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Ultra High Rate Filtration of Activated Sludge Plant Effluent

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ULTRA HIGH RATE FILTRATION OF ACTIVATED SLUDGE PLANT EFFLUENT

by

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ABSTRACT

Pilot plant studies were conducted at the Southerly Wastewater Treatment Plant in Cleveland to evaluate the capabilities of the deep bed, dual media, ultra high rate filtration process for treating an activated sludge plant secondary effluent.

The various operating variables that were tested and evaluated included different media sizes, various bed depths, filtration rates from 8 to 32 gpm/sq ft, different types of polymers, and different combinations of coagulants and polymers.

The principal parameter for evaluating process efficiency was suspended solids. High removals were obtained with respect to suspended solids and to pollutants associated with suspended solids. The removal of these pollutants reduced biochemical oxygen demand, chemical oxygen demand and total phosphate values.

Capital costs for a filtration process of this type are estimated to range from $1,200,000 for a 25 MGD plant to $5,400,000 for a 200 MGD plant. Total treatment costs, including capital and operating charges, are estimated to be 4.32 - 2.97 ¢/1000 gallons for the 25 and 200 MGD plants, respectively.

This report was submitted by Hydrotechnic Corporation in fulfillment of Project #17030 HMM under the partial sponsorship of the Environmental Protection Agency.

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SECTION I

CONCLUSIONS

Pilot plant testing results based on deep bed, dual media, ultra high rate filtration of secondary effluent at the Southerly Wastewater Treatment Plant in Cleveland support the following conclusions:

1. Conclusions are based on: two hundred and five pilot filtration test runs conducted in 1971 and 1972 on an activated sludge plant secondary effluent utilizing the aforementioned system. One hundred and forty three testing runs were conducted in eight three-inch diameter filtration columns, and sixty two filtration runs were performed in three six-inch diameter filtration pilot units. Thirty polymers were evaluated in combination with coagulants (alum, ferric chloride or lime) or polymer alone to determine their effect on the ultra high rate filtration process.

2. Based on limited pilot test results, a filter media comprised of No. 2 anthracite (effective size 1.78 mm) over No. 1220 sand (effective size 0.95 mm) was shown superior to coarser or finer media tested and this media was selected as the filtration component of the treatment system.

3. When the suspended solids concentrations in an activated sludge plant secondary effluent (filter influent) were below 30 mg/l, the filter effluent suspended solids concentrations generally remained in a range of 1.0 to 12 mg/l for filtration rates of up to 32 gpm/sf with or without polymer or coagulant and polymer.

4. Filtration with coagulant and polymer addition produced better effluent quality or higher removal efficiency of suspended solids than plain filtration, when the secondary effluent (filter influent) suspended solids concentrations exceeded 60 mg/l.

5. For filtration with coagulant (alum) and polymer addition, total phosphate reduction was related to the effectiveness of suspended solids removal in the filter media.

6. It was determined that no significant relationship exists between filtration rates and effluent BOD, COD and suspended solids concentrations in the range of rates studied.

7. During filtration runs, head loss developed more slowly under declining rate conditions than under constant rate control, and it developed more rapidly at higher filtration rates and higher influent suspended solids concentrations.

8. Area requirements for full size ultra high rate filtration plants, including deep bed filtration units, a filter gallery, a control and chemical building, backwashing facilities, and a low lift pumping stations, but not including backwash sludge handling facilities, are estimated as follows:

Plant Capacity	Design @ 24 gpm/sq ft
25 MGD	3,000 sq ft
50 MGD	4,600 sq ft
100 MGD	9,300 sq ft
200 MGD	16,500 sq ft

9. Capital costs for ultra high rate filtration plants, including a low lift pumping station, chemical feed, the filtration plant and engineering, but not including the cost of land, backwash sludge handling and interest during construction, are estimated as follows (design at filtration rate of 24 gpm/sq ft).

