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Project Summary

Removal of Trihalomethane Precursors by Direct Filtration and Conventional Treatment

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Removal of trihalomethane (THM) precursors from drinking water was studied in direct filtration and conventional treatment plants. The research had two objectives: (1) to investigate direct filtration as a water treatment process using cationic polymers as the sole coagulant, and (2) to evaluate two existing conventional water treatment plants for THM formation through the plants and for removals of THM precursors. Direct filtration was evaluated by means of traditional measures of filter performance (head loss development and filtered water turbidity and color) and by removals of nonpurgeable total organic carbon (NPTOC) and THM precursors. Conventional treatment was studied in two full-scale plants through evaluation of NPTOC and THM precursor removals.

Two different water sources were studied: the Grasse River, a highly colored supply, and the Glenmore Reservoir, a low turbidity, protected upland supply. Pilot plant studies showed that direct filtration with cationic polymers is an effective treatment process. Excellent performance was generally achieved with filtered water turbidities less than 0.3 nephelometric turbidity unit (ntu) and apparent color less than 15 Pt-Co units. Though the two water supplies are different in type and in raw water NPTOC and THM precursor concentrations, similar removals were achieved by direct filtration: 37 to 39 percent for NPTOC and 41 to 42 percent for THM precursors.

The two full-scale conventional water treatment plants both use alum as a primary coagulant and achieve greater removals of organic matter and THM precursors than direct filtration. The removals were similar for both plants, with 69 to 71 percent for NPTOC and 68 to 72 percent for THM precursors.

This study also demonstrated that UV (254 nm) absorbance may be used as a surrogate parameter for predicting raw water NPTOC and THM precursors and for monitoring treatment performance.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Interest in direct filtration was stimulated following passage of the Safe Drinking Water Act in 1974 and the issuance of the National Interim Primary Drinking Water Regulations (NIPDWR). A turbidity standard of 1 ntu was set. Many communities have used low turbidity supplies and have provided no treatment other than disinfection and pH control. They are now faced with providing additional treatment to meet the turbidity standard. In addition to concerns about turbidity, it was found in the 1970's that trihalomethanes (THM's) are produced within water treatment plants as byproducts of chlorination. A variety of organic compounds (THM precursors) react with chlorine to form trihalomethanes. The precursors may exist in dissolved, colloidal, or particulate forms in water supplies. Humic substances (natural color) constitute the major fraction of organic matter and THM precursors in most water supplies. In 1979, EPA amended the NIPDWR by establishing a maximum contaminant level (MCL) of 0.10 mg/L for total trihalomethanes (TTHM's).

Several methods exist for reducing THM formation and removing THM precursors from water supplies. For example, low turbidity humic (colored) waters are normally treated by coagulation with alum in conventional treatment plants employing coagulation-flocculation, sedimentation, and filtration processes. One method of controlling THM's is improved coagulation and operation of the conventional plant. Direct filtration, however, can offer savings in capital costs and operating costs when compared with conventional treatment. Since most direct filtration plants have been designed and operated for turbidity removal, direct filtration must be evaluated for the removals of organic matter and THM precursors when used in the treatment of low turbidity humic waters.

This research project had two major objectives. First, direct filtration was investigated as a water treatment process using cationic polymers as the sole coagulant. In some experiments, alum and polymer filter aids were also examined. Direct filtration was evaluated for the removal of turbidity and color (traditional parameters in assessing filter performance) and for removals of TOC and THM precursors. The second objective was to evaluate two existing conventional water treatment plants for THM formation through the plants and for removals of THM precursors.

Procedures

Water Supplies

Two water supplies were used in this research — the Grasse River at Canton, New York, and the Glenmore Reservoir at Oneida, New York. The Grasse River was selected for this research project because it is a low turbidity, highly colored water typical of many raw water supplies found in certain regions of the United States (e.g., Central and Northern New York, New England, and the Pacific Northwest). Another important feature of the Grasse River site is that no municipal or industrial wastewaters are being discharged to the river upstream. Consequently, the organic material in the river is naturally occurring and high in humic matter, giving it the characteristic yellow-brown color of colored waters.

The Glenmore Reservoir was chosen for this study for the following reasons. First, it is a protected upland water supply of low turbidity. This supply therefore represents many water supplies in the United States and provides a good model for this research. Second, the nature and concentration of organic matter in the reservoir would differ from that in the Grasse River and provide a contrasting system for study. Finally, the concentration of organic matter in Glenmore Reservoir is much lower than that in the Grasse River. In this research, then, two water supplies were used in which the organic matter and THM precursors are naturally occurring.

