

EVALUATION OF ALTERNATIVE PRETREATMENT METHODS  
FOR USE IN DIRECT FILTRATION WATER TREATMENT

by

Harold Thomas Eberly

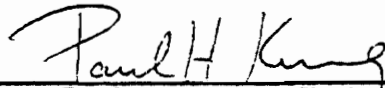
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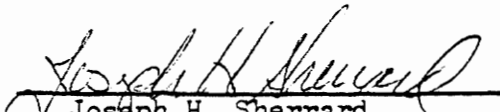
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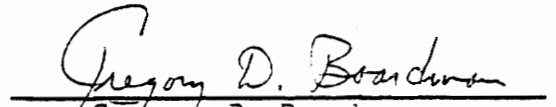
in

Sanitary Engineering

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## I. INTRODUCTION

For many years the conventional full-scale treatment of water for the removal of turbidity and colloidally dispersed solids has been limited to use of an extended process chain consisting of coagulation, flocculation, sedimentation, filtration through a bed of granular media, and chlorination. Other systems have frequently been operated utilizing only chlorination of higher quality groundwaters. However, with the passage of Public Law 93-523, the Safe Drinking Water Act, by Congress in December, 1974, and its enactment on June 24, 1977, the federal government established minimum water quality standards for drinking water with which all public water supply systems must comply.

Of the standards established by PL 93-523, the turbidity standard will have the most significant impact in terms of the number of systems affected. By establishing the acceptable turbidity limit at 1.0 turbidity units, many of the existing public water systems will be required to install filtration facilities in order to comply with the federal regulations, whereas previously the only requirement for many systems was disinfection. Since the installation and maintenance of filtration facilities involve large capital and operational costs, many of the smaller public water supplies will be hard pressed to comply with the turbidity standard.

One alternative to the high capital and operational costs is the elimination of the sedimentation basin(s) and/or flocculation basin(s) from the process chain and the use of direct filtration for low turbidity waters. In the employment of direct filtration, the key parameter is the

size and quality of floc produced for filtration since the direct filtration process is designed to make optimal use of the filter as a flocculator and storage reservoir (21). As shown in Figures 1, 2, and 3, direct filtration differs from conventional coagulation-filtration in that the total solids, both natural and manmade, must be stored in the filter whereas in conventional coagulation-filtration the solids are stored principally in the sedimentation basin (14).

The effectiveness of the direct filtration process for a given raw water source is largely a function of that source's raw water quality, with turbidity being the principal parameter of concern. For effective use of direct filtration, the raw water turbidity should be within the range of 25-50 NTU (Nephelometric Turbidity Units) since above this average the process may prove inefficient, resulting in short filter runs and premature turbidity breakthrough.

Proper control of the coagulation-flocculation processes is the most important factor contributing to the efficiency or inefficiency of a direct filtration water treatment plant. Proper monitoring of these processes is essential since improper coagulation-flocculation can not be corrected later in the treatment scheme. Monitoring also helps to insure that the optimum coagulant dose is applied to the raw water (21). The significance of improper coagulation-flocculation takes on added importance when it is considered that there is essentially no lag time between these processes and filtration in the direct filtration treatment scheme. The determination of an optimum coagulant dose is difficult to predict because of the large number of parameters involved. These parameters include the nature of the coagulant, pH, and alkalinity of the raw

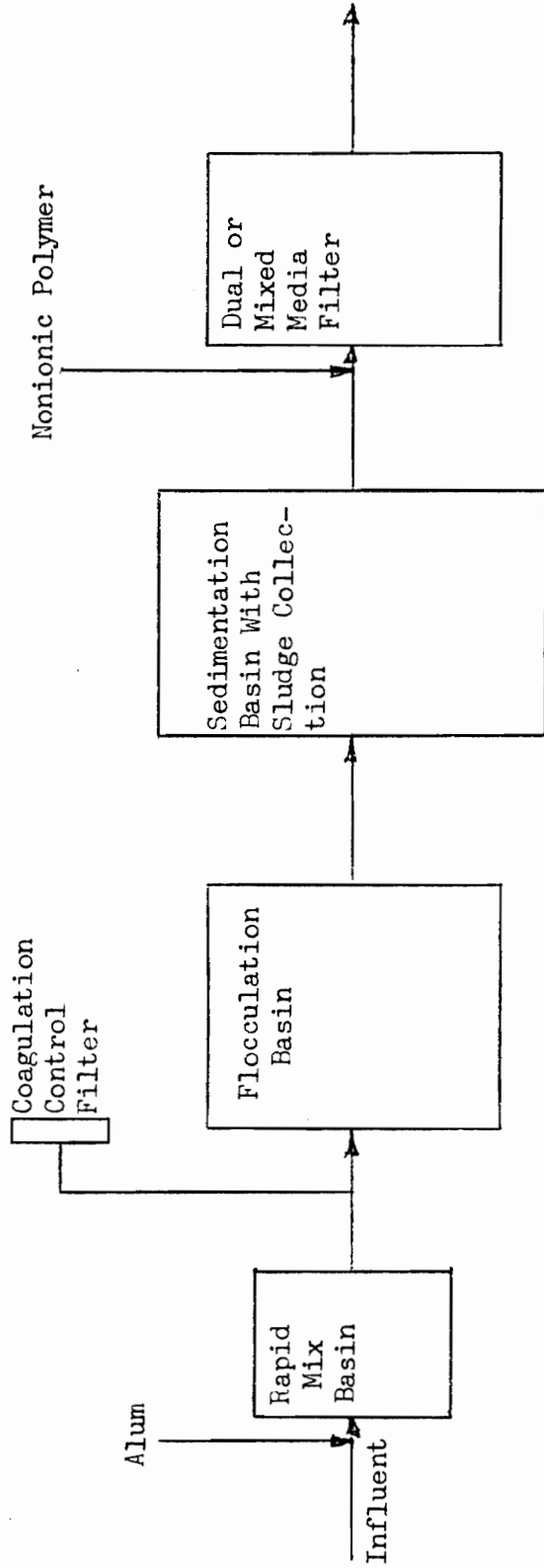


Figure 1 Flow Sheet for Typical Recent Design Trends for Conventional Filter Plant ( 7 )

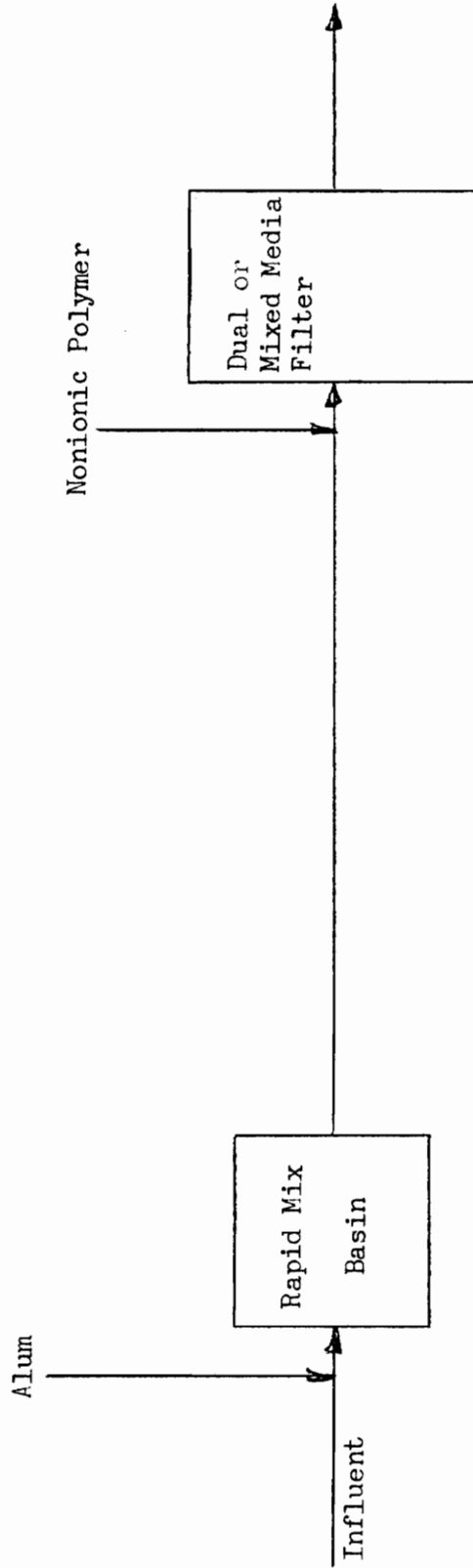


Figure 2 Flow Sheet for Typical Direct Filtration  
Using Alum and Nonionic Polymer (7)

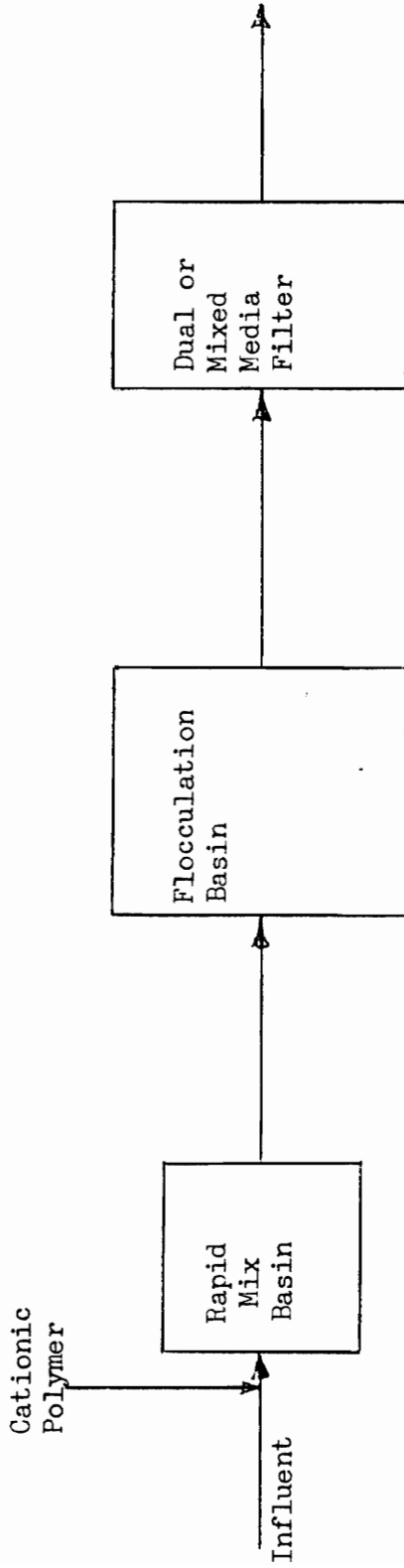


Figure 3 Flow Sheet for Typical Direct Filtration Using Flocculation Basin (7)

water, as well as the size, shape, chemical nature, hydration, and charge of the colloidal particles in suspension (10).

Although coagulants have been used for many years in water treatment, the introduction of high rate filters and particularly the direct filtration process has led to the development of new coagulants and coagulant aids to strengthen small volume, weak floc. The increasing interest in direct filtration has led to the development of polyelectrolytes and polymers which could act as primary coagulants, coagulant aids, and filter aids to strengthen floc and prevent premature breakthrough (21).

The purpose of this study was to evaluate the performance of a coagulant (alum), a coagulant aid (Hercofloc 812), and a primary coagulant polymer (Catfloc) in the coagulation-flocculation-sedimentation portion of a water treatment process and to study the implications of the results with respect to future use in direct filtration. Of particular importance to this study was the flocculation time and settling time as well as the alkalinity, pH, and turbidity of the raw water.

## II. LITERATURE REVIEW

Direct filtration, as defined by the Committee on Coagulation-Filtration, Water Quality Division of the American Water Works Association, refers to those treatment systems in which filtration is not preceded by sedimentation. The applicability of a direct high-rate filtration process is dependent on many physical and chemical characteristics of the raw water to be treated and the treatment process itself. A direct filtration treatment process is usually essentially the same as a conventional treatment process, with the exception of the sedimentation basin. With the elimination of the sedimentation basin, the key to the direct filtration process becomes the filter itself, since the filter will be required to act as both a flocculation reactor and floc storage reservoir (26). Following is a brief discussion of some physical and chemical considerations which influence the direct filtration process with particular emphasis on the use of coagulant aids and polyelectrolytes designed to make optimum use of the filter floc storage reservoir capacity.

