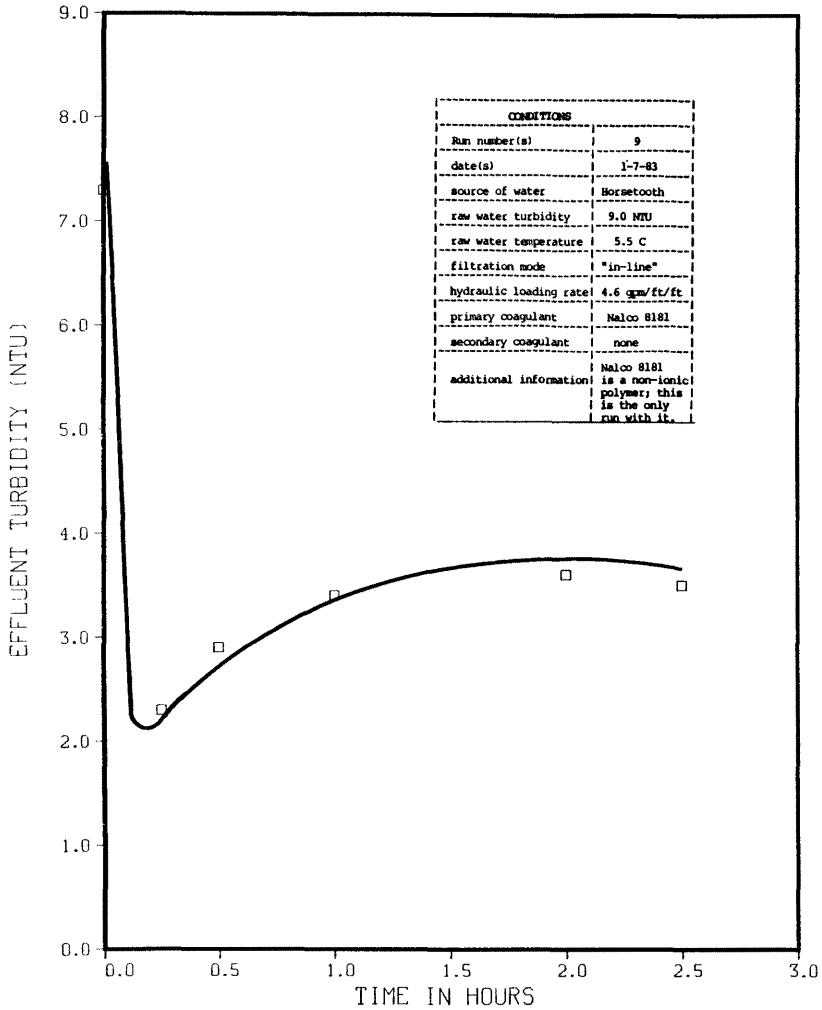

Figure E-7. Effluent-turbidity vs time using 6.7 mg/l of Nalco 8181 (non-ionic polymer). Familiarization testing

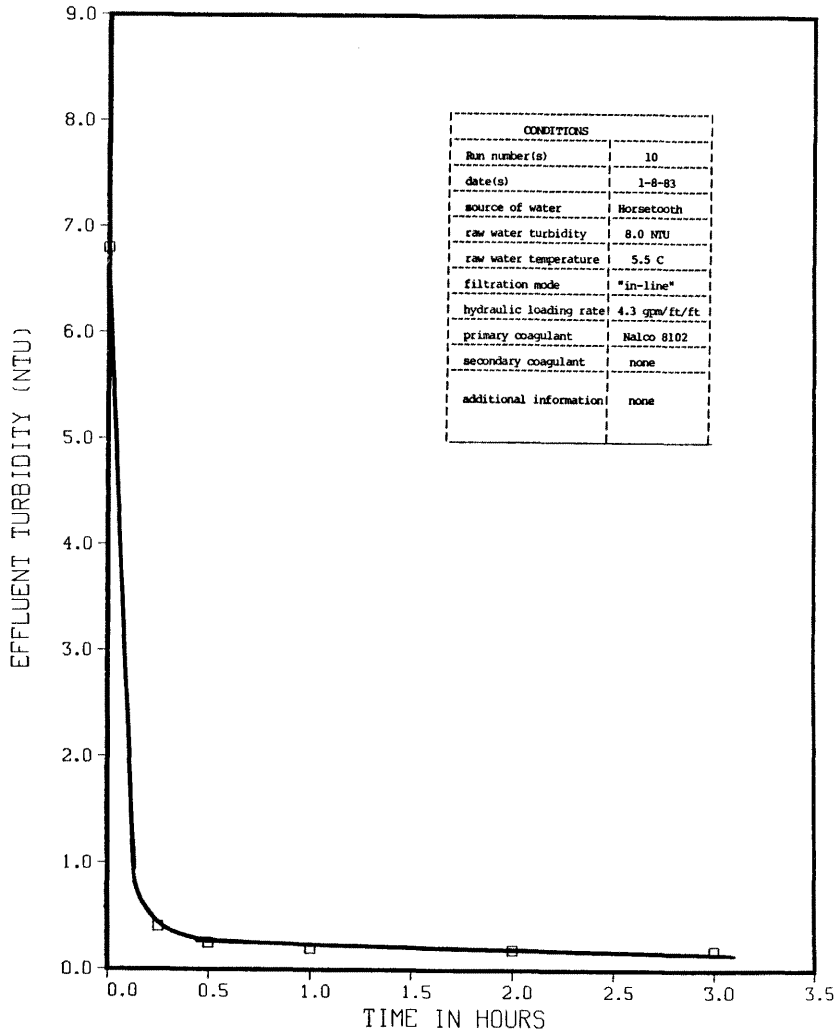

Figure E-8. Effluent-turbidity vs time using 4.3 mg/l of Nalco 8102. Familiarization testing