Raw water samples were collected periodically from the Grasse River and Glenmore Reservoir. The samples were characterized as to their concentrations of organic matter as measured by NPTOC, total trihalomethane formation potential (TTHMFP), and UV (254 nm) absorbance; seasonal changes in these parameters were also identified. THM precursor concentrations were measured by determining the 7-day TTHMFP at pH 7.5 and 20°C. For the Grasse River, samples were collected on 57 dates between February 1980 and March 1982. The Glenmore Reservoir was sampled on 44 dates between February and June 1982.

Conventional Water Treatment Evaluation

Existing full-scale plants at Canton and Oneida were monitored during this study to evaluate removals of NPTOC and THM precursors and to investigate THM formation through the plants. Monitoring of the Canton plant took place 16 times between February 1980 and March 1982. The Canton plant normally operates at 11.4 million L/day (3 mgd), and is a high rate conventional water plant employing the processes of coagulation-flocculation, sedimentation (tube settlers), and filtration (mixed media filters). Alum is used for coagulation, and a nonionic polymer is used as a coagulant aid. Prechlorination is normally practiced but at low doses of 1 to 2 mg/L. For postchlorination, the chlorine is applied at a point between the filters and the clearwell.

The Oneida plant has a rated process capacity of 15.1 million L/day (4 mgd). This plant was monitored on 16 occasions between April 1980 and May 1982. Oneida has a conventional plant using coagulation-flocculation, sedimentation (rectangular settling basins), and filtration (dual media filters). Alum is used for coagulation, and a nonionic polymer is used as a filter aid. Chlorine is added to the top of the filters and again after filtration. During the course of this study, Fe and Mn problems associated with the raw water were treated by the addition of chlorine (prechlorination), chlorine dioxide, and potassium permanganate. Beginning in the spring of 1981 and for the remainder of the study, potassium permanganate was used when needed.

Samples were collected at several locations throughout the plants — raw, settled, filtered, and finished water (pumped water from the clearwell to the distribution system). The analyses included temperature, pH, turbidity, apparent color, true color, total UV (254 nm) absorbance (unfiltered samples), soluble UV (254 nm) absorbance (filtered samples), NPTOC, instantaneous TTHM (Inst TTHM), TTHMFP, terminal TTHM (Term TTHM), and free residual Cl_2. For the raw waters, the 7-day TTHMFP's (pH 7.5, 20°C) were used as the measure of raw water THM precursor concentration. Within the water plants, Term TTHM samples were buffered at pH 7.5 and spiked with chlorine to maintain a residual for 7 days — that is, Term TTHM's (7-day, pH 7.5, 20°C). THM precursor removal through the plants is the difference between the raw water 7-day TTHMFP and the finished water 7-day Term TTHM.

Direct Filtration

Small-scale and large-scale direct filtration pilot plant studies were conducted at the Grasse River in Canton and at the Glenmore Reservoir near Oneida. The small-scale studies were conducted using columns of 4.45 cm ID. The large-scale studies used a Waterboy* pilot plant with a filter area of 0.372 m^2 (4 ft^2) and was operated at flows of 0.5 to 1.51 L/s (8 to 24 gpm).

The pilot plant studies were designed to evaluate the effects of chemical variables (pH, various polymers, polymer dosages, and alum) and physical variables (filtration rate, in-line direct filtration versus direct filtration with flocculation, and water temperature) on direct filtration performance. The studies evaluated traditional measures of filter performance such as filtered water turbidity, color, and head loss development. Reductions in UV (254 nm) absorbance, NPTOC, and THM precursors were also investigated. THM precursor removal by the pilot plants was calculated as the difference between the 7-day TTHMFP's (pH 7.5, 20°C) of the raw and filtered waters.