### Water Quality Considerations

As stated previously, the applicability of direct filtration is dependent on many variables, one of which is raw water quality. Of the many raw water parameters the ones of principal concern are alkalinity, pH, temperature, turbidity, and biological content.

Alkalinity and pH of natural waters generally do not pose a significant problem, but can be adjusted, if needed, by addition of an acid or alkaline substance. Kawamura (15) reports that pH is one of the most important variables to be considered for effective flocculation but goes

on to state that for optimum flocculation both the pH and alkalinity must be considered since an optimum level exists for each. Clark, et. al. (5) and Sawyer and McCarty (25) state that a residual alkalinity must be maintained because it serves to buffer the system above pH 5.0 and insures complete precipitation of coagulating ions.

Optimum pH for aluminum sulfate flocculation in the presence of ions and turbidity found in natural waters is 6.0-7.8, while the optimum pH range for direct filtration is generally in the range of 7.0-8.0 (15)(21). Kawamura (15) reports that the use of polyelectrolytes as primary coagulants gives a system which is less dependent on pH than one in which aluminum sulfate is employed.

While alkalinity and pH generally cause no significant problems, temperature may produce adverse effects on the overall treatment process. Research conducted by Hannah, et.al. (11) and Tredgett (31) concluded that it was extremely important to evaluate the effects of temperature on the treatment process, since as temperatures decreased a deterioration in the sedimentation, filtration, and coagulation processes were noted. Tredgett (31) indicated that the problem may be overcome by increasing mixing time, increasing chemical dosage, or both.

Of significance in determining the applicability of raw water to direct filtration is the biological content of that water. Hutchison (14) states that diatoms were found to be the most troublesome form of aquatic life to the direct filtration process. According to Hutchison (14) and Hutchison and Foley (13) the appearance of diatoms occurred in temperature range of 10-14° C. in the late spring. Hutchison (14) reports concentration of diatoms upwards of 8000 asu/ml which generally

remained from two to six weeks. Research by Hutchison (14) and Hutchison and Foley (13) concluded diatom concentrations of less than 500 asu/ml affected the length of filter run, but the actual result was dependent on the effective size of filter media. Tredgett (31) reported no adverse affects with diatom concentrations of 65-1900 asu/ml. However, Culp (7) notes that the direct filtration process may not be applicable to raw waters having appreciable quantities of paper fibers present or diatom concentrations exceeding 500-1000 asu/ml.

Of the raw water characteristics listed previously, the applicability of the direct filtration process is most dependent on raw water turbidity. Culp (7) and Culp and Culp (8) indicate that the possibility of applying a direct filtration process to raw water is generally good if the average turbidity does not exceed 25 turbidity units. Culp (7) reports that occasional peaks in turbidity of as high as 200 turbidity units can be tolerated without adversely affecting the applicability of direct filtration. Hutchison (14) states that in order for direct filtration to remain a viable alternative, the turbidity levels should be low enough to allow coagulant dosages of less than 15 mg/l to be used on a continuous basis. He further feels that turbidity levels requiring a maximum coagulant dosage of 20 mg/l can be tolerated on a short term basis without placing an undue strain on the backwash facilities. Research by Adin and Rebhun (1) and Robeck, et.al. (23) concluded that even the flocculation basins may be removed for low turbidity waters, but noted that this scheme was predicted upon use of a coarser size filter media. Hutchison (14), Beardsley (2), and Robinson (24) report that for high turbidity waters the use of polyelectrolytes are generally as ef-

fective if not more effective than aluminum sulfate in removing turbidity.

### Coagulation in Direct Filtration

Although the previously discussed variables are important in determining the applicability of direct filtration to a given raw water, the success or failure of the process is dependent almost entirely upon proper coagulation. The dependence of the direct filtration process on proper coagulation takes on added significance when it is realized that little or no lag time exists between coagulation and filtration, thus improper coagulation can not be corrected later in the treatment process. For this reason many researchers feel that proper coagulation is the most important step in a water treatment process (17)(19)(20)(22)(29)(32).

Coagulation, the introduction of chemical reagents into water to promote agglomeration of colloidal and suspended particles into a floc, takes place in the rapid mix basin (18). This process is essentially instantaneous in nature and usually requires intense mixing to insure that the coagulant comes in contact with the particles and to insure uniform distribution of the coagulant. Hammer (10) reports that the efficiency of a water treatment facility is usually dependent on proper coagulation, which in turn relies on the determination of an optimum chemical dosage. Prediction of optimum coagulant dosage is extremely difficult due to the large number of parameters involved. Some of these parameters include nature of coagulant, pH, alkalinity, ionic constituents, and base exchange of raw water, and the size, shape, chemical nature, hydration, and charge of colloidal particles in suspension (21). While proper

coagulation is essential to direct filtration, some consideration must be given to flocculation. As indicated previously, Adin and Rebhun (1) and Fobeck, et.al. (23) concluded that retention of flocculation basins in the treatment scheme may be entirely dependent on raw water turbidity.

Essential to the understanding of coagulation-flocculation is a distinguishing of the two processes and factors which cause them. Moffett (18) defines coagulation as destabilization produced by the compression of the electrical double layer surrounding the colloidal particle. Flocculation is defined as the agglomeration of particles due to the transport process (18). In order for the coagulation-flocculation process to be effective colloidal particles must be destabilized. The colloidal particle predominates in the size range of 0.2 to 2.0 microns and as such has a relatively large surface area which enhances the colloids affinity to remain stable or disperse (10)(22). The most important factors contributing to colloid stability are hydration and zeta potential. Black (4) defines hydration as the particles' ability to attract relatively large numbers of solvent molecules to their surface. Particles which attract water to their surface are hydrophilic and use the water to form a cushion to prevent contact with other hydrophilic particles (10). Zeta potential is related to the surface charge of a particle. This charge brings about an electrical field of an opposite pole, thereby promoting a repulsive force preventing particles from approaching each other (4). The most important forces of colloidal instability are Brownian movement and Van der Waals forces. Black (4) defines Brownian movement as movement imparted to suspended colloidal

particles because of impact with invisible rapidly moving particles of the medium. Van der Waals forces are molecular cohesive forces that increase in intensity as particles approach each other (4). These forces become more effective with decreasing particle size. Since during the coagulation process the degree of hydration or zeta potential, or both, are unable to maintain particle discreteness and stability, the factors contributing to instability tend to predominate resulting in particle agglomeration, flocculation, and eventual settling (10).

Two theories have been advanced in an attempt to explain the mechanisms involved in the stability and instability of colloidal systems. The first theory is the chemical theory which assumes that colloids are aggregates of definite chemical structural units and emphasizes specific chemical interactions between the coagulant and colloids (27). This theory assumes that specific chemical interactions between the coagulant and colloid result in the precipitation of insoluble complexes. The second theory is the physical or double layer theory which emphasizes the importance of the electrical double layers surrounding the colloidal particles in solution and the effects of counter-ion adsorption and zeta potential reduction in the destabilization of the colloidal systems (27). This theory closely follows the definition of coagulation stated by Moffett (10)(18).

Since destabilization of the colloidal particles is the ultimate objective of the coagulation process, it is essential that the particle and coagulant come into contact for a period long enough to insure destabilization. This contact is accomplished in the rapid mix basin at a sufficient mixing intensity to insure contact. Vrale and Jordan (32)

report that a wastage of chemicals and slower particle aggregation rates for a given chemical dosage result from inefficient rapid mixing. The rapid mix period thus may have a significant influence on flocculation. Hudson (12) and Letterman, et.al. (17) reported that floc formed following rapid mixing appeared to contain considerably more solids than did floc not subjected to rapid mixing. Hudson (12) stated that entrapment of suspended matter by floc is influenced by volume produced rather than by size or appearance of floc particles.

#### Polymer Utilization

Although iron and alum salts have been used for many years as coagulant aids, the demands placed on the alum and iron flocs by high rate filtration have shown these flocs to be too weak to withstand the high shear forces developed (21). Therefore, synthetic polymers and polyelectrolytes have come into increasing importance. A polymer or polyelectrolyte is defined as a high molecular weight, water soluble compound which may be either cationic, anionic, or nonionic (8). Since the direct filtration process requires a strong, pinpoint floc those polymers which form a strong floc are of considerable importance (13)(21). Research done by Stump and Novak (29) states that the process variables which control polymer performance are rapid mix time, mixing intensity, and flocculation time.

Kleber (16) states that cationic polymers differ from inorganic coagulants in that they have slower destabilization times and, therefore, require more mixing, particularly rapid mixing. This need for longer and more intense mixing may be attributable to the long polymer chains

and the need for even distribution throughout the water to be treated (16). Kleber further states that high intensity mixing for 1 to 2 minutes at a flocculation parameter (G) of 400 to 1000  $\text{sec}^{-1}$  generally proved effective and resulted in equal distribution of the polymer throughout the water promoting rapid destabilization. Work done by Morrow (19), Stump and Novak (29), Beardsley (2), and Pressman (20) generally concur with Kleber that some degree of mixing must be provided. Morrow (19) noted that a G value of 300  $\text{sec}^{-1}$  was not always effective in producing complete destabilization and usually resulted in nonuniform polymer distribution and short contact periods which limited interparticle action. He stated further that the cationic polyelectrolyte was most effective at high G values. These levels generally resulted in a decrease in chemical dosage and a decrease in the time required to provide complete distribution and colloid destabilization. Birkner and Morgan (3) concluded that the rate controlling step in the overall destabilization reaction was the particle collision process.

Pressman (20) reported that the nature of the water, rather than the specific polymer used, is the predominant factor in determining the optimum dosage range. Adin and Rebhun (1) reported that flocculation using cationic polyelectrolytes was characterized by a relatively narrow dosage range with a high settling velocity. Shea, et.al. (26) and Hebian and O'Melia (9) reported that the optimum polymer dosage appeared to be in direct proportion to the particulate concentration in the raw water. Pressman (20) also noted that the optimum dosage is dependent on pH and turbidity and that the effectiveness of polymer is

reduced with increasing pH. Beardsley (2) notes that polyelectrolytes do not exhibit any effects on pH while providing particle neutralization.

The advantage of using polyelectrolytes as primary coagulants in direct filtration can best be ascertained from the type of floc produced. In addition to providing the strong pinpoint floc required for direct filtration, Culp (7) reports that the direct filtration process produces less sludge than conventional treatment and that the sludge produced is more dense. Beardsley (2) reports that for systems using coagulant dosages consisting of part aluminum sulfate and part polyelectrolyte, the sludge volume is reduced in proportion to the aluminum sulfate replaced. He further notes that alum replacement with a polyelectrolyte generally results in a reduction of chemicals required, a more compact floc, and improved flocculation as a result of favorable pH and alkalinity conditions. Kleber (16) concurs with Culp (7) in that the use of polyelectrolyte tended to increase the solids content and weight of the sludge produced.

#### Control Considerations

Of considerable importance in insuring that the coagulation process functions properly is the application of the proper coagulation control techniques. The most frequently used control technique is the laboratory jar test. Hannah, et.al. (11) notes that the frequency of controlling coagulation is largely dependent on the character of the raw water. He further notes that when using jar tests, several methods exist to correlate the results to obtain the optimum coagulant dose for a given raw water. In evaluating jar test results, Moffett (18) reports that very little correlation can be obtained from test to test because of incon-

sistency in the technique of the person performing the test, the unreliability of the human eye, and the fact that the test is time consuming. In addition to the above problems with the test, Hannah, et. al. (11) points out the following areas of possible error: size and shape of containers and paddles used, methods of measuring mixing intensities, and the difference in the full scale versus prototype unit. When polyelectrolytes are evaluated using the jar test procedure, Stump and Novak (29) report that for direct filtration studies jar tests are only useful in obtaining the optimum polymer dose and are otherwise of little use.

### III. EXPERIMENTAL METHODS

The author's laboratory investigation consisted of a series of jar tests using aluminum sulfate, two polymers (Tables 1A and 1B), and natural water from three sources (Table 2). The laboratory studies evaluated the effects of the aluminum sulfate and polymers on each of the waters in terms of pH, turbidity, total hardness, total alkalinity, and total solids for varying polymer and aluminum sulfate dosages.