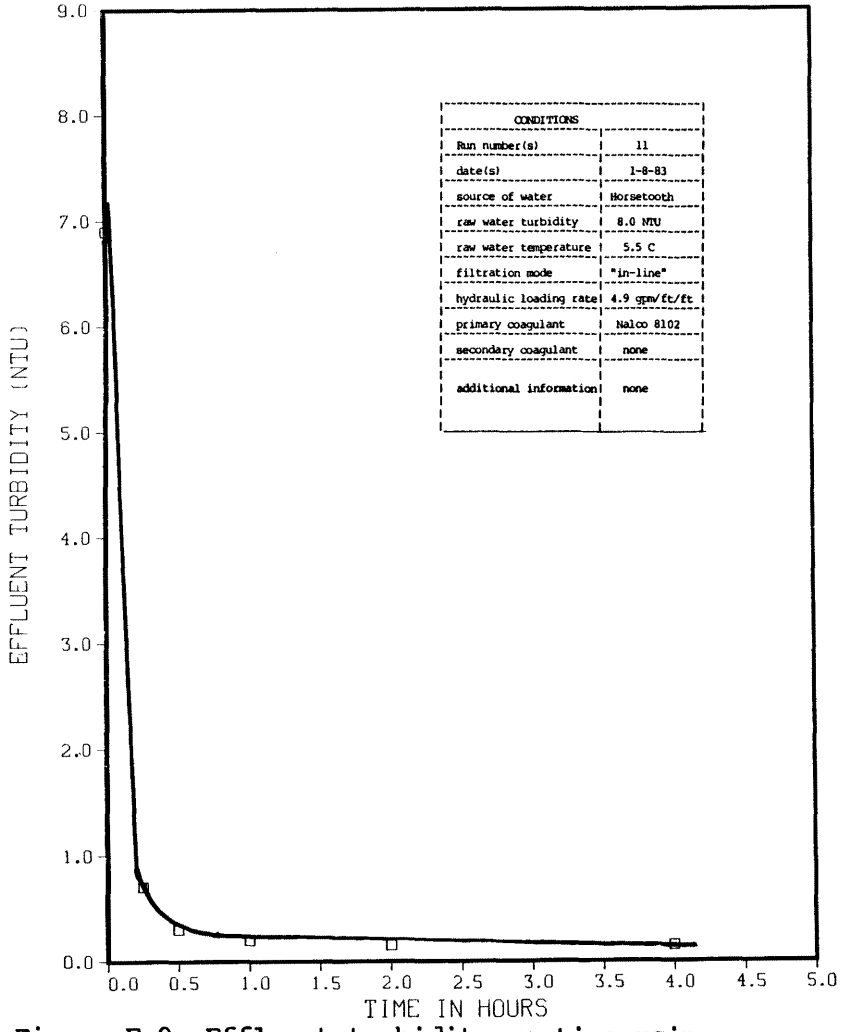

Figure E-9. Effluent-turbidity vs time using 8.0 mg/l of Nalco 8102. Familiarization testing