Results and Conclusions

Characterization of Raw Waters

The Grasse River contains high concentrations of organic matter and THM precursors as indicated by the data in Table 1. The highest concentrations of organic matter and THM precursors for the Grasse River occur in the summer, particularly late in the season. Summer mean values are 0.48 cm^{-1} UV (254 nm), 9.8 mg/L NPTOC, and 783 $\mu g/L$

* Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Table 1. Summary of Raw Water Characteristics (February 1980 - June 1982)

Parameter	Grasse River		Glenmore Reservoir	
	Mean	Range (n)	Mean	Range (n)
Turbidity (ntu)	2.7	1.2-6.5 (56)	1.3	0.54-3.5 (44)
Apparent Color (Pt-Co Units)	114	45-228 (57)	59	22-129 (43)
Total UV (cm^{-1})	0.35	0.113-0.666 (57)	0.16	0.084-0.309 (44)
NPTOC (mg/L)	7.5	2.75-14.7 (53)	4.2	2.0-10.6 (40)
TTHMFP* (μg/L)	576	232-1108 (54)	304	152-597 (42)

*7-day, pH 7.5, 20°C.

TTHMFP. Lowest concentrations occur in the winter when the Grasse River is ice-covered — 0.18 cm^{-1} UV (254 nm), 4.2 mg/L NPTOC, and 309 μg/L TTHMFP.

This seasonal variation in organic matter and THM precursors has practical applications for water supply utilities, consulting engineering firms, and regulatory agencies concerned with pilot plant studies or evaluations of existing water treatment plants. For rivers such as the Grasse, the worst water quality in terms of organic matter and THM precursors occurs in the summer, not in the fall during leaf fall or in the spring during snowmelt and runoff. Pilot plant studies should be conducted during the summer, particularly late in the season, to assess performance under the highest concentrations of organic matter and to determine coagulant requirements.

The Glenmore Reservoir contains lower concentrations of organic matter and THM precursors than the Grasse River, as shown by the data in Table 1. Like the Grasse River, the Glenmore Reservoir undergoes a well-defined seasonal variation. Lowest values occur in the winter when the Glenmore Reservoir is ice-covered. Mean winter values are 0.10 cm^{-1} UV (254 nm), 2.9 mg/L NPTOC, and 200 μg/L TTHMFP. Highest values occur in the summer with mean values for UV (254 nm), NPTOC, and TTHMFP of 0.21 cm^{-1}, 6.0 mg/L, and 412 μg/L, respectively.

Conventional Water Treatment Plant Performance

Given the high concentrations of NPTOC and THM precursors present in the Grasse River, the Canton Water Filtration Plant achieves excellent removals of NPTOC and THM precursors. Average percent removals for NPTOC, Term TTHM's (THM precursors), and UV (254 nm) absorbance appear in Table 2. In spite of the relatively high THM precursor level of the raw water, which ranged from 232 to 1108 μg/L, the average Inst TTHM concentration of the finished water (16 plant monitorings) was only 37 μg/L.

The Canton plant uses alum coagulation with the addition of a nonionic polymer to aid floc formation. Normally the plant is operated between pH 6 and 7, and occasionally the pH after alum addition is as low as 5. The excellent performance of the Canton plant in removing THM precursors and controlling THM formation through the water plant is due to the effectiveness of the coagulation process, pH conditions during treatment, chlorination practice, the short hydraulic detention time of the plant, and relatively low water temperatures. Though prechlorination is practiced, the dosages are low at 1 to 2 mg/L. The plant has tube settlers so that the total hydraulic detention time through the plant (excluding the clearwell) is approximately 1 hr. The prechlorination practice and the short hydraulic detention time allow removal of THM precursors before large concentrations of THM's are formed.

The Oneida Water Treatment Plant also achieves excellent removals of NPTOC and THM precursors, as shown by the data in Table 2. The Oneida plant uses alum coagulation (measured pH after sedimentation is typically 6 to 6.5) with addition of a nonionic polymer ahead of the filters to improve filtration. Sedimentation is achieved with conventional rectangular settling basins so that the total hydraulic time through the plant (excluding the clearwell) is approximately 6 hr.

This study showed that although the Glenmore Reservoir contains lower concentrations of organic matter and THM precursors, the percent removals (Table 2) are quite similar to those achieved at Canton. During the summer stratification period in the Glenmore Reservoir, reduced iron and manganese in the raw water requires oxidation and removal by the treatment plant. On two occasions when the plant was using chlorine at the front end of the facility for oxidation purposes, the Inst TTHM concentrations of the finished water were 134 and 148 μg/L. The plant later substituted $KMnO_4$ for Cl_2 at the front end of the plant (a small Cl_2 dosage of 1 mg/L or less is added to the top of the filters), and the average finished water Inst TTHM concentration for 12 monitorings dropped to 27.5 μg/L (Table 2).