All jar tests were conducted using a Phipps and Bird multiple-stirring apparatus. The general jar test procedure consisted of measuring 1.0 liter raw water samples into six 1.5 liter square jars to which predetermined quantities of coagulant were added. Following addition of the coagulant the water samples underwent approximately a two-minute rapid mix period at 100 rpm. Subsequently, this rate was reduced to 30 rpm for the appropriate flocculation period. Finally, each sample was subjected to a predetermined sedimentation period to allow the particle aggregates to settle from suspension. Following the sedimentation period approximately 400 milliliters of supernatant was withdrawn by suction approximately 2.5 inches below the liquid surface and used for pH, residual turbidity, total hardness, total alkalinity and total solids analyses.

Utilizing the general jar test procedure outlined above, water from each source underwent three series of three runs each or nine jar test runs designed to evaluate the performance of the aluminum sulfate and polymers in varying degrees of treatment prior to filtration. The treatment variations each water underwent included conventional high rate (C), modified high rate (M), and ultra high rate (U) treatment schemes. The

conventional treatment scheme included the two-minute rapid mix period followed by a 30 minute flocculation period and a 60 minute sedimentation period. Modified high rate treatment included the rapid mix period but reduced the flocculation and sedimentation periods to 10 and 20 minutes, respectively. The ultra high rate treatment scheme included the rapid mix period and retained the 10 minute flocculation period but further reduced the sedimentation period to five minutes. Within each treatment scheme three jar test runs were performed. The first run provided treatment utilizing aluminum sulfate only, run two utilized aluminum sulfate plus a polymer for treatment, and the final run provided treatment utilizing only a polymer.

Residual turbidity analyses were determined with a Hach turbidimeter, Model 2100A. Turbidity units were recorded as Nephelometric Turbidity Units (NTU). The turbidimeter was calibrated before each jar test run using calibration standards commercially prepared by the Hach Chemical Company.

Total alkalinity and total hardness determinations were made by titration of  $0.02N H_2SO_4$  and ethylenediamine tetraacetic acid (EDTA), respectively. The results of these determinations were recorded as milligrams per liter  $CaCO_3$ . Analytical techniques utilized for these determinations conformed with those given in Standard Methods (28) with the exception that for total alkalinity a methyl purple indicator was utilized instead of the prescribed methyl orange indicator. Total solids determinations technique was as prescribed in Standard Methods (28) and the solids concentration was reported as milligrams per liter. Analyses for pH were determined with a Corning pH meter, Model 7. The meter

TABLE 1A

Typical Specification for Catfloc\* Used in Laboratory Study

<u>Property</u>	<u>Typical Value</u>
Ionic Nature	Cationic
Appearance	Liquid
Solubility	Soluble in all portions
Specific gravity @ 25° C.	1.025 Avg.
Viscosity	2000 cps @ 25° C. max.
pH	3.5 ± 0.5
Flash Point	> 200° F.
Freeze Point	27° F.

\*Manufactured by Calgon Corporation, Pittsburg, PA.

TABLE 1B

Typical Specification for Hercofloc 812\* Used in Laboratory Study

<u>Property</u>	<u>Typical Value</u>
Ionic Character	Cationic
Appearance	White Powder
Bulk Density, g/ml	0.7
Particle Size	25 - 30 (A)**
Moisture (% as packed)	12
pH - 1% H <sub>2</sub> O Solution	6.0
Viscosity - 1% Solution	780 cps @ 25° C.

\*Manufactured by Hercules, Incorporated, Wilmington, Delaware.

\*\*Maximum 25-35% through 200 mesh.

TABLE 2

Analysis of Raw Water Used in Laboratory Studies\*

<u>Parameter</u>	<u>Water Source</u>		
	Duck Pond	Maury River	New River
pH	7.9	8.2	7.7
Total Hardness, mg/l CaCO <sub>3</sub>	178	132	49
Total Alkalinity, mg/l CaCO <sub>3</sub>	154	125	45
Total Solids, mg/l	311	170	89
Turbidity, NTU	29	2.7	7.9

\*Representative of average values of all raw water analyses performed for specific water source.

readings were recorded as pH units. The pH meter was calibrated daily using a pH of  $7.0 \pm 0.02$  buffer solution commercially prepared by the Fischer Scientific Company.

#### IV. EXPERIMENTAL RESULTS

The laboratory jar test studies were conducted in three phases. Phase One represented analysis of the raw water collected from the VPI & SU Duck Pond, Phase Two analysis of water collected from the Maury River, and Phase Three analysis of water collected from the New River. Of particular interest to this study was the effect on turbidity removal which variations in the coagulation-filtration-sedimentation treatment process and variations in chemical dosages would produce in waters of differing quality.

##### Phase One - Duck Pond Results

The raw water for this phase was collected on June 22, 1977 following a period of mild rain. As indicated in Table 2, analysis of raw water characteristics shows a high turbidity water which contains considerable hardness. In Figures 4, 5, and 6, turbidity removal efficiency for aluminum sulfate, aluminum sulfate plus Hercofloc 812, and Catfloc is shown as a function of the coagulant dosage for each treatment process variation. Variations in total alkalinity, total hardness, pH, and total solids for the predetermined quantities of coagulant added in each treatment process are summarized in Tables 3 through 11. The raw water characteristics for each treatment process are summarized in Table 31.

In addition to the previously listed analyses, water from the Duck Pond was utilized to estimate the sludge volume and total solids concen-

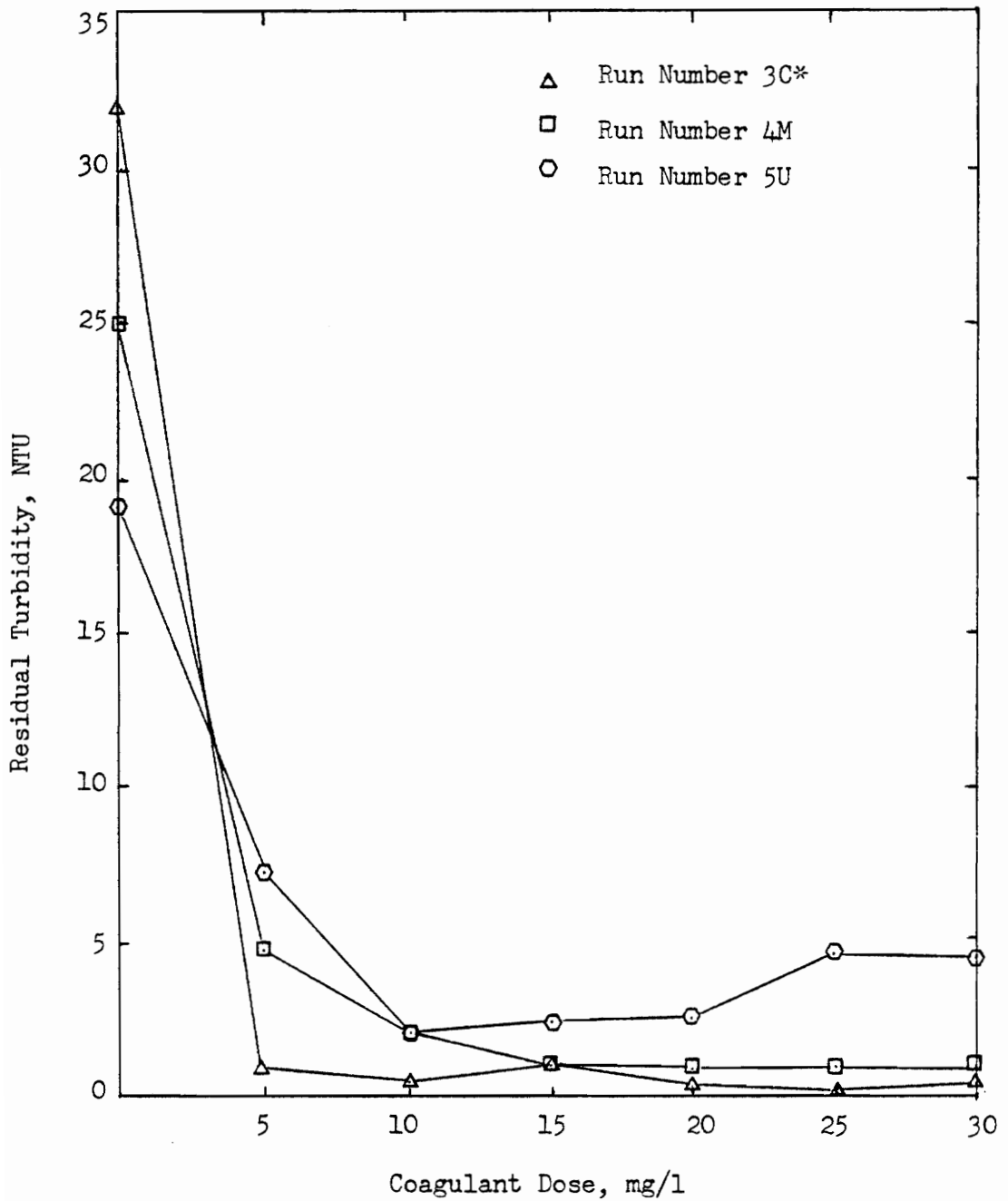


Figure 4 Residual Turbidity of Duck Pond Water Following Treatment With Aluminum Sulfate

\*Run Numbers Correspond to Tables in Appendix

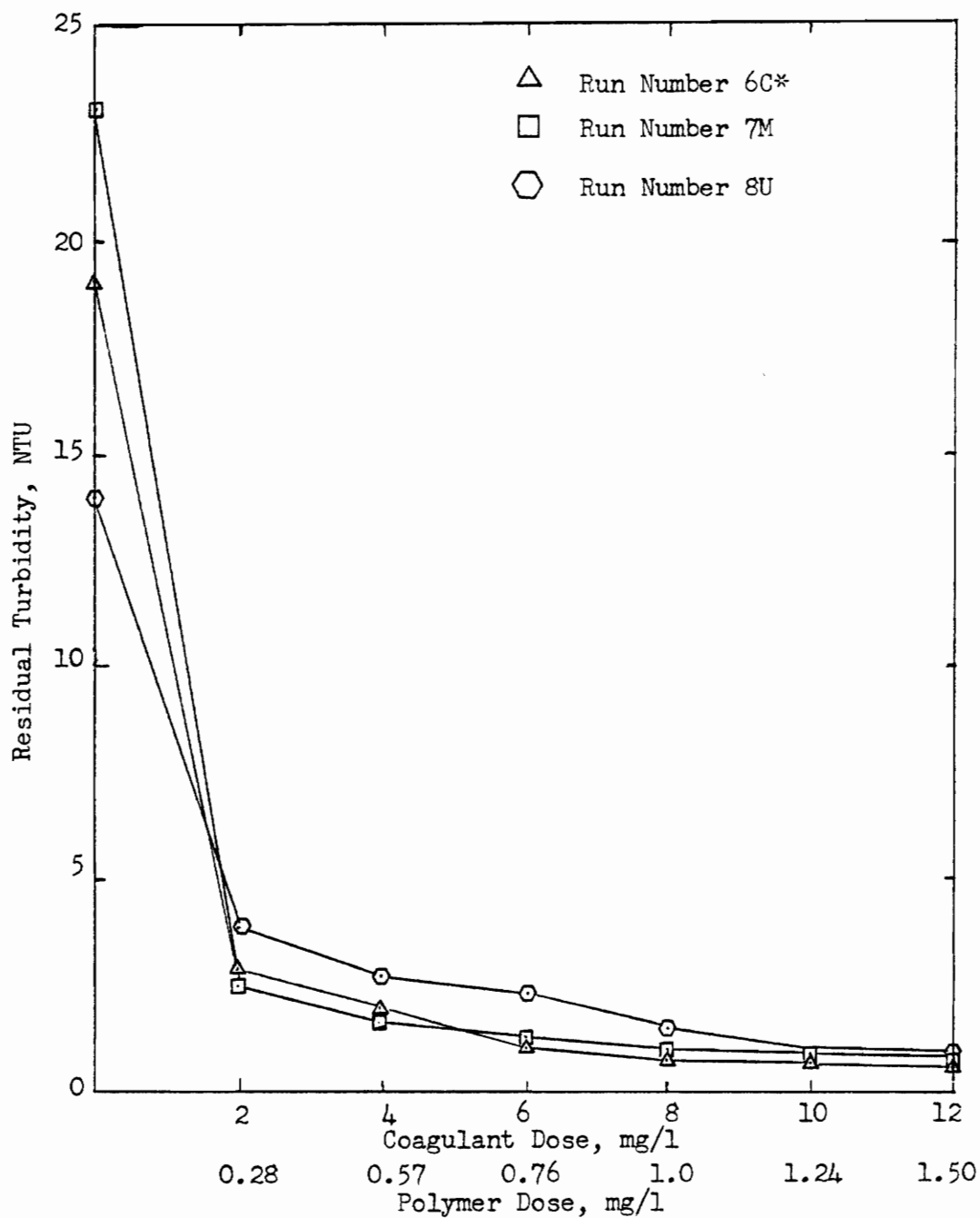


Figure 5 Residual Turbidity of Duck Pond Water Following Treatment With Aluminum Sulfate and Hercofloc 812