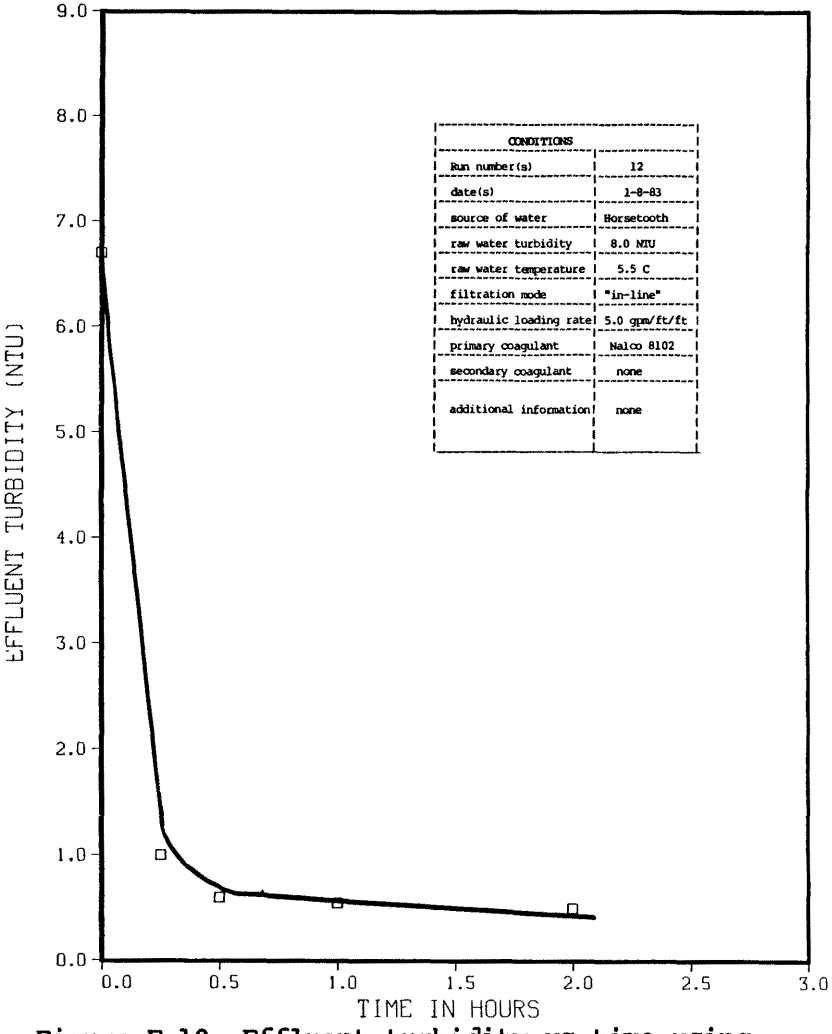

Figure E-10. Effluent-turbidity vs time using 10.5 mg/l of Nalco 8102. Familiarization testing

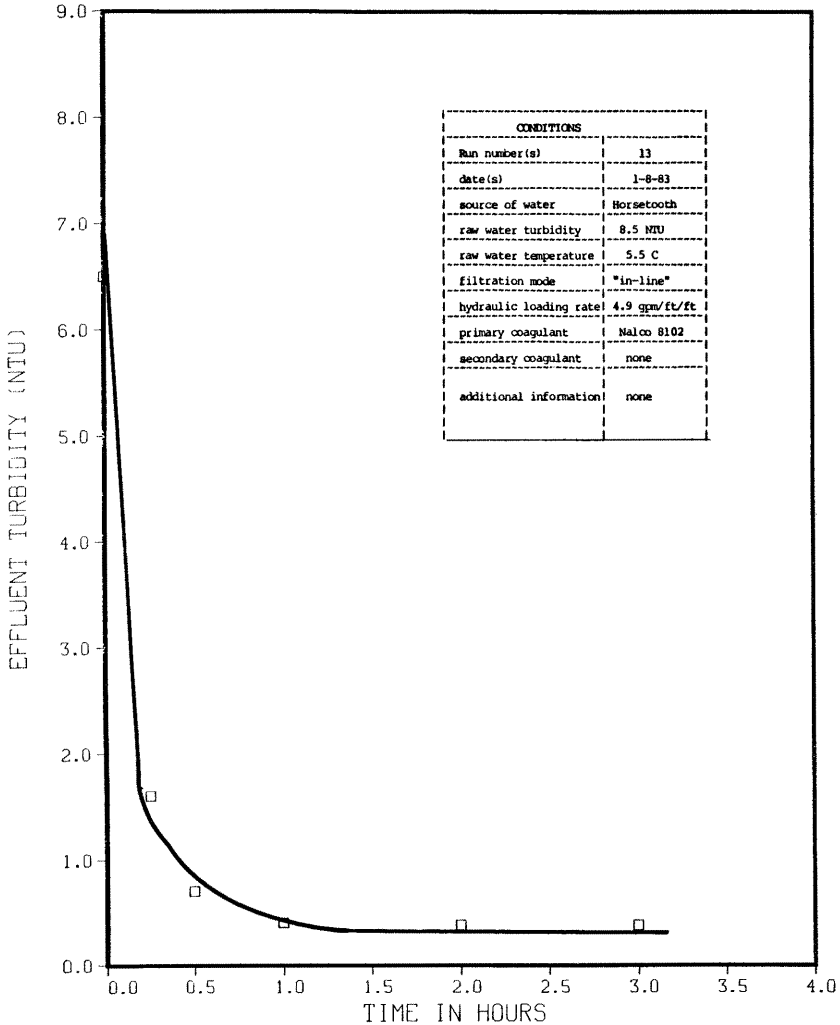

Figure E-11. Effluent-turbidity vs time using 0.9 mg/l of Nalco 8101. Familiarization testing