Plant Capacity	Capital Cost (ENR = 1682)
25 MGD	1,184,810
50 MGD	1,725,370
100 MGD	3,121,500
200 MGD	5,329,150

10. Annual costs and treatment costs per 1000 gallons, including amortization, operation and maintenance, for ultra high rate filtration plants, are estimated as follows (designed after a filtration rate of 24 gpm/sq ft, plant operated 365 days per year, and including low lift pumping station and chemicals):

Plant Capacity	Annual Costs	Treatment Costs per 1000 gallons
25 MGD	$ 394,110	4.32¢
50 MGD	$ 627,790	3.44¢
100 MGD	$ 1,161,735	3.18¢
200 MGD	$ 2,164,610	2.97¢

SECTION II

RECOMMENDATIONS

Additional pilot plant studies with larger UHR filters should be undertaken to further evaluate some of the design variables studied in this project and to study and quantify some of the following:

1. The addition of powdered activated carbon as well as coagulant ahead of the UHR filter in a physical-chemical treatment sequence.

2. The application of UHR filtration with coagulant addition for the removal of suspended solids, suspended and colloidal organic matter and phosphorus from raw wastewater.

3. The necessary backwashing requirements to properly cleanse the UHR filter media.

4. The applicability of the UHR filter to the treatment of raw wastewaters mixed with chemical sludges from water treatment plants.

5. The feasibility of accomplishing denitrification within the UHR filter when used for polishing of a nitrified effluent (1).

SECTION III

INTRODUCTION

General

In recent years considerable emphasis has been placed upon the need to improve the quality of water at a cost that would not be ruinous to the economy.

Attention, in the United States, has been centered on the Great Lakes Drainage Basin and more specifically on Lake Erie. A great deal has been written about the advanced state of eutrophication or aging, of Lake Erie and numerous theories have been advanced to explain the causes of this condition. It is generally accepted that phosphorus, acting as a prime nutrient, has greatly accelerated the natural aging process.

Currently, water pollution control is desired to improve water quality with respect, mainly, to suspended solids, biochemical oxygen demand (BOD) and phosphates. This high level of treatment seems necessary so as not to cause further eutrophication of the Great Lakes.

Based upon the encouraging results from Hydrotechnic's previous work (2), the current project was undertaken at the City of Cleveland's Southerly Wastewater Treatment Plant in an effort to investigate high rate filtration methods of upgrading effluent quality. This study evaluated the applicability and effectiveness of the ultra high rate filtration process in removing residual suspended solids and other contaminants from the effluent of a conventional activated sludge secondary treatment plant.

Scope of Project

The research and development project at Cleveland's Southerly Wastewater Treatment Plant involved deep bed, dual media, ultra high rate filtration for treating the effluent of a conventional activated sludge sewage treatment plant. The project entailed filter media selection, evaluation and selection of polymer - coagulant combinations, testing the efficiency and effectiveness of the high rate filtration process in removing residual contaminants and data evaluation and design of representative treatment units with associated cost estimates.

The field testing, sampling and evaluation program was conducted from August, 1971 through February, 1972. The field test work consisted of optimizing the performance of the proposed system.

Essentials of High Rate Filtration

The history of water filtration began with the use of slow sand filters to clarify drinking water. These were beds of granular material, arranged in various acreages, which were doused with the water to be filtered. The water was collected after percolating through several feet of the filter bed. Usual rates of filtration were in the order of 0.02 to 0.2 gpm/sq ft. At the end of the 19th Century, the development of the rapid sand filtration process occurred. This process required the prior application of chemicals to effect coagulation. The water was then passed through clarification tanks where most of the floc formed was settled out prior to filtration. These improved filters provided good water at filtering rates of 2 gpm/sq ft. However, of even greater significance was the fact that they could be cleaned mechanically without removing the media from the bed. Much recent attention and test work in potable water filtration has been given to the feasibility of filtering at higher rates, up to 10 gallons a minute per square foot (3).