\*Run Numbers Correspond to Tables in Appendix

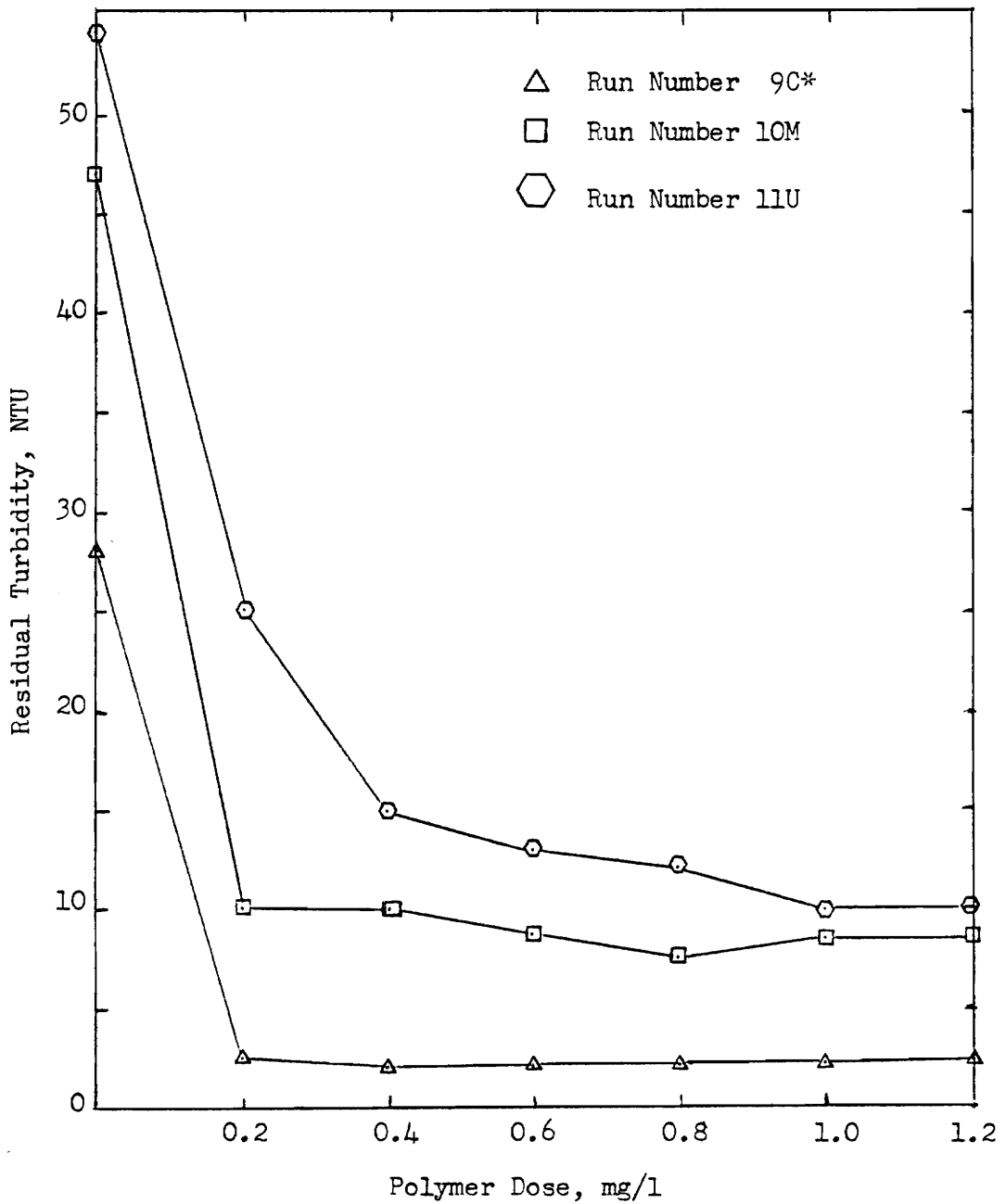


Figure 6 Residual Turbidity of Duck Pond Water Following Treatment With Catfloc

\*Run Numbers Correspond to Tables in Appendix

tration of the sludge when the optimum dosages of aluminum sulfate and Catfloc were utilized in the conventional high rate treatment scheme. These data are shown in Table 12.

#### Phase Two - Maury River Results

Raw water for this phase was collected on June 29, 1977 from the raw water intake of Maury Service Authority water treatment plant in Lexington, Virginia. As indicated by Table 2, analysis of the raw water characteristics shows a low turbidity water which is quite similar in terms of alkalinity and hardness to that of the Duck Pond. In Figures 7, 8, and 9, turbidity removal efficiency for aluminum sulfate, aluminum sulfate plus Hercofloc 812, and Catfloc is shown as a function of the coagulant dosage utilized in each treatment process. Tables 13 through 21 summarize the variations in total alkalinity, total hardness, pH, and total solids produced by the variations in the quantities of coagulant added during each treatment process. Raw water characteristics for each treatment process are summarized in Table 32.

#### Phase Three - New River Results

Raw water for this phase was collected on July 4, 1977 from the raw water sampling pump of the Blacksburg-Christiansburg-VPI Water Authority water treatment plant located in Montgomery County, Virginia, during a relatively dry period. As indicated by the analysis shown in Table 2, the raw water characteristics indicate a low turbidity, and low alkalinity water which is quite dissimilar to that of either the Duck Pond or Maury River. In Figures 10, 11, and 12, turbidity removal efficiency for aluminum sulfate, aluminum sulfate plus Hercofloc 812, and Catfloc is shown as a function of the coagulant dosage utilized in each treatment

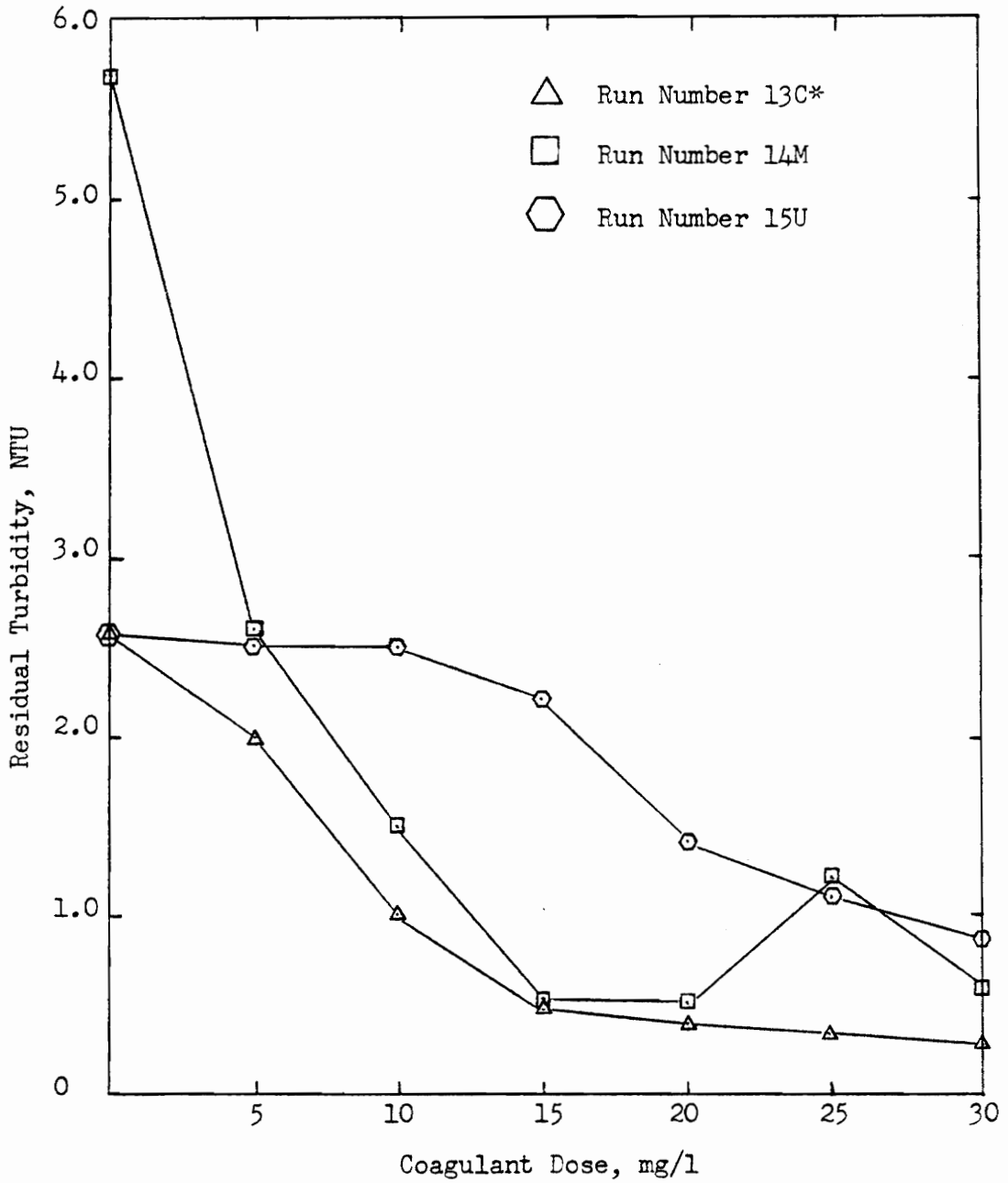


Figure 7 Residual Turbidity of Maury River Water Following Treatment With Aluminum Sulfate