Table 2. Performance Summaries for the Conventional Water Plants

Item	Canton Plant*	Oneida Plant*
Percent removals		
Total UV	80	82
NPTOC	69	71
TERM TTHM+	72	68
Mean Inst TTHM of finished water (μg/L)	37	27.5

* For Canton, 16 monitorings between April 1980 and March 1982; for Oneida, 12 monitorings between December 1980 and May 1982.
+7-day, free Cl_2 present, pH 7.5, 20°C.

Direct Filtration

General

For the Grasse River pilot plant studies, the raw water turbidity and apparent color ranged from 1 to 6 ntu and 50 to 200 Pt-Co units, respectively. Good filtration performance was achieved using cationic polymers as the sole coagulant with filtered water turbidity and apparent color of 0.2 ntu and 5 to 10 Pt-Co units, respectively. The pH (from 5.5 to 7.5), filtration rate (4.88 to 14.6 m/hr), type of filtration (in-line direct versus direct with flocculation), and water temperature had little or no effect on filter performance based on removals of turbidity, color, and organic matter. Figure 1 shows typical results for two experiments comparing in-line direct filtration with direct filtration preceeded by flocculation. The experiments were conducted at pH 7.4 (no pH adjustment) and a filtration rate of 4.88 m/hr using Grasse River water of similar raw water quality. Excellent filter performance was achieved with low filtered water apparent color and turbidity. A major difference exists in head loss development between in-line direct filtration and direct filtration with flocculation, as shown in the bottom plots of Figure 1. This result will be discussed later.

The pilot plant studies on the Glenmore Reservoir showed that cationic polymers can be used successfully to treat a low turbidity, moderately colored water. With raw water turbidities of 0.75 to 1.5 ntu and apparent color values of 40 to 75 Pt-Co units, filtered water turbidities of less than 0.3 ntu and apparent color of 5 to 15 Pt-Co units were obtained. Little difference was noted between the performance of in-line direct filtration and direct filtration with floccula-