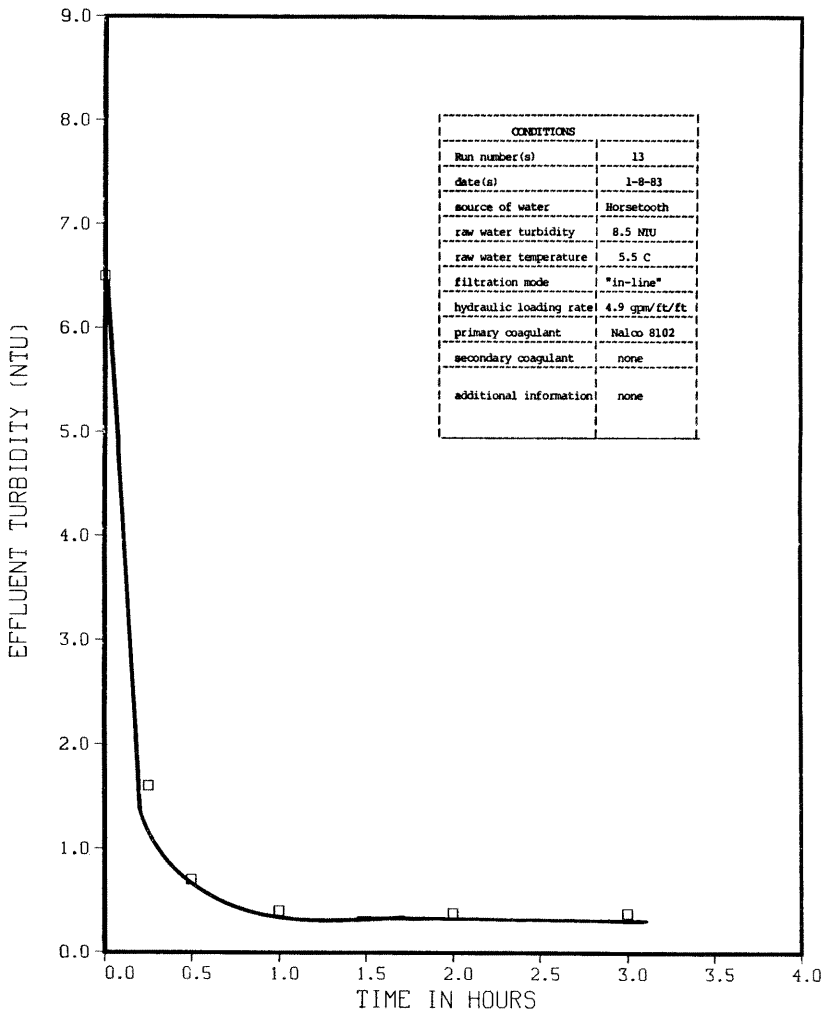

Figure E-12. Effluent-turbidity vs time using 6.7 mg/l of Magnifloc 572-C. Familiarization testing

APPENDIX F

DESCRIPTION OF THE BENCH AND LABORATORY RAPID RATE FILTRATION PILOT PLANTS

BENCH SCALE PILOT PLANT

The bench scale rapid rate filtration "pilot plant" was comprised of the conventional jar test equipment augmented by six, two-inch diameter tubes, filled with 20 inches of "dual" filtration media. This is the same filtration media that is in the WATER BOY, and shown in Figure A-5. The test proceedure developed for the use of the equipment, as a means to estimate coagulat dosages, is termed the "jar filtration test". The purpose of the "jar filtration test" ,as used in this research, was to estimate chemical dosages for the operation of the lab-scale and field scale pilot plants.

The protocol for the "jar filtration test" consists of pouring the supernatant from the conventional jar test through the tubes filled with filtration media. The turbidity of the effluent water is measured after percolating through the media. This turbidity is then plotted against coagulant dose to define an optimum dose range.

LABORATORY SCALE PILOT PLANT

The laboratory scale rapid rate filtration pilot plant has all unit processes as used in a complete water treatment plant. Its flow capacity is 0.6 l/min. It is comprised of: three rapid mix basins in series, two 5-stage flocculation basins in parallel, two variable detention time sedimentation basins in parallel, and four filters in parallel (two 2-inch diameter and two 4-inch diameter). This laboratory plant has the capacity to be operated in any of the three modes of filtration: conventional, direct, or "in-line". Provisions were made in operation to permit control of the water temperature, and to inject and sample for Giardia cysts and coliform bacteria.

APPENDIX G

MANUFACTURER'S DATA ON THE THREE POLYMERS USED: MAGNIFLOC 572-C, MAGNIFLOC 573-C, and NALCO 8102

Magnifloc 572-C (sheet 1 of 2)

CYANAMID

MSDS NO. 1869-01
CAS NO.
DATE: 08/03/82

MATERIAL SAFETY DATA

PRODUCT IDENTIFICATION

TRADEMARK:	**MAGNIFLOC® 572C Flocculant**
SYNONYMS:	Polyquaternary amine
CHEMICAL FAMILY:	Cationic polyamine
MOLECULAR FORMULA:	Mixture
MOLECULAR WGT.:	Mixture

WARNING

SPILLS OF THIS PRODUCT ARE VERY SLIPPERY

HAZARDOUS INGREDIENTS

COMPONENT	CAS. NO.	%	TWA/CEILING	REFERENCE
No Permissible Exposure Limits (PEL), have been established by OSHA				

NFPA HAZARD RATING

Not Established

HEALTH HAZARD INFORMATION

EFFECTS OF OVEREXPOSURE:	Acute oral (rat) and acute dermal (rabbit) LD50 values are 5.36 ml/kg and > 16.0 ml/kg, respectively. No eye irritation and no significant skin irritation were produced during primary irritation studies with rabbits.
FIRST AID:	No specific first aid procedures are necessary for accidental exposure to this product.