\*Run Numbers Correspond to Tables in Appendix

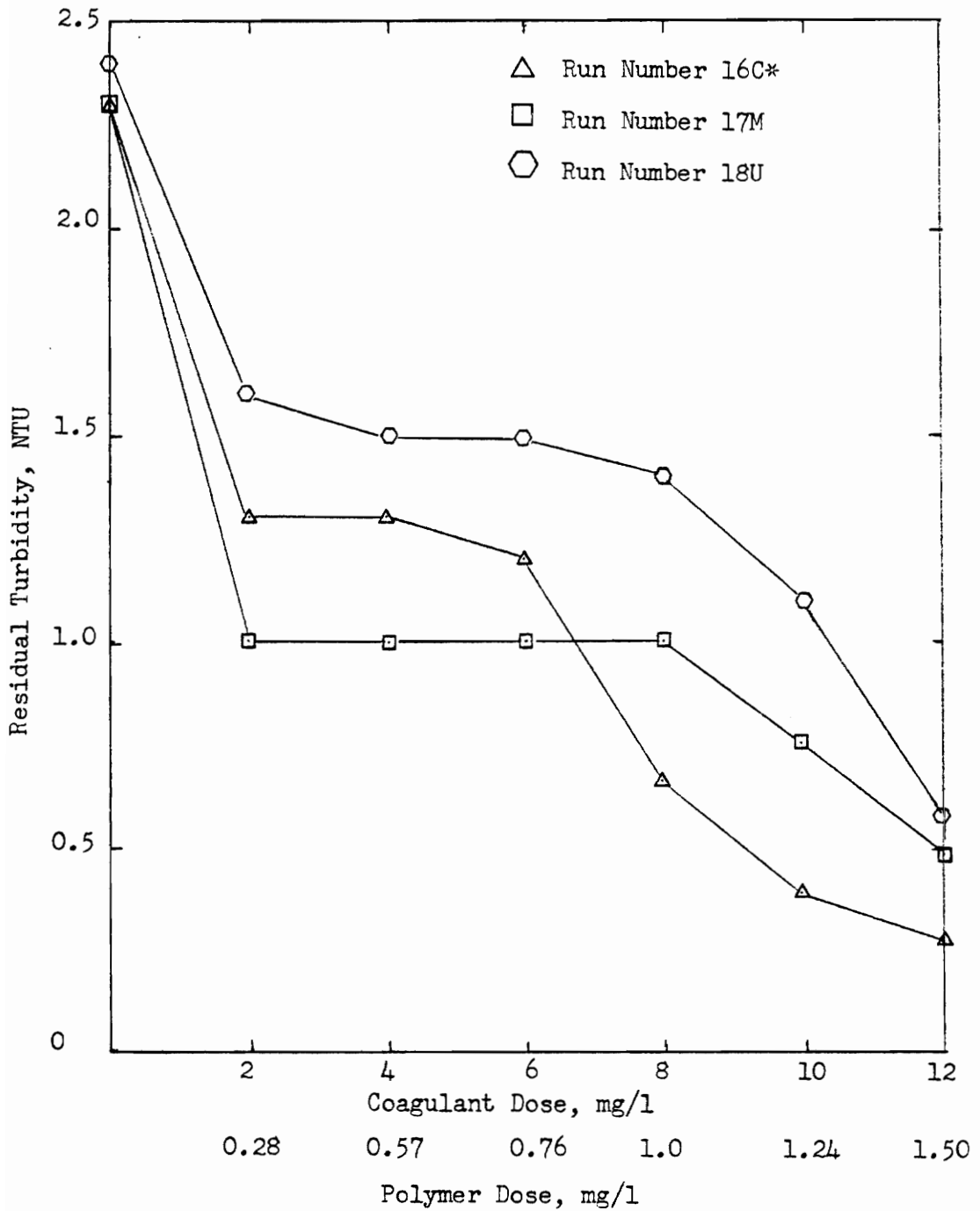


Figure 8 Residual Turbidity of Maury River Water Following Treatment With Aluminum Sulfate and Hercofloc 812

\*Run Numbers Correspond to Tables in Appendix

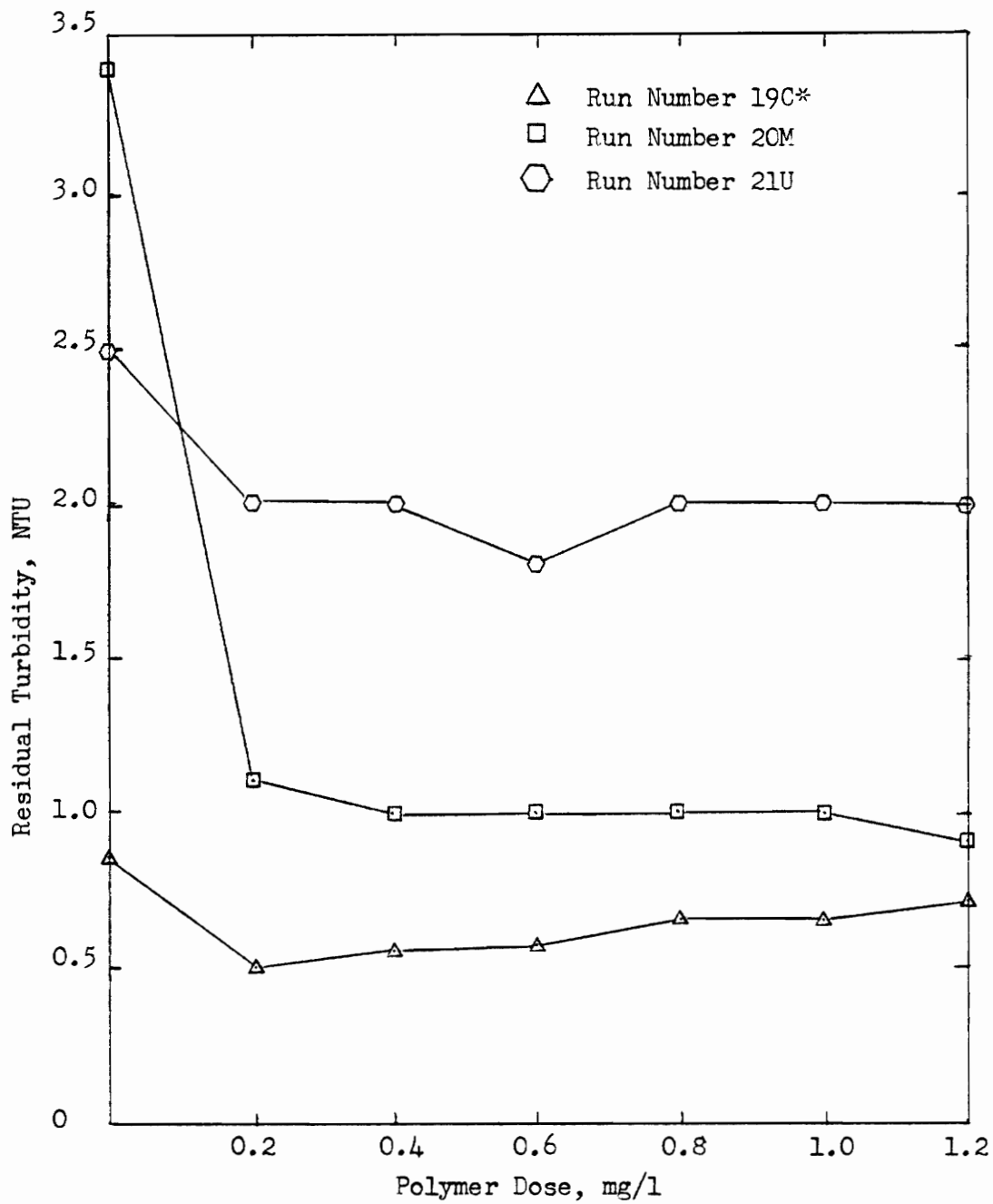


Figure 9 Residual Turbidity of Maury River Water Following Treatment with Catfloc

\*Run Numbers Correspond to Tables in Appendix

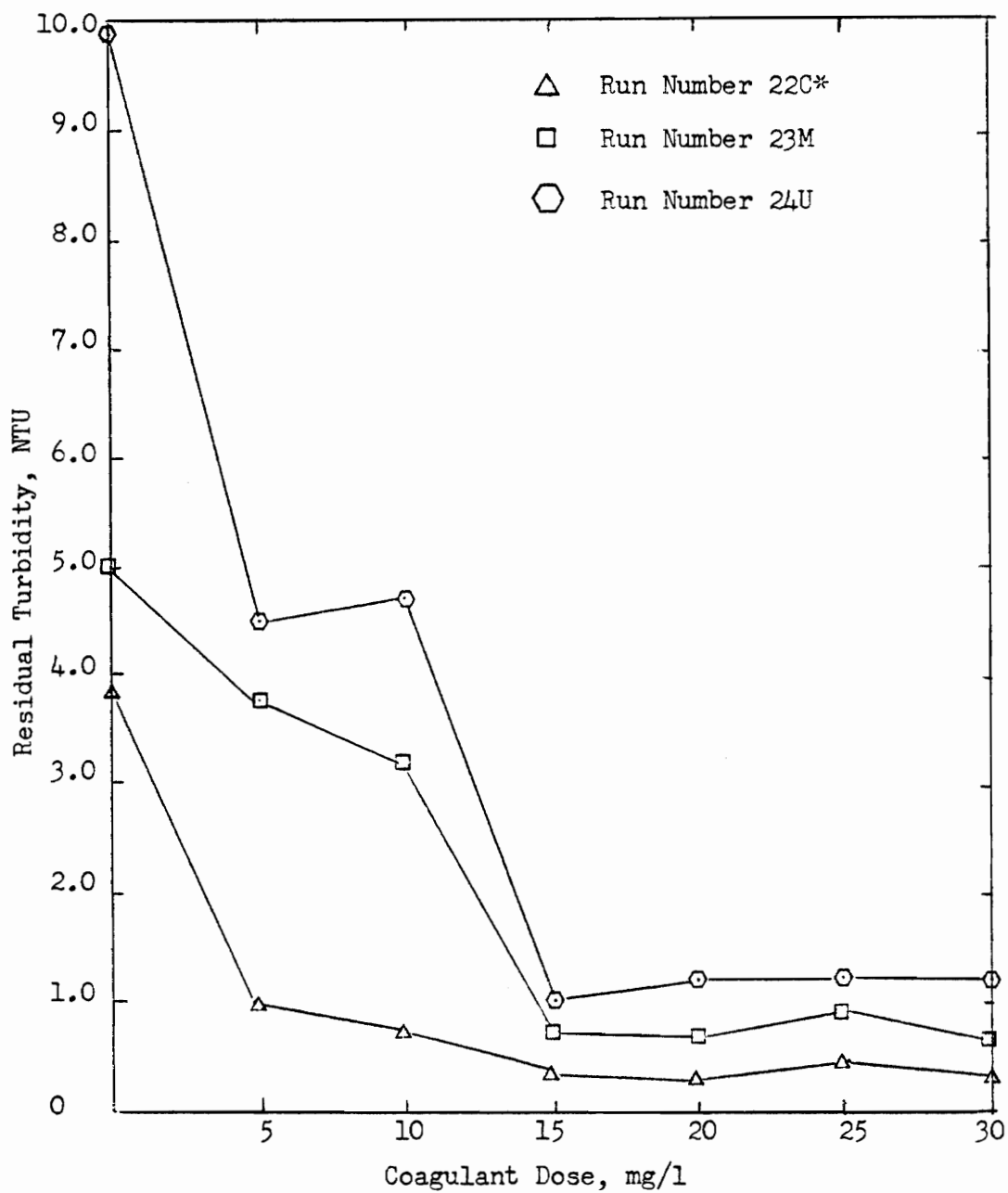


Figure 10 Residual Turbidity of New River Water Following Treatment with Aluminum Sulfate