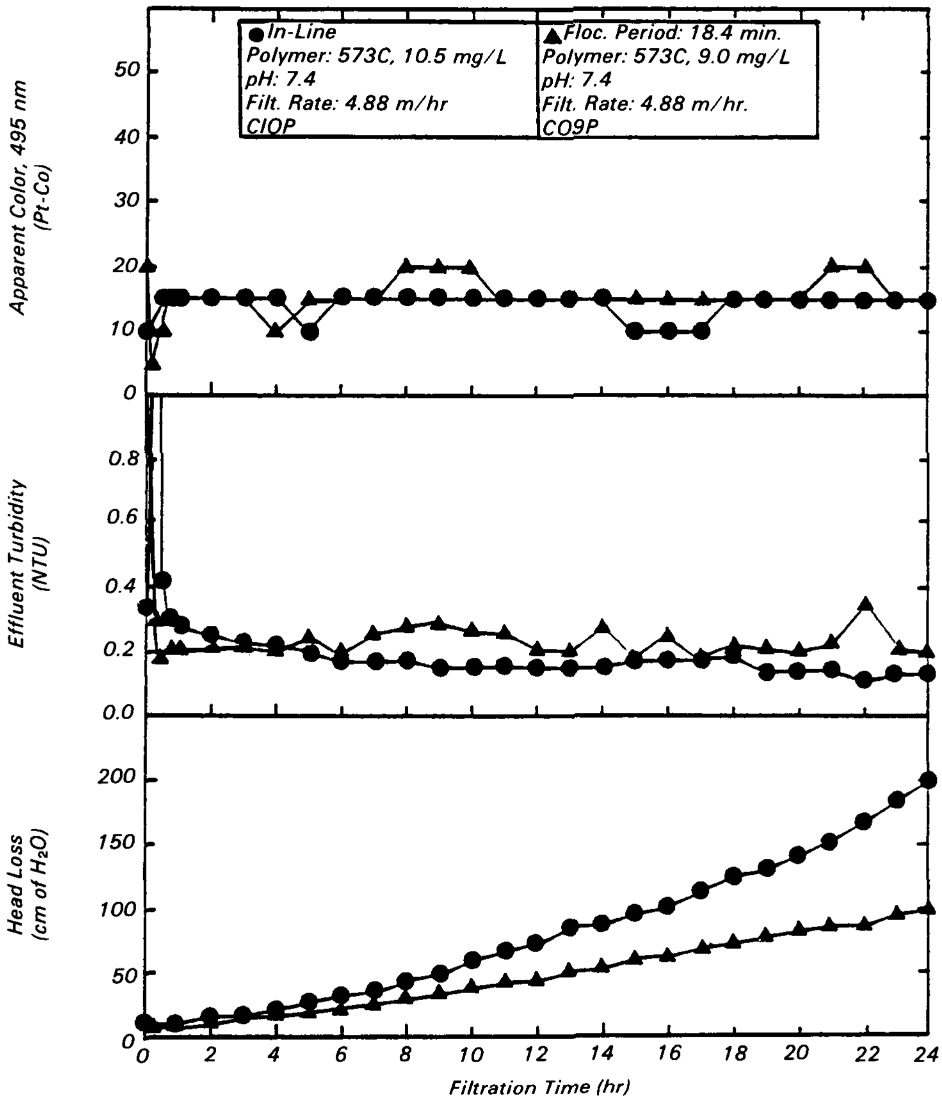

Figure 1. *Direct filtration by in-line treatment versus a flocculation period before filtration (raw water quality conditions: 2.5 ntu turbidity, 108 to 115 Pt-Co units of apparent color, 0.37 to 0.40 cm^{-1} UV (254 nm), 7.3 to 8 mg/L NPTOC, and 657 to 674 µg/L TTHMFP).*

tion, based on removals of turbidity, color, and organic matter.

Pilot plant studies of direct filtration were conducted on both a small and a large scale. An important practical finding was that the small-scale pilot plant gave similar results to the large-scale plant in evaluating various coagulants and coagulant dosages, filtered water turbidity and color, and removals of organic matter and THM precursors.

Polymer Dosage Selection

This study demonstrated that jar tests can be used to select cationic polymer dosages for direct filtration. Figure 2 illustrates this procedure for an experiment with Grasse River water. The jar test results plotted in the top figure show a sharp drop in true color at cationic polymer dosages of 2 to 4 mg/L; above 4 mg/L, little change occurs in the true color readings. These results indicate that the required polymer dose for coagulation is 4 mg/L. The bottom figure shows direct filtration results where the polymer dose was varied during the course of the experiment. Best results were obtained at 4 mg/L, as the jar tests predicted. Underdosing and overdosing occur in direct filtration and can be predicted from the jar test data.

For the Grasse River, regression equations were developed between the required cationic polymer (Magnifloc 573C) dosage for direct filtration and either raw water apparent color or total UV (254 nm) absorbance. Figure 3 shows the data and regression equation for polymer dose versus total UV. Since the UV absorbance is proportional to the NPTOC concentration, these data indicate a stoichiometric relation between polymer dose and concentration of organic matter in the raw water. These results are highly significant and practical. The predictive equation developed in this study is specific to the Grasse River, but the principle is generally applicable. In practice, a water utility could make in-line spectrophotometric UV measurements of the raw water quality. From a predictive equation relating polymer dose to raw water UV (254 nm), the utility could then select the polymer dosage.

In-Line versus Flocculation

As previously mentioned, the removals of organic matter, filtered water turbidity, and color did not differ between in-line direct filtration and direct filtration with a flocculation period provided by a flocculation basin. For the Grasse River in particular, substantially less head loss developed when treating the same water by direct filtration with flocculation compared with in-line direct filtration (see Figure 1). These results are significant and have design ramifications. In the treatment of a water like the Grasse River, direct filtration with flocculation will give longer filter runs. This fact is explained by considering that a water with large amounts of humic matter contains high concentrations of submicron particles (the humic particles). By providing a flocculation period, through the use of a flocculation basin or otherwise, the humic particles can aggregate to larger sizes. The flocculation period reduces the number and surface area of the particles retained in the filter by increasing their size. This process results in less head loss development and longer filter runs.

A flocculation period is recommended in direct filtration, since it will lengthen filter runs, especially for waters containing submicron particles (humics, viruses, asbestos, etc.). The flocculation tank also provides the water plant operator with some time to adjust chemical (coagulant) dosages for direct filtration.