The general practice of industrial wastewater filtration first emerged in Europe where the supply of water for industrial purposes became limited. The industrial wastewater filters in Europe were designed to operate in the general range of 6 to 10 gallons per minute per square foot. These units were designed to provide reliable treatment for many years without any great maintenance effort.

Ultra high rate filtration, under study for the treatment of an activated sludge treatment plant effluent, is similar to the industrial type filtration in Europe except that two layers of media of different composition are used (4). Together, they form a filter bed that is much deeper than used previously (7 feet or more). By using more than one medium, high capacity filter bottoms and special backwashing facilities, the rate of wastewater filtration has been increased greatly.

One of the essential differences between a deep bed, dual media, ultra high rate filter and its counterpart for potable water treatment is that the deep bed filter is designed to accept appreciable solids loadings, on the order of many hundreds of milligrams per liter. To be most effective, filtration through media that are graded from coarse to fine in the direction of filtration is desirable. A single medium filter cannot conform to this principle since backwashing of the bed automatically grades the bed from coarse to fine in the direction of washing; however, the concept can be approached by using a two layer bed. A typical case is the use of coarse anthracite particles on top of less coarse sand. Since the coarse anthracite is less dense than sand, the larger anthracite particles can remain on top of the bed after the backwash operation. Another alternate to achieve filtration through coarse to fine media would be an upflow filter, but these units have limitations in that they cannot accept high filtration rates.

Over the past few decades, many theories have been advanced to describe the manner and mechanism by which suspended matter is entrapped within a filter. Tchobanoglous (5) has categorized filter removal mechanisms into nine areas, which include straining, sedimentation, inertial impaction, interception, chemical adsorption, physical adsorption, adhesion and adhesion forces, coagulation-flocculation, and biological growth.

Just how suspended matter is intercepted in depth rather than at the surface of a high rate filter, and which mechanisms are principally involved, is not yet fully understood (6).

The principal parameters to be evaluated in selecting a high rate filtration system are media size, media depth and filtration rate. Since much of the removal of solids from the water takes place within the filter media, their structure and composition is of major importance. Too fine a media may produce a high quality effluent but also may cause excessive head losses and extremely short filter runs. On the other hand media that is too coarse may fail to produce the desired effluent quality. The selection of media for ultra high rate filtration must be determined by pilot testing using various materials in different proportions, different flow rates and under various operational modes. Depth of media is limited by head loss and back-wash considerations. The deeper the bed, the greater the head loss and the harder it is to clean. On the other hand, the media should be of sufficient depth so as to be able to retain the removed solids within the depth of the media for the duration of filter run at the design rate without permitting a breakthrough. A deeper bed also affords greater opportunity for interplay of the various forces which are generated within the filter bed.

The design filtration rate (7, 8) must be such that the effluent will be of a desired quality without causing excessive head loss through the filter, which in turn requires frequent backwashing. At high filtration rates, shear forces appear to have a significant effect on solids retention and removal in a high rate filter. Recent experience at a high rate filtration facility treating industrial wastewater seems to reinforce this theory, as winter performance of the filtration facility (without chemicals) was poorer than summer performance, when water viscosities are lower due to higher water temperatures. Polymer addition was required during cold water operating conditions (winter) to maintain required effluent quality. The addition of polymer, and/or coagulant prior to filtration has a very significant effect on process efficiency.

SECTION IV

WASTEWATER TREATMENT PLANT OPERATION

General

The deep bed, dual media, ultra high rate filtration test facilities, were located at the Southerly Wastewater Treatment Plant, in Cleveland (see Figure 1). This plant services roughly half of Metropolitan Cleveland which consists of residential, commercial and industrial areas encompassing approximately 81,500 acres. The residential population is estimated to be 600,000 persons or about 46 percent of the people residing in the Greater Cleveland area. This treatment facility has tributary to it between 50 and 60 percent of the industrial community of the region. This community consists of plating shops, major steel mills, chemical manufacturing plants and other