\*Run Numbers Correspond to Tables in Appendix

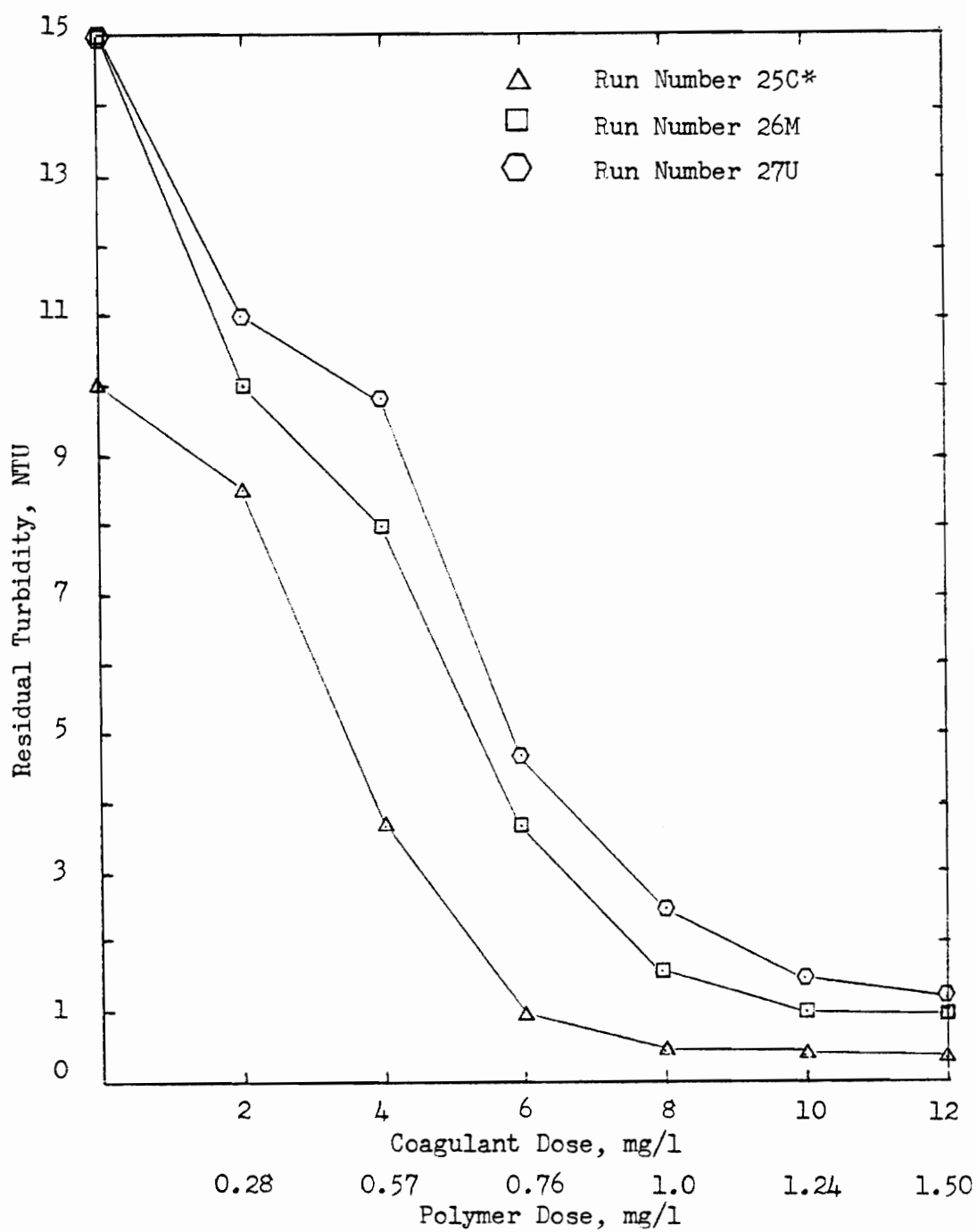


Figure 11 Residual Turbidity of New River Water Following Treatment with Aluminum Sulfate and Hercofloc 812

\*Run Numbers Correspond to Tables in Appendix

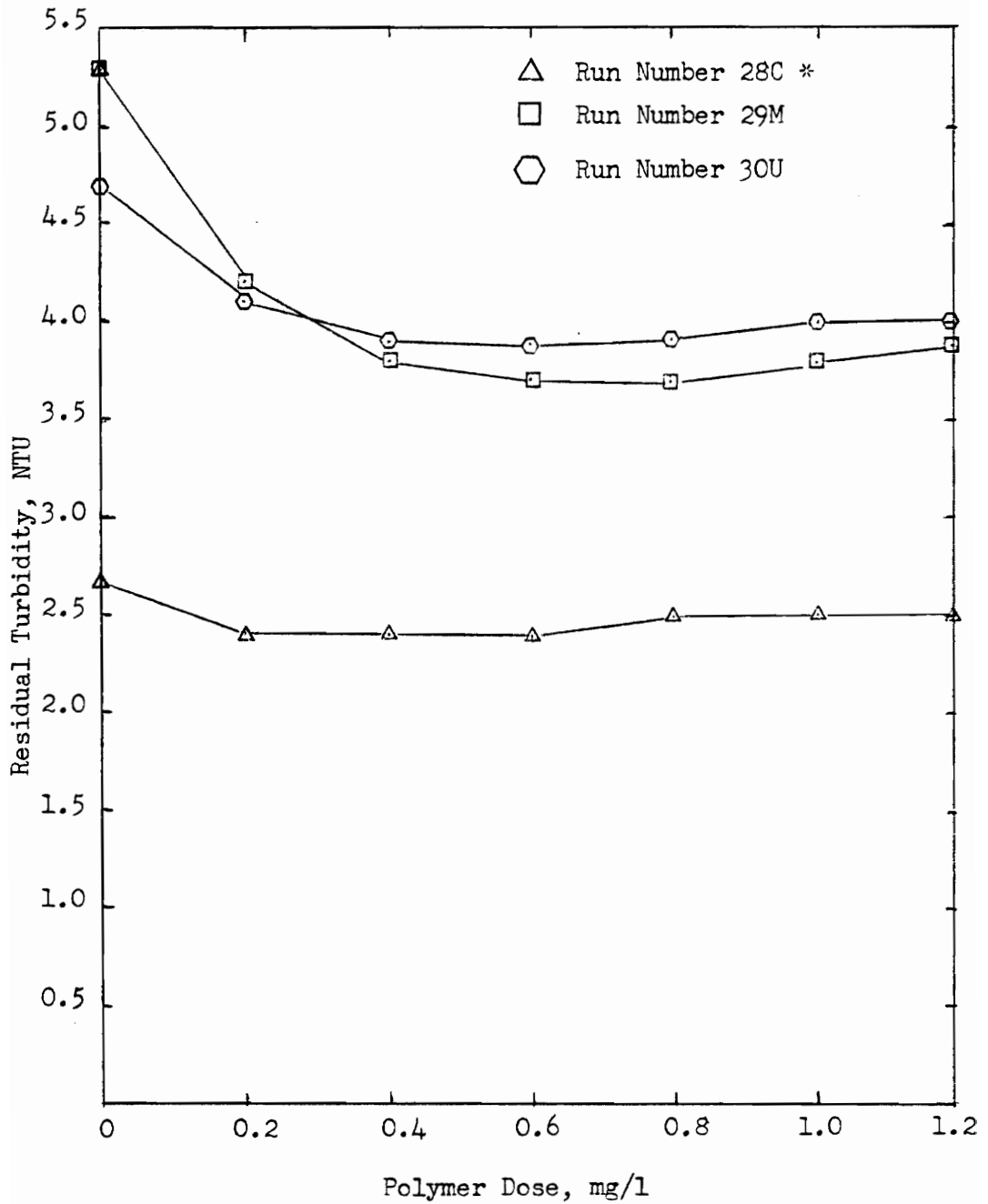


Figure 12 Residual Turbidity for New River Water Following Treatment with Catfloc

\*Run Numbers Correspond to Tables in Appendix

process. Tables 22 through 30 summarize the variations in total alkalinity, total hardness, pH, and total solids experienced for the predetermined coagulant dosages utilized in each treatment process. Table 33 summarizes the raw water characteristics for each treatment process.

## V. DISCUSSION OF RESULTS

The previously described results indicate the effects of process variables such as raw water quality, treatment scheme, and coagulant selected on the efficiency of selected pre-filtration processes in water treatment. Of the process variables evaluated for each treatment scheme, the raw water turbidity appeared to be the most significant. The treatment variations, as defined in Section III, included conventional high rate (C), modified high rate (M), and ultra high rate (U) treatment schemes. The conventional treatment scheme included a two-minute rapid mix period followed by a 30 minute flocculation period and a 60 minute sedimentation period. Modified high rate treatment included the rapid mix period but reduced the flocculation and sedimentation periods to 10 and 20 minutes, respectively. The ultra high rate treatment included the rapid mix period and retained the 10 minute flocculation period but further reduced the sedimentation period to 5 minutes.

Figures 4, 7, and 10 show turbidity removal for the Duck Pond, Maury River, and New River water, respectively, with increasing aluminum sulfate dosage. As indicated by these figures, the optimum coagulant dosage in each case appears to be in the range of 10-15 mg/l. Also shown in these figures is that as the flocculation and sedimentation periods are decreased in each treatment process the residual turbidity tends to show a small increase. This small increase is attributable to a higher percentage of floc remaining in suspension during reduced

sedimentation periods. Of considerable significance is that while the conventional treatment process employs extended flocculation and sedimentation periods, the use of the shortened periods in the modified and ultra high rate schemes did not result in any significant increase in residual turbidity. Thus, it would appear that the solids concentrations delivered to the filter would be approximately equal regardless of treatment scheme employed. Figures 4 and 10 indicate that once the optimum coagulant dosage is reached, turbidity removal remains relatively constant with increasing coagulant dosage.

Analysis of Tables 3, 4, 5, 13, 14, 15, 22, 23, 24, 31, 32, and 33 shows that the alkalinity destruction is on the order of approximately 0.5 mg/l as  $\text{CaCO}_3$  destroyed per 1.0 mg/l alum added and that the pH depressing characteristic of aluminum sulfate was exhibited in all cases. Total hardness and total solids concentrations tended to remain relatively constant for each treatment process.

Figures 5, 8, and 11 show the extent of turbidity removal for Duck Pond, Maury River, and New River water, respectively, treated with increasing aluminum sulfate and Hercofloc 812 dosages. Figures 5 and 8 indicate that when the polymer was used in conjunction with the aluminum sulfate, coagulant dosages required to obtain comparable turbidity reductions were substantially less than when only aluminum sulfate was utilized. However, Figure 11 shows that for the moderately turbid New River water, the required polymer and coagulant dosages approached the optimum dosage required using aluminum sulfate alone. As noted

previously, the decrease in the flocculation and sedimentation periods did not result in any significant increase in residual turbidity, regardless of the coagulant or treatment scheme employed. In fact, comparison of aluminum sulfate data and the aluminum sulfate and Hercofloc 812 data appears to indicate that the coagulant aid itself was responsible for a decrease in residual turbidity in the systems in which it was utilized. This decrease may be attributed to more retention of particulate matter in the floc using a coagulant aid as opposed to only aluminum sulfate.

Analysis of Tables 6, 7, 8, 16, 17, 18, 25, 26, 27, 31, 32, and 33 shows that in addition to the alkalinity destruction effect previously noted for the system using alum alone, the total hardness and total solids concentrations tended to remain relatively constant, although the total solids did exhibit a slight overall decrease from the initial values.

Figures 6, 9, and 12 show the extent of turbidity removal for Duck Pond, Maury River, and New River water, respectively, with increasing Catfloc dosage. Figure 6 indicates that when a relatively high turbidity water is used large turbidity reductions are experienced, while Figures 9 and 12 indicate that the utilization of lower turbidity waters results in some turbidity reduction but it is not as appreciable as that noted for waters with higher initial turbidity. Figures 6 and 12 indicate further that the residual turbidity levels noted for the conventional high rate treatment and modified and ultra high rate treatment schemes differ considerably. The large variations among the treatment processes employed is significant because it seems to indicate

that the effectiveness of the polyelectrolyte used is dependent on the length of the flocculation period as well as the intensity of the rapid mixing provided.

Analysis of Tables 9, 10, 11, 19, 20, 21, 28, 29, 30, 31, 32, and 33 shows that the alkalinity destruction for systems using a polyelectrolyte as primary coagulant is approximately one-third of that experienced when aluminum sulfate was employed and that the pH had a tendency to increase approximately 0.1 to 0.2 units with the use of the polymer alone. Total hardness and total solids concentrations remained relatively constant, although the total solids did exhibit a slight overall reduction with increasing polymer dosage.

Since the direct filtration process is designed to make optimal use of the filter, the key parameter in evaluating the applicability of the aluminum sulfate and polymers utilized in the laboratory study is the size and quality of floc produced. The direct filtration process requires a strong pinpoint floc which is just barely visible. Comparison of the data shown in the figures and summarized in the tables with observations during the experimental period indicated that while the aluminum sulfate yielded substantial turbidity reductions, the floc formed was rather large in nature and required considerably longer flocculation and sedimentation periods than the polymer treated waters. When aluminum sulfate was used in conjunction with Hercofloc 812 and Catfloc was employed alone it was observed that the floc formed in low turbidity waters was generally pinpoint in nature and tended to remain in suspension. High turbidity waters treated with Catfloc and Hercofloc 812 exhibited a tendency to form a large clumpy floc which generally

settled within 10 to 15 minutes. Thus, sedimentation was essentially effected by the end of the flocculation period.

Of considerable importance in the evaluation of floc characteristics is the volume and weight of sludge produced by settling of the floc formed. Table 12, while not being indicative of a low turbidity water, does give some indication of the sludge characteristics of a high turbidity water treated with aluminum sulfate and Catfloc. The significance of these data is that for ultimate sludge volumes of 5 and 6 mls, respectively, the total solids concentrations were 4485 and 5432 mg/l, respectively. Therefore, the indication is that the polymer used as a primary coagulant tends to produce a heavier and more rapidly settling floc than does aluminum sulfate and that a smaller thickener would be required in the polymer system.