Removals of THM Precursors

Average percent removals of organic matter and THM precursors (TTHMFP) for direct filtration with a cationic polymer (Magnifloc 573C) and with alum are summarized in Table 3. For each method of treatment, the removals of NPTOC and TTHMFP are approximately the same for both the Grasse River (a highly colored river) and the Glenmore Reservoir (a low turbidity, protected upland reservoir). A comparison of the direct filtration results with the performance results

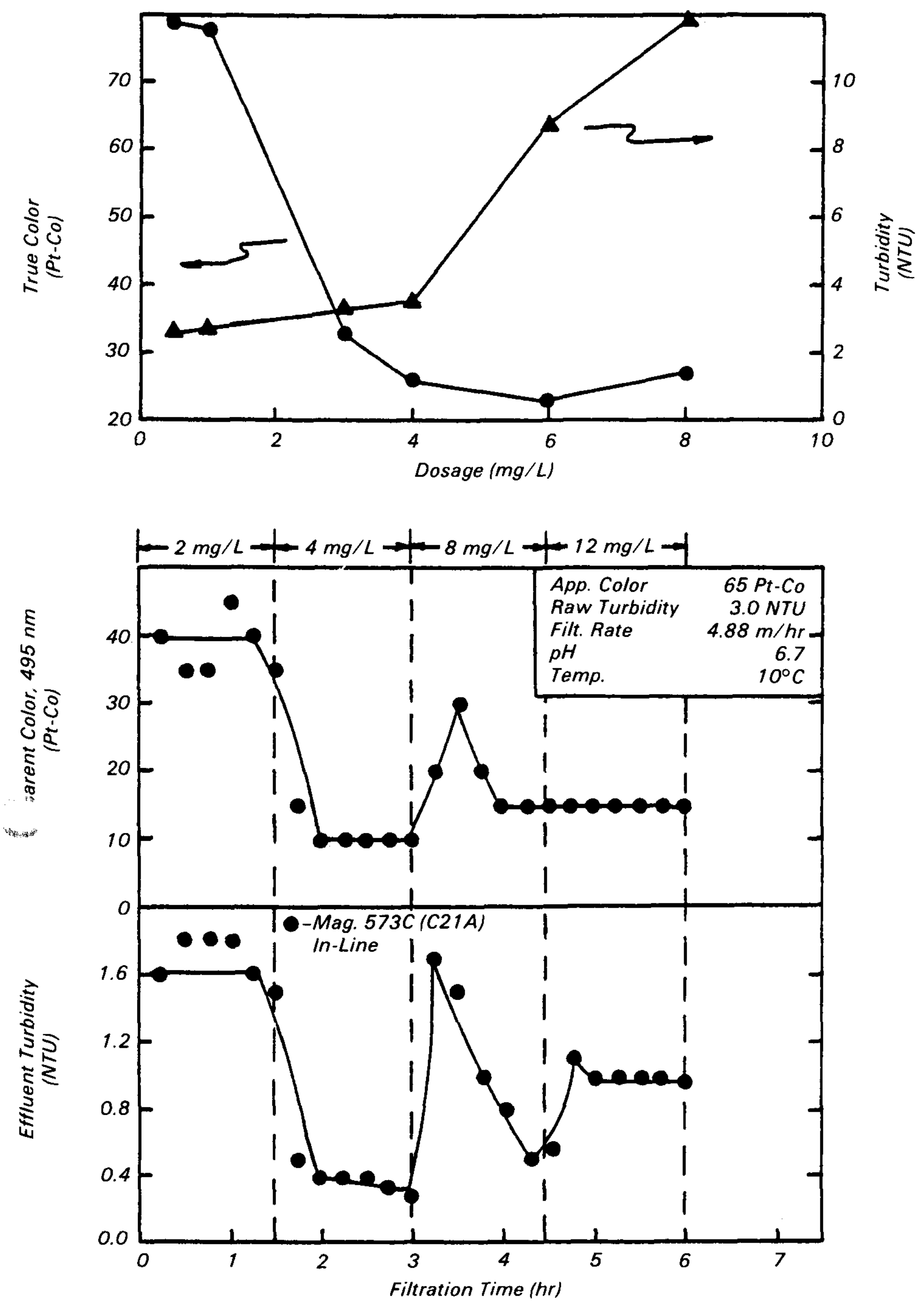

Figure 2. *Top figure: Jar test results using a cationic polymer. Bottom figure: Direct filtration results for varying cationic polymer dosage during the filter run.*

in Table 2 shows that the conventional type treatment plants produce higher removals of NPTOC and THM precursors than direct filtration with cationic polymers.