EMERGENCY PHONE: 201/835-3100

AMERICAN CYANAMID COMPANY, WAYNE, NEW JERSEY 07470

Magnifloc 572-C (sheet 2 of 2)

MSDS NO. 1869-01
MAGNIFLOC® 572C Flocculant

FIRE AND EXPLOSION HAZARD INFORMATION	FLASH POINT: METHOD:	> 200 F (> 93.3 C) Closed Cup
	FLAMMABLE LIMITS (% BY VOL):	Not Available
	AUTOIGNITION TEMP:	Not Available
	DECOMPOSITION TEMP:	Not Available
	FIRE FIGHTING:	Use water, carbon dioxide or dry chemical to extinguish fires. Wear self-contained, positive pressure breathing apparatus and full firefighting protective clothing.
REACTIVITY DATA	STABILITY: CONDITIONS TO AVOID:	Stable None known
	POLYMERIZATION: CONDITIONS TO AVOID:	Will Not Occur None known
	INCOMPATIBLE MATERIALS:	Strong oxidizing agents. This material reacts slowly with iron, copper and aluminum, resulting in corrosion and product degradation.
	HAZARDOUS DECOMPOSITION PRODUCTS:	Thermal decomposition or combustion may produce carbon monoxide, carbon dioxide, ammonia, oxides of nitrogen and/or hydrogen chloride gas.
PHYSICAL PROPERTIES	APPEARANCE AND ODOR:	Straw colored liquid; slight amine odor
	BOILING POINT:	Not Available
	MELTING POINT:	0 F (−18 C)
	VAPOR PRESSURE:	Not Available
	SPECIFIC GRAVITY:	1.14-1.18
	VAPOR DENSITY:	Not Available
	% VOLATILE (BY VOL):	≈50%
	OCTANOL/H_2O PARTITION COEF.:	Not Available
	pH:	5-7 as is
	SATURATION IN AIR (BY VOL):	Not Available
	EVAPORATION RATE:	Not Available
	SOLUBILITY IN WATER:	Complete
SPILL OR LEAK PROCEDURES	STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED:	Spills of this material are very slippery. Cover spills with some inert absorbent material and scoop into a container. Wash area thoroughly with water. Repeat if slipperiness remains.
WASTE DISPOSAL	Disposal must be made in accordance with applicable governmental regulations.	
SPECIAL PRECAUTIONS	HANDLING AND STORAGE/OTHER:	None

Marvin A. Friedman, Ph.D., Director of Toxicology and Product Safety

This information is given without any warranty or representation. We do not assume any legal responsibility for same, nor do we give permission, inducement, or recommendation to practice any patented invention without a license. It is offered solely for your consideration, investigation and verification. Before using any product read its label.

Magnifloc 573-C (sheet 1 of 2)

CYANAMID

MATERIAL SAFETY DATA

MSDS NO. 1868-01
CAS NO. ----------
DATE: 10/13/82

PRODUCT IDENTIFICATION

TRADEMARK:	**MAGNIFLOC® 573C Flocculant**
SYNONYMS:	Polyquaternary amine
CHEMICAL FAMILY:	Cationic polyamine
MOLECULAR FORMULA:	Mixture
MOLECULAR WGT.:	Mixture

WARNING

SPILLS OF THIS PRODUCT ARE VERY SLIPPERY

HAZARDOUS INGREDIENTS

COMPONENT	CAS. NO.	%	TWA/CEILING	REFERENCE
No Permissible Exposure Limits (PEL), have been established by OSHA				

NFPA HAZARD RATING

Not Established

HEALTH HAZARD INFORMATION

EFFECTS OF OVEREXPOSURE:	Acute oral (rat) LD50 value is 4.67 ml/kg. Acute dermal (rabbit) LD50 value for a similar product is > 10.0 ml/kg. No signs of irritation of sensitization were produced by MAGNIFLOC 573C treated paper during a repeat insult patch test in humans. No eye irritation was produced during primary irritation studies with rabbits.
FIRST AID:	No specific first aid procedures are necessary for accidental exposure to this product.

EMERGENCY PHONE: 201/835-3100

AMERICAN CYANAMID COMPANY, WAYNE, NEW JERSEY 07470

Magnifloc 573-C (sheet 2 of 2)