## VI. CONCLUSIONS

1. When aluminum sulfate or aluminum sulfate with polymer were used the modified and ultra high rate treatment processes were comparable to the conventional process in pretreating water for filtration.
2. When polyelectrolyte was used as a primary coagulant the conventional treatment scheme appeared to produce superior results than either the modified or ultra high rate treatment systems.
3. When polyelectrolytes were utilized as either primary coagulants or coagulant aids the chemical dosage required to produce significant turbidity removals were considerably less than aluminum sulfate dosages required to produce comparable results.
4. When aluminum sulfate was utilized alone or with a coagulant aid alkalinity destruction was on the order of 0.5 mg/l alkalinity as  $\text{CaCO}_3$  destroyed per 1.0 mg/l aluminum sulfate added.
5. Utilization of polyelectrolytes as a primary coagulant tended to raise the pH of the sample by 0.1 to 0.2 units in most cases.

6. Raw water treated with the polyelectrolyte, either as a primary coagulant or coagulant aid, tended to form a pin-point floc which settled more rapidly than did the floc formed from use of alum alone.

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VIII. APPENDIX

TABLE 3  
 Conventional High Rate Treatment Data Summary of  
 Duck Pond Water Treated With Aluminum Sulfate

Parameter	J A R N U M B E R					
	1	2	3	4	5	6
Coagulant Dose, mg/l	5	10	15	20	25	30
Polymer Dose, mg/l						
pH	7.45	7.35	7.2	7.1	7.1	6.9
Total Alkalinity, mg/l CaCO <sub>3</sub>	139	138	135	135	133	133
Total Hardness, mg/l CaCO <sub>3</sub>	166	167	170	168	170	172
Total Solids, mg/l	243	240	247	251	255	274
Turbidity, NTU	1.0	0.43	1.0	0.28	0.23	0.29

TABLE 4  
 Modified High Rate Treatment Data Summary of  
 Duck Pond Water Treated With Aluminum Sulfate

Parameter	J A R N U M B E R					
	1	2	3	4	5	6
Coagulant Dose, mg/l	5	10	15	20	25	30
Polymer Dose, mg/l						
pH	7.6	7.5	7.4	7.3	7.3	6.9
Total Alkalinity, mg/l CaCO <sub>3</sub>	142	142	137	135	135	128
Total Hardness, mg/l CaCO <sub>3</sub>	170	170	172	168	172	169
Total Solids, mg/l	280	239	276	267	260	277
Turbidity NTU	4.8	1.9	1.0	0.88	1.0	0.89

TABLE 5  
 Ultra High Rate Treatment Data Summary of  
 Duck Pond Water Treated With Aluminum Sulfate

Parameter	J A R N U M B E R					
	1	2	3	4	5	6
Coagulant Dose, mg/l	5	10	15	20	25	30
Polymer Dose, mg/l	7.9	7.7	7.75	7.6	7.55	7.5
pH	7.9	7.7	7.75	7.6	7.55	7.5
Total Alkalinity, mg/l CaCO <sub>3</sub>	141	137	135	133	132	131
Total Hardness, mg/l CaCO <sub>3</sub>	172	168	174	172	166	166
Total Solids, mg/l	282	271	95	290	233	271
Turbidity, NTU	7.3	2.1	2.4	2.5	4.6	4.5

TABLE 6

Conventional High Rate Treatment Data Summary of  
Duck Pond Water Treated With Aluminum Sulfate and Hercofloc 812

Parameter	J A R N U M B E R					
	1	2	3	4	5	6
Coagulant Dose, mg/l	2	4	6	8	10	12
Polymer Dose, mg/l	0.28	0.57	0.76	1.0	1.24	1.50
pH	7.9	7.8	7.7	7.7	7.6	7.6
Total Alkalinity, mg/l CaCO <sub>3</sub>	142	141	139	140	138	138
Total Hardness, mg/l CaCO <sub>3</sub>	170	167	168	168	166	168
Total Solids, mg/l	257	267	279	281	280	289
Turbidity, NTU	2.8	2.0	0.99	0.65	0.6	0.44

TABLE 7  
 Modified High Rate Treatment Data Summary of  
 Duck Pond Water Treated With Aluminum Sulfate and Hercofloc 812

Parameter	J A R N U M B E R					
	1	2	3	4	5	6
Coagulant Dose, mg/l	2	4	6	8	10	12
Polymer Dose, mg/l	0.28	0.57	0.76	1.0	1.24	1.50
pH	7.8	7.9	7.7	7.7	7.65	7.6
Total Alkalinity, mg/l CaCO <sub>3</sub>	143	139	140	139	139	137
Total Hardness, mg/l CaCO <sub>3</sub>	171	174	169	166	170	166
Total Solids, mg/l	246	252	249	234	255	269
Turbidity, NTU	2.5	1.6	1.1	0.91	0.73	0.6

TABLE 8  
 Ultra High Rate Treatment Data Summary of Duck  
 Pond Water Treated With Aluminum Sulfate and Hercofloc 812

Parameter	J A R N U M B E R					
	1	2	3	4	5	6
Coagulant Dose, mg/l	2	4	6	8	10	12
Polymer Dose, mg/l	0.28	0.57	0.76	1.0	1.24	1.50
pH	7.9	7.75	7.75	7.7	7.65	7.6
Total Alkalinity, mg/l CaCO <sub>3</sub>	138	140	142	140	139	140
Total Hardness, mg/l CaCO <sub>3</sub>	164	170	170	170	166	168
Total Solids, mg/l	281	275	282	284	291	302
Turbidity, NTU	3.9	2.7	2.3	1.4	0.8	0.7

TABLE 9  
 Conventional High Rate Treatment Data Summary of  
 Duck Pond Water Treated With Catfloc

Parameter	J A R N U M B E R					
	1	2	3	4	5	6
Coagulant Dose, mg/l	0.2	0.4	0.6	0.8	1.0	1.2
Polymer Dose, mg/l	8.0	8.0	8.1	8.1	8.1	8.1
pH	143	142	142	143	143	142
Total Alkalinity, mg/l CaCO <sub>3</sub>	164	164	166	170	168	162
Total Hardness, mg/l CaCO <sub>3</sub>	225	227	241	258	240	236
Turbidity, NTU	2.3	2.1	2.1	2.2	2.2	2.5

TABLE 10  
 Modified High Rate Treatment Data Summary of  
 Duck Pond Water Treated With Catfloc

Parameter	J A R N U M B E R					
	1	2	3	4	5	6
Coagulant Dose, mg/l	0.2	0.4	0.6	0.8	1.0	1.2
Polymer Dose, mg/l	7.7	7.8	7.7	7.8	7.8	7.8
pH	180	180	182	182	181	181
Total Alkalinity, mg/l CaCO <sub>3</sub>	200	198	196	202	200	204
Total Hardness, mg/l CaCO <sub>3</sub>		297	291	299	315	300
Turbidity, NTU	10	10	8.6	7.5	8.5	8.4

TABLE 11  
 Ultra High Rate Treatment Data Summary of  
 Duck Pond Water Treated With Catfloc

Parameter	J A R N U M B E R					
	1	2	3	4	5	6
Coagulant Dose, mg/l	0.2	0.4	0.6	0.8	1.0	1.2
Polymer Dose, mg/l	7.8	7.8	7.8	7.8	7.8	7.9
pH	184	181	182	182	183	183
Total Alkalinity, mg/l CaCO <sub>3</sub>	198	196	194	196	200	196
Total Hardness, mg/l CaCO <sub>3</sub>	363	344	335	329	323	333
Turbidity, NTU	25	15	13	12	10	10

TABLE 12  
 Comparison of Sludge Volume and Total Solids  
 Concentration of Duck Pond Water Treated with  
 Aluminum Sulfate and Catfloc

Parameter	@ C O A G U L A N T	
	Alum	Catfloc
Coagulant Dosage, mg/l	15.0	1.0
Initial Sample Volume, l	6.0	6.0
Raw Water Turbidity, NTU	60	60
Residual Turbidity, NTU	22	34
Total Solids Concentration, mg/l	4485	5423
Sludge Volume, mls	5	6
Sludge Volume, % of initial volume	0.08	0.10

TABLE 13  
 Conventional High Rate Treatment Data Summary of  
 Maury River Water Treated With Aluminum Sulfate

Parameter	J A R N U M B E R					
	1	2	3	4	5	6
Coagulant Dose, mg/l	5	10	15	20	25	30
Polymer Dose, mg/l						
pH	7.9	7.8	7.65	7.6	7.6	7.5
Total Alkalinity, mg/l CaCO <sub>3</sub>	124	119	118	117	114	111
Total Hardness, mg/l CaCO <sub>3</sub>	134	136	134	132	132	134
Total Solids, mg/l	169	186	175	156	177	187
Turbidity, NTU	2.0	1.0	0.47	0.40	0.34	0.29

TABLE 14  
 Modified High Rate Treatment Data Summary of  
 Maury River Water Treated With Aluminum Sulfate

Parameter	J A R N U M B E R					
	1	2	3	4	5	6
Coagulant Dose, mg/l	5	10	15	20	25	30
Polymer Dose, mg/l	8.1	7.9	7.8	7.7	7.6	7.5
pH	123	121	118	116	114	110
Total Alkalinity, mg/l CaCO <sub>3</sub>	129	129	124	130	128	128
Total Hardness, mg/l CaCO <sub>3</sub>	511	188	197	197	201	215
Turbidity, NTU	2.6	1.5	0.54	0.52	1.2	0.58

TABLE 15  
 Ultra High Rate Treatment Data Summary of  
 Maury River Water Treated With Aluminum Sulfate

Parameter	J A R N U M B E R					
	1	2	3	4	5	6
Coagulant Dose, mg/l	5	10	15	20	25	30
Polymer Dose, mg/l						
pH	7.9	7.8	7.7	7.6	7.5	7.4
Total Alkalinity, mg/l CaCO <sub>3</sub>	121	119	118	119	115	111
Total Hardness, mg/l CaCO <sub>3</sub>	132	130	128	132	134	136
Total Solids, mg/l	132	171	131	141	141	139
Turbidity, NTU	2.5	2.5	2.2	1.4	1.1	0.87

TABLE 16  
 Conventional High Rate Treatment Data Summary of  
 Maury River Water Treated With Aluminum Sulfate and Hercofloc 812

Parameter	J A R N U M B E R					
	1	2	3	4	5	6
Coagulant Dose, mg/l	2	4	6	8	10	12
Polymer Dose, mg/l	0.28	0.57	0.76	1.0	1.24	1.50
pH	8.2	8.1	8.0	7.9	7.9	7.9
Total Alkalinity, mg/l CaCO <sub>3</sub>	124	123	122	117	119	116
Total Hardness, mg/l CaCO <sub>3</sub>	134	132	132	134	132	132
Total Solids, mg/l	141	142	142	150	147	146
Turbidity, NTU	1.3	1.3	1.2	0.66	0.38	0.27

TABLE 17

Modified High Rate Treatment Data Summary of

Maury River Water Treated With Aluminum Sulfate and Hercofloc 812

Parameter	J A R N U M B E R					
	1	2	3	4	5	6
Coagulant Dose, mg/l	2	4	6	8	10	12
Polymer Dose, mg/l	0.28	0.57	0.76	1.0	1.24	1.50
pH	8.1	8.0	7.8	7.7	7.6	7.8
Total Alkalinity, mg/l CaCO <sub>3</sub>	125	122	123	121	120	118
Total Hardness, mg/l CaCO <sub>3</sub>	130	132	134	132	132	134
Total Solids, mg/l	169	166	170	158	154	174
Turbidity, NTU	1.0	1.0	1.0	1.0	0.75	0.49

TABLE 18  
 Ultra High Rate Treatment Data Summary of  
 Maury River Water Treated With Aluminum Sulfate and Hercofloc 812

Parameter	J A R N U M B E R					
	1	2	3	4	5	6
Coagulant Dose, mg/l	2	4	6	8	10	12
Polymer Dose, mg/l	0.28	0.57	0.76	1.0	1.24	1.50
pH	8.15	8.1	8.0	7.9	7.9	7.8
Total Alkalinity, mg/l CaCO <sub>3</sub>	122	122	119	121	117	119
Total Hardness, mg/l CaCO <sub>3</sub>	132	134	134	134	130	132
Total Solids, mg/l	170	171	181	178	181	190
Turbidity, NTU	1.6	1.5	1.5	1.4	1.1	0.58