This research shows that direct filtration using only cationic polymers removes approximately 40 percent of the THM precur- ...rs at about pH 7 and a slightly higher percent at lower pH conditions. Considering the advantages of direct filtration with cationic polymers only, these removals are good. The report discusses the applicability of direct filtration on humic waters in light of the MCL of 0.10 mg/L for Inst TTHM's. The discussion stresses that pilot plant studies are needed to determine whether a particular water supply can meet the THM regulations. But a guideline is developed for determining the feasibility of direct filtration with cationic polymers. According to the guideline, if the yearly mean raw water quality does not greatly exceed 0.2 cm^{-1} for UV (254 nm), 4.6 mg/L NPTOC, and 350 μg/L TTHMFP (7-day, pH 7.5, 20°C), then direct filtration may be feasible and should be considered for pilot plant studies.

Cost Evaluation

Cost estimates were prepared to compare direct filtration and conventional water treatment for the Grasse River and the Glenmore Reservoir. These costs were prepared for 5 mgd (18.9 million L/day) treatment facilities operating at 60 percent capacity. The costs are in January 1982 dollars. Annual capital costs were computed based on an interest rate of 10 percent over a 20-year period. With a few exceptions, the cost estimates for the conventional plants followed existing practice. A major difference in the conventional plants between Canton and Oneida is the use of tube settlers at Canton.

Direct filtration is cheaper at both sites. For Canton, the cost is estimated at 36.1¢ per thousand gallons compared with 45.6¢ for conventional treatment. For Oneida, direct filtration is estimated at 34.1¢ per thousand gallons compared with 50.1¢ for conventional treatment.

Direct filtration has the following economic advantages with regard to capital costs:

- Elimination of the sedimentation process,
- Replacement of rapid-mix coagulation tanks with in-line static mixers,
- Use of a smaller flocculation tank, and
- Reduced sludge lagoon construction because of smaller sludge volumes.

Though chemical costs are slightly higher for direct filtration, overall operating and maintenance costs are less. Savings result from the use of in-line static mixers (lower energy and maintenance costs), smaller flocculation basins (lower energy and maintenance costs), and reduced sludge volumes over conventional treatment.

Surrogate Parameters

UV (254 nm) absorbance is a good surrogate parameter for predicting raw water NPTOC and TTHMFP (THM precursors) for both the Grasse River and the Glenmore Reservoir. For the Grasse River, r^2 values of 0.93 and 0.94 were obtained for NPTOC and TTHMFP, and for the Glenmore Reservoir, the values were 0.71 and 0.82, respectively. An example of one of the correlations is shown by Figure 4 for TTHMFP versus UV for the Grasse River.

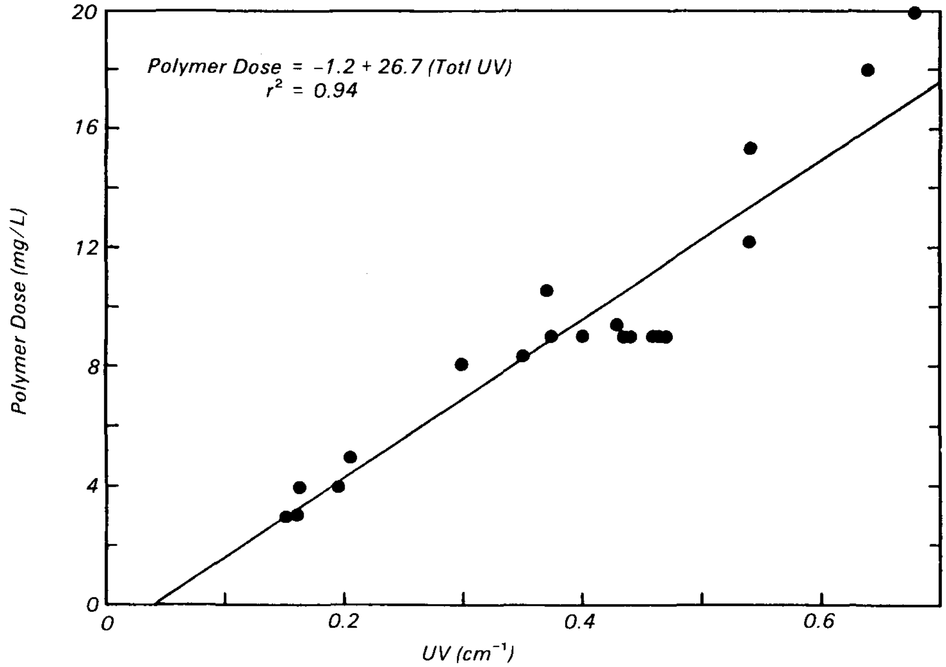

Figure 3. *Cationic polymer dose for direct filtration versus total UV absorbance for raw water from the Grasse River.*