MSDS NO. 1868-01
MAGNIFLOC® 573C Flocculant

FIRE AND EXPLOSION HAZARD INFORMATION	FLASH POINT: METHOD:	> 200 F > 93.3 C Closed Cup
	FLAMMABLE LIMITS (% BY VOL):	Not Available
	AUTOIGNITION TEMP:	Not Available
	DECOMPOSITION TEMP:	Not Available
	FIRE FIGHTING:	Use carbon dioxide, dry chemical, or water spray to extinguish fires. Wear self-contained, positive pressure breathing apparatus and full firefighting protective clothing.
REACTIVITY DATA	STABILITY: CONDITIONS TO AVOID:	Stable None known
	POLYMERIZATION: CONDITIONS TO AVOID:	Will Not Occur None known
	INCOMPATIBLE MATERIALS:	Strong oxidizing agents. This material reacts slowly with iron, cooper and aluminum, resulting in corrosion and product degradation.
	HAZARDOUS DECOMPOSITION PRODUCTS:	Thermal decomposition or combustion may produce carbon monoxide, carbon dioxide, ammonia, oxides of nitrogen and/or hydrogen chlorde gas.
PHYSICAL PROPERTIES	APPEARANCE AND ODOR:	Amber liquid; slight amine odor
	BOILING POINT:	Similar to water
	MELTING POINT:	0 F (−18 C)
	VAPOR PRESSURE:	Similar to water
	SPECIFIC GRAVITY:	1.08-1.18
	VAPOR DENSITY:	Similar to water
	% VOLATILE (BY VOL):	≈50%
	OCTANOL/H_2O PARTITION COEF.:	Not Available
	pH:	5 - 7
	SATURATION IN AIR (BY VOL):	Not Available
	EVAPORATION RATE:	Similar to water
	SOLUBILITY IN WATER:	Complete
SPILL OR LEAK PROCEDURES	STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED:	Wear impervious boots. Spills of this material are very slippery. Spilled material should be absorbed onto an inert material and scooped up. The area should be thoroughly flushed with water and scrubbed to remove residue.
WASTE DISPOSAL	Disposal must be made in accordance with applicable governmental regulations.	
SPECIAL PRECAUTIONS	HANDLING AND STORAGE/OTHER:	None

Marvin A. Friedman — Marvin A. Friedman, Ph.D., Director of Toxicology and Product Safety

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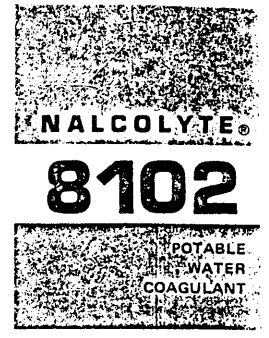
Nalco 8102 (sheet 1 of 2)

NALCOLYTE 8102 is a moderate molecular weight, cationic polyelectrolyte developed for both potable water clarification and waste treatment systems.

NALCOLYTE 8102 aids in:

- *Improving effluent quality*
- *Reducing or eliminating the need for metal salts*
- *Producing a dense, rapid-forming, easily settled floc*
- *Forming a compact, easily dewatered sludge*
- *Producing quality water in prechlorinated systems*
- *Reducing or eliminating the need for pH adjustment*



PRINCIPAL USES

NALCOLYTE 8102 is a moderate molecular weight, polycationic polymer recommended for use as a primary coagulant in raw water clarification and lime softening. NALCOLYTE 8102 is approved by the USEPA for treatment of potable water at an application rate up to 50 ppm.

Application Programs	Use
• Conventional Clarification or Lime Softening	Primary coagulant to partially or completely replace inorganic salts
• Direct Filtration	Primary coagulant for low turbidity and colored water
• Filter Aid	Secondary coagulant to improve filter effluent quality
• Clay/Polymer	Primary coagulant in a total alum or iron replacement

Your local Nalco representative can help determine the best clarification program for your needs.

GENERAL DESCRIPTION

Form	Liquid
Charge in Solution	Cationic
Density (Typical)	9.09 lb/gal
Color	Pale amber
Appearance	Slight haze
Odor	Slight
pH Neat (Typical)	4.5
Viscosity	See Figure 1
Freeze Point (Neat)	14°F
Freeze-Thaw Recovery	Complete

DOSAGE

The specific dosage of NALCOLYTE 8102 will depend on raw water characteristics, the type of application, equipment operation, and the results required. Your Nalco representative will recommend the dosage ranges expected for your system.

FEEDING

Conventional Clarification, Clay/Polymer, Direct Filtration

NALCOLYTE 8102 can be fed neat or as a diluted stock solution. See Figure 2. Use a positive displacement pump, BIF 1711 Series or equivalent, to meter the product or solution into a water line where it can be continuously diluted to 0.5% or less before application. NALCOLYTE 8102 should be applied prior to the rapid mix zone to ensure efficient distribution into the water.

When preparing a stock solution in cold water (less than 60°F) additional mixing may be required. NALCOLYTE 8102 solutions greater than 10% concentrations are stable for one week.

Filter Aid Application

NALCOLYTE 8102 should be fed as a 10–30% solution to the distribution header prior to the filters. In some cases, better performance can be obtained by feeding each filter individually at the inlet flume. The feed point should be selected to ensure distribution of the polymer within the water prior to filter contact.

Nalco 8102 (sheet 2 of 2)

MATERIALS OF CONSTRUCTION

PVC feed lines should be used when handling concentrated NALCOLYTE 8102. Stainless steel pump heads can be used. Store NALCOLYTE 8102 in fiberglass (DK-411 or equivalent), polyethylene, or rubber-lined tanks. If existing mild steel tanks are used, line with Plasite 4005 or equivalent. Consult your local representative for recommended tank designs.

SHIPPING AND STORAGE

NALCOLYTE 8102 is available in bulk or 55-gallon, non-returnable lined drums. Drums can be stored for one year in unopened containers. Although freezing is harmless, it should be avoided, since lower temperatures increase product viscosity.

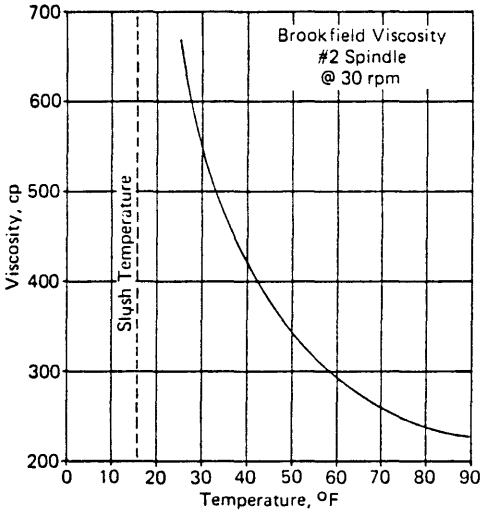


FIGURE 1 — *Typical viscosity as function of temperature NALCOLYTE 8102*

HANDLING

NALCOLYTE 8102 should be handled as a mildly acidic product. Avoid contact with skin, eyes, and clothing. Use in a well ventilated area. Avoid prolonged or repeated breathing of vapors and do not take internally. In case of contact with skin, wash with water. For eyes, wash with water for 15 minutes and call a physician.

NOTE: This bulletin shall not be construed as recommending the infringement of any patent, or extending any license, expressed or implied or assuming any liability under any issued or pending patent.

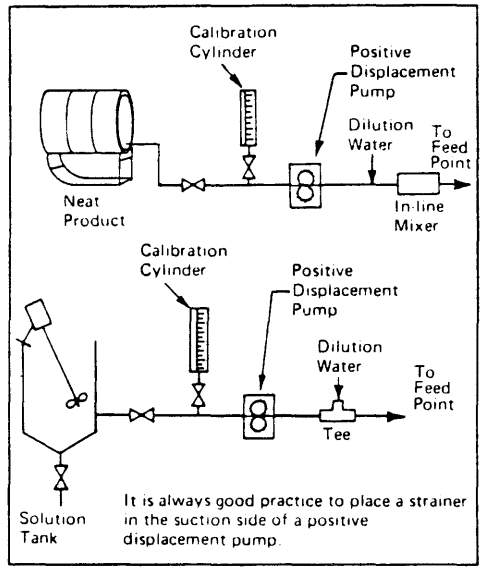


FIGURE 2 — *Recommended coagulant feed systems*

APPENDIX H

CHEMICAL PRETREATMENT SURVEY

The results of a survey of the chemical pretreatment practices of Rocky Mountain Water Treatment Plants are presented as Tables H-1 and H-2. The survey, conducted during January 1983, by visiting 14 Rocky Mountain Water Treatment Plants was done for two reasons: i) to ascertain coagulation pretreatment practices in the Rocky Mountains, and ii) as a means to search for coagulants which could be effective in filtration of cold, low-turbidity waters. Table H-1 summarizes the chemical pretreatment practices for the spring, summer, and early fall seasons. Table H-2 is for the late fall and winter season.

TABLE H-1. Results of Survey of Chemical Pretreatment Practices of Rocky Mountain Water Treatment Plants

Summary of Spring, Summer and Early Fall Seasons

Name of Plant	Avg. Inf. Temp.	Avg. Turb. Inf/Eff	Avg. Flow (mgd)	Source of Water	Primary Coag. Name	Primary Coag. Dose (mg/l)	Coag. Aid Name	Coag. Aid Dose (mg/l)	Filter Aid Name	Filter Aid Dose (mg/l)	Rapid Mix	Floccu-lation	Sedimen-tation	Filtra-tion
Greeley-Bellvue	12°C	3.0/0.6	12.0	Poudre River	Alum	0-40	None	0	Cat Floc T	0.4-0.5	Yes	Yes	Yes	Yes
Fort Collins #1	12°C	2.0/0.2	10.0	Poudre River	Alum	20-30	1986 N	0.1-0.5	8181	0.02-0.06	Yes	Yes	Yes	Yes
Fort Collins #2	8°C	5.0/0.2	1/	Horsetooth	Alum	8-30	None	-	8181	0.02-0.06	Yes	Yes	Yes	Yes
Golden	1/	1/	1/	Clear Creek	1/	1/	1/	1/	1/	1/	Yes	Yes	Yes	Yes
Soldier Canyon	8°C	6.0/0.3	8.0	Horsetooth	8102	0.8-1.2	None	0	None	0	Yes	No	No	Yes
Vail District	10°C	2.0/0.50	1.5	Booth & Gore Creeks	1/	1/	1/	1/	1/	1/	1/	1/	1/	1/
Avon Metro	10°C	2.0/0.30	0.40	Buck Creek	Alum	8-15.0	8102	0.2-0.4	None	0	Yes	No	No	Yes
Gore Valley/ Big Horn	10°C	2.5/0.75	0.60	Blackgore Stream	Alum	10-20	8102	0.8-2.0	None	0	Yes	Yes	Yes	Yes
Eagle Vail	10°C	4.0/0.60	0.70	Stone Creek	Alum	1/	8102	1/	None	0	Yes	No	No	Yes
Kremmling	9°C	12/0.5	0.60	Sheep Creek	Alum	10-15	None	0	NP-10	1-2.0	Yes	Yes	Yes	Yes
Dillon	9°C	1.5/0.4	0.20	Staight & Laskey Creeks	Alum	20	Np-10	0.1-0.5	None	0	Yes	Yes	Yes	Yes
Brecken Ridge	1°C	4.0/0.1	3.0	Blue River Goose Pasture Tarn Res.	Alum	4-6.0	8102	1.5-2.0	None	0	Yes	Yes	Yes	Yes
Boulder Betasso	15°C	1.2/0.4	25.0	Silver & Barker Lakes	Alum	12-14	None	0	None	0	Yes	Yes	Yes	Yes

1/ No data available

TABLE H-2. Results of Survey of Chemical Pretreatment Practices of Rocky Mountain Water Treatment Plants

Summary of Late Fall and Winter Treatment Practices

Name of Plant	Avg. Inf. Temp.	Avg. Turb. Inf/Eff	Avg. Flow (mgd)	Source of Water	Primary Coag. Name	Primary Coag. Dose (mg/l)	Coag. Aid Name	Coag. Aid Dose (mg/l)	Filter Aid Name	Filter Aid Dose (mg/l)	Rapid Mix	Floccu-lation	Sedimen-tation	Filtra-tion
Greeley-Bellvue	1.2°C	0.75/0.65	10.0	Poudre River	None	0	None	0	None	0	No	No	Yes	Yes
Fort Collins #1	1.0°C	0.60/0.35	8.0	Poudre River	None	0	None	0	8102	0.45-0.55	Yes	No	No	Yes
Golden	1.0°C	1/	1/	Clear Creek	Alum	1/	LT 25	1/	LT 25	1/	Yes	Yes	Yes	Yes
Soldier Canyon	6.0°C	10/0.5	5.0	Horsetooth	8102	1.0-2.0	None	0	None	0	Yes	No	No	Yes
Vail District	1.9°C	1.3/0.45	1.0	Booth & Gore Creeks	1/	1/	1/	1/	1/	1/	1/	1/	1/	1/
Avon Metro	1.0°C	0.9/0.25	0.25	Buck Creek	Alum	6-10.0	8102	0.1-0.15	None	0	Yes	No	No	Yes
Gore Valley/ Big Horn	1.0°C	1.5/0.20	0.50	Blackgore Stream	Alum	7-10.0	8102	0.6-1.0	None	0	Yes	Yes	Yes	Yes
Eagle Vail	1.0°C	0.7/0.35	0.20	Stone Creek	Alum	1/	None	0	8102	1.5-2.0	Yes	No	No	Yes
Kremmling	5.0°C	7.0/0.20	0.30	Sheep Creek	Alum	10-12	None	0	8170	0.2-0.50	Yes	Yes	Yes	Yes
Dillon	1.0°C	0.50/0.25	0.20	Stright & Laskey Creeks	Alum	20	Soda Ash	15	Np-10	0.1-0.5	Yes	Yes	Yes	Yes
Brecken Ridge	2.0°C	0.75/0.1	2.0	Blue River-Goose Pasture Tarn Res.	Alum	2-3.0	8102	1-1.5	None	0	Yes	Yes	Yes	Yes
Boulder Betasso	4.0°C	1.0/0.1	10.0	Silver Lake	Alum	10-12.0	None	0	None	0	Yes	Yes	Yes	Yes
Dillon Valley	1.0°C	0.5-0.07	1/	1/	Alum	50	Soda Ash	50	Np-10	0.2	1/	1/	1/	1/

1/ No data available

APPENDIX I

DESCRIPTION OF MICROPIPETTE TECHNIQUE[1/]

Giardia samples from membrane filtration are placed in mason jars and taken to the Pathology laboratory and refrigerated overnight to settle the cysts and debris. The following day the supernatant is pipetted off, without disturbing the sediment, leaving less than 50 ml in the mason jar. This remaining volume is remixed and poured into a 50 ml, conical centrifuge tube. The tube is centrifuged for 5 minutes at 1500 rpm. The supernatant in this tube is then pipetted off, leaving about 5 ml. This procedure is repeated until the sample has been concentrated to 1 ml.

Once the sample has been concentrated to 1 ml, the micropipette technique is used to determine the cyst concentration. This entails adding 5 to 6 ml of Lugol's Iodine to the 1 ml concentrated sample. After thorough mixing, 0.05 ml is withdrawn by a micropipette and placed in a vaseline well on a glass slide. A cover slip is affixed, and the slide is examined at 400x magnification. If cysts are seen, a mimimum of two aliquots are counted and averaged. The total number of cysts in the sample is found by multiplying by a factor of twenty.

[1/] Abstracted from "Processing Dog Fecal Samples and Cyst Counting Techniques" by C. Helmick and D. Howell.