TABLE 19

Conventional High Rate Treatment Data Summary of  
Maury River Water Treated With Catfloc

Parameter	J A R N U M B E R					
	1	2	3	4	5	6
Coagulant Dose, mg/l	0.2	0.4	0.6	0.8	1.0	1.2
Polymer Dose, mg/l	8.1	8.15	8.1	8.15	8.15	8.2
pH						
Total Alkalinity, mg/l CaCO <sub>3</sub>	125	124	123	122	122	123
Total Hardness, mg/l CaCO <sub>3</sub>	136	130	130	130	130	132
Total Solids, mg/l	195	217	208	196	207	216
Turbidity, NTU	0.50	0.55	0.57	0.65	0.65	0.70

TABLE 20

Modified High Rate Treatment Data Summary of  
Maury River Water Treated With Catfloc

Parameter	J A R N U M B E R					
	1	2	3	4	5	6
Coagulant Dose, mg/l	0.2	0.4	0.6	0.8	1.0	1.2
Polymer Dose, mg/l	8.2	8.2	8.2	8.3	8.3	8.3
pH						
Total Alkalinity, mg/l CaCO <sub>3</sub>	125	125	126	124	124	123
Total Hardness, mg/l CaCO <sub>3</sub>	132	132	132	132	130	132
Total Solids, mg/l	177	168	169	162	174	158
Turbidity, NTU	1.1	1.0	1.0	1.0	1.0	0.9

TABLE 21

Ultra High Rate Treatment Data Summary of  
Maury River Water Treated With Catfloc

Parameter	J A R N U M B E R					
	1	2	3	4	5	6
Coagulant Dose, mg/l	0.2	0.4	0.6	0.8	1.0	1.2
Polymer Dose, mg/l	8.35	8.4	8.4	8.4	8.4	8.4
pH	127	127	128	127	127	128
Total Alkalinity, mg/l CaCO <sub>3</sub>	136	134	136	136	136	136
Total Hardness, mg/l CaCO <sub>3</sub>	140	150	137	124	137	142
Total Solids, mg/l	2.0	2.0	1.8	2.0	2.0	2.0
Turbidity, NTU						

TABLE 22  
 Conventional High Rate Treatment Data Summary of  
 New River Water Treated With Aluminum Sulfate

Parameter	J A R N U M B E R					
	1	2	3	4	5	6
Coagulant Dose, mg/l	5	10	15	20	25	30
Polymer Dose, mg/l	7.6	7.4	7.3	7.2	7.0	7.0
pH	42	40	37	35	31	30
Total Alkalinity, mg/l CaCO <sub>3</sub>	46	50	48	46	46	48
Total Hardness, mg/l CaCO <sub>3</sub>	115	140	106	112	108	117
Turbidity, NTU	0.98	0.75	0.35	0.28	0.45	0.26

TABLE 23  
 Modified High Rate Treatment Data Summary of  
 New River Water Treated With Aluminum Sulfate

Parameter	J A R N U M B E R					
	1	2	3	4	5	6
Coagulant Dose, mg/l	5	10	15	20	25	30
Polymer Dose, mg/l						
pH	7.5	7.4	7.3	7.2	7.1	7.0
Total Alkalinity, mg/l CaCO <sub>3</sub>	42	41	39	36	34	31
Total Hardness, mg/l CaCO <sub>3</sub>	50	48	48	48	48	50
Total Solids, mg/l	66	80	88	65	75	66
Turbidity, NTU	3.8	3.2	0.72	0.68	0.85	0.65

TABLE 24  
 Ultra High Rate Treatment Data Summary of  
 New River Water Treated With Aluminum Sulfate

Parameter	J A R N U M B E R					
	1	2	3	4	5	6
Coagulant Dose, mg/l	5	10	15	20	25	30
Polymer Dose, mg/l	7.5	7.4	7.2	7.1	6.9	6.9
pH	44	41	40	39	36	32
Total Alkalinity, mg/l CaCO <sub>3</sub>	48	48	48	48	48	46
Total Hardness, mg/l CaCO <sub>3</sub>	89	86	49	59	53	47
Total Solids, mg/l	4.5	4.7	1.0	0.93	1.2	1.2
Turbidity, NTU						

TABLE 25

Conventional High Rate Treatment Data Summary of  
New River Water Treated With Aluminum Sulfate and Hercofloc 812

Parameter	J A R N U M B E R					
	1	2	3	4	5	6
Coagulant Dose, mg/l	2	4	6	8	10	12
Polymer Dose, mg/l	0.28	0.57	0.76	1.0	1.24	1.50
pH	7.65	7.65	7.6	7.55	7.5	7.4
Total Alkalinity, mg/l CaCO <sub>3</sub>	45	43	44	42	41	40
Total Hardness, mg/l CaCO <sub>3</sub>	50	48	46	48	46	50
Total Solids, mg/l	98	88	89	76	95	99
Turbidity, NTU	8.5	3.7	1.0	0.46	0.38	0.27

TABLE 26  
 Modified High Rate Treatment Data Summary of  
 New River Water Treated With Aluminum Sulfate and Hercofloc 812

Parameter	J A R N U M B E R					
	1	2	3	4	5	6
Coagulant Dose, mg/l	2	4	6	8	10	12
Polymer Dose, mg/l	0.28	0.57	0.76	1.0	1.24	1.50
pH	7.7	7.6	7.5	7.5	7.4	7.3
Total Alkalinity, mg/l CaCO <sub>3</sub>	43	42	41	40	40	37
Total Hardness, mg/l CaCO <sub>3</sub>	48	48	48	44	48	46
Total Solids, mg/l	67	88	96	67	97	79
Turbidity, NTU	10	8.0	3.7	1.6	1.0	0.98

TABLE 27

Ultra High Rate Treatment Data Summary of  
New River Water Treated With Aluminum Sulfate and Hercofloc 812

Parameter	1	2	3	4	5	6
Coagulant Dose, mg/l	2	4	6	8	10	12
Polymer Dose, mg/l	0.28	0.57	0.76	1.0	1.24	1.50
pH	7.6	7.6	7.5	7.4	7.35	7.3
Total Alkalinity, mg/l CaCO <sub>3</sub>	44	44	42	41	40	38
Total Hardness, mg/l CaCO <sub>3</sub>	48	48	50	48	46	48
Total Solids, mg/l	100	86	84	72	69	73
Turbidity, NTU	11	9.8	4.7	2.5	1.5	1.2

TABLE 28

Conventional High Rate Treatment of  
New River Water Treated With Catfloc

Parameter	J A R N U M B E R					
	1	2	3	4	5	6
Coagulant Dose, mg/l	0.2	0.4	0.6	0.8	1.0	1.2
Polymer Dose, mg/l	7.8	7.8	7.8	7.8	7.8	7.8
pH	45	43	44	44	43	43
Total Alkalinity, mg/l CaCO <sub>3</sub>	50	50	48	48	48	52
Total Hardness, mg/l CaCO <sub>3</sub>	61	29	61	40	46	41
Turbidity, NTU	2.4	2.4	2.4	2.5	2.5	2.5

TABLE 29  
 Modified High Rate Treatment of  
 New River water Treated With Catfloc

Parameter	J A R N U M B E R					
	1	2	3	4	5	6
Coagulant Dose, mg/l	0.2	0.4	0.6	0.8	1.0	1.2
Polymer Dose, mg/l	7.8	7.7	7.8	7.7	7.8	7.8
pH	44	42	43	43	43	43
Total Alkalinity, mg/l CaCO <sub>3</sub>	48	48	48	50	48	48
Total Hardness, mg/l CaCO <sub>3</sub>	133	129	125	129	127	142
Turbidity, NTU	4.2	3.8	3.7	3.7	3.8	3.9

TABLE 30  
 Ultra High Rate Treatment of  
 New River Water Treated With Catfloc

Parameter	J A R N U M B E R					
	1	2	3	4	5	6
Coagulant Dose, mg/l	0.2	0.4	0.6	0.8	1.0	1.2
Polymer Dose, mg/l	7.8	7.8	7.8	7.8	7.6	7.7
pH	44	44	43	44	42	43
Total Alkalinity, mg/l CaCO <sub>3</sub>	48	48	50	48	48	48
Total Hardness, mg/l CaCO <sub>3</sub>	65	63	157	138	166	139
Turbidity, NTU	4.1	3.9	3.9	3.9	4.0	4.0

TABLE 31  
Data Summary of Duck Pond Raw Water Characteristics

Table Number	pH	Total Alkalinity mg/l CaCO <sub>3</sub>	Total Hardness mg/l CaCO <sub>3</sub>	Total Solids mg/l	Turbidity NTU
3	7.6	144	170	290	32
4	7.8	149	170	285	25
5	8.0	145	176	311	19
6	8.0	145	167	269	19
7	8.1	146	196	270	23
8	8.0	144	170	299	14
9	7.9	150	170	275	28
10	7.7	183	206	376	47
11	7.7	184	204	421	54

TABLE 32  
Data Summary of Maury River Raw Water Characteristics

Table Number	pH	Total Alkalinity mg/l CaCO <sub>3</sub>	Total Hardness mg/l CaCO <sub>3</sub>	Total Solids mg/l	Turbidity NTU
13	8.3	126	134	177	2.6
14	8.3	125	134	223	5.7
15	8.1	123	130	126	2.6
16	8.3	125	132	129	2.3
17	8.2	125	136	161	2.3
18	8.2	124	130	185	2.4
19	8.1	124	130	215	0.86
20	8.1	127	128	178	3.4
21	8.4	129	134	139	2.5

TABLE 33  
Data Summary of New River Raw Water Characteristics

Table Number	pH	Total Alkalinity mg/l CaCO <sub>3</sub>	Total Hardness mg/l CaCO <sub>3</sub>	Total Solids mg/l	Turbidity NTU
22	7.7	44	50	111	3.9
23	7.6	46	48	66	5.0
24	7.7	47	52	44	9.9
25	7.7	46	50	82	10
26	7.7	44	54	93	15
27	7.7	44	54	93	15
28	7.7	46	48	31	2.6
29	7.9	46	46	123	5.3
30	7.8	46	46	155	4.7

## IX. VITA

Harold Thomas Eberly was born January 9, 1952, in Neptune, New Jersey. Grades 1 through 8 were spent in the Neptune City Public Schools, Neptune City, New Jersey. In June 1970 the author graduated from Neptune Senior High School, Neptune, New Jersey. From August 1970 to December 1974, he attended the Virginia Military Institute receiving his Bachelor of Science degree in Civil Engineering on December 31, 1974. From January 1975 to September 1976, he was employed by the Virginia Department of Health, Bureau of Sanitary Engineering, in Lexington, Virginia. In September 1976 he entered graduate school in Sanitary Engineering at Virginia Polytechnic Institute and State University to work toward a Master of Science degree while on educational leave from the Virginia Department of Health.

*Harold T Eberly*

EVALUATION OF ALTERNATIVE PRETREATMENT METHODS  
FOR USE IN DIRECT FILTRATION WATER TREATMENT

by

Harold Thomas Eberly

(ABSTRACT)

The purpose of this study was to evaluate the performance of alum alone, alum in conjunction with a polymeric coagulant aid, and a primary coagulant polymer in the coagulation-flocculation-sedimentation portion of a water treatment process and to study the implications of the results with respect to future use in direct filtration. The performance of the coagulant, coagulant aid, and primary coagulant polymer was evaluated by altering the flocculation and sedimentation retention times in the pretreatment process chain. Among the water quality parameters monitored were turbidity, pH, total alkalinity, total hardness, and total solids. A brief literature review for direct filtration and coagulation-flocculation theory was also conducted.

The results of this investigation indicated that reduced retention times in the pretreatment process chain treated the selected raw waters sufficiently to enable consideration of direct filtration a viable treatment alternative. Analysis of data obtained indicated the use of polyelectrolyte as a primary coagulant or coagulant aid produced a pin-point floc which is essential to successful utilization of direct filtration and that the floc formed settled more rapidly than floc from use of aluminum sulfate alone. The use of a polyelectrolyte as a primary coagulant or coagulant aid also reduced the chemical dosages required to provide appropriate turbidity removals.