Table 3. *Average Percent Removals by Direct Filtration*

Percent Removals	Cationic Polymer: Grasse River	Cationic Polymer: Glenmore Res.	Alum: Grasse River	Alum: Glenmore Res.
Total UV	58	51	76	71
NPTOC	37	39	57	56
TTHMFP*	42	41	59	59

*7-day, pH 7.5, 20°C.

UV can be used to monitor direct filtration pilot plant performance for removals of NPTOC and TTHMFP. For pilot plant studies on the Grasse River, r^2 values of 0.86 for NPTOC and 0.90 for TTHMFP were obtained for the respective predictive equations. For the Glenmore Reservoir, r^2 values were 0.72 for NPTOC and 0.89 for TTHMFP.

Apparent color, total UV (unfiltered samples), and soluble UV (filtered samples) are all good surrogates for monitoring the removals of NPTOC and TTHMFP by the Canton and Oneida water treatment plants.

The full report was submitted in fulfillment of Cooperative Agreement No. CR807034 by Clarkson College of Technology under the sponsorship of the U.S. Environmental Protection Agency.

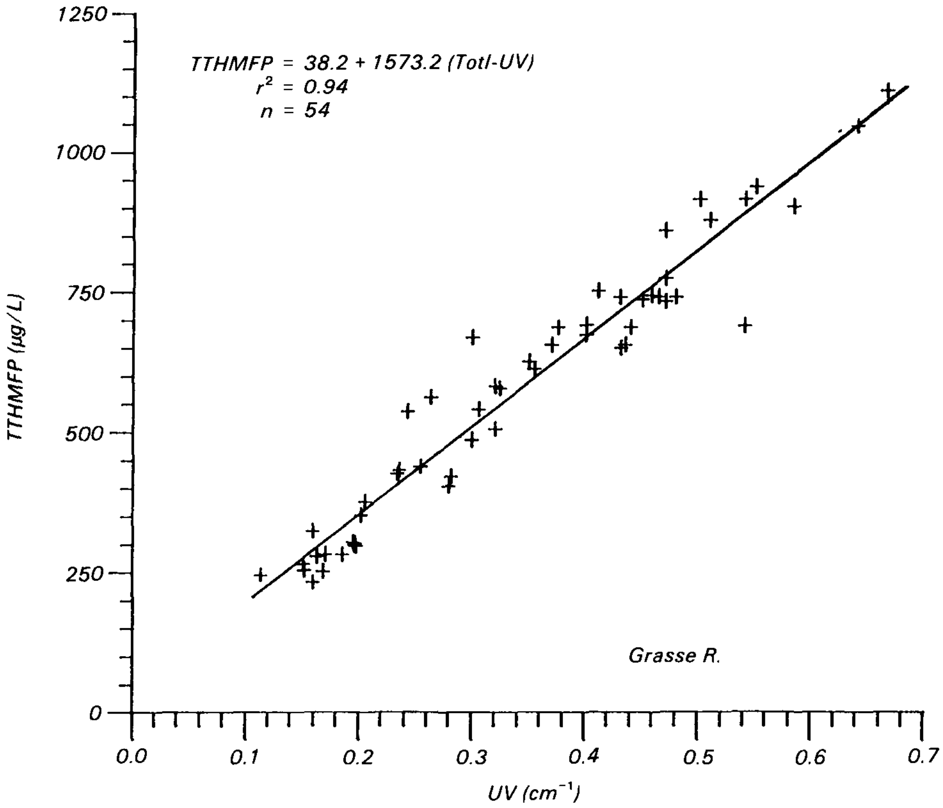

Figure 4. *Correlation between TTHMFP (7-day, pH 7.5, 20°C) and total UV (254 nm) absorbance for Grasse River raw water.*

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The complete report, entitled "Removal of Trihalomethane Precursors by Direct Filtration and Conventional Treatment," (Order No. PB 84-163 278; Cost: $20.50, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
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The EPA Project Officer can be contacted at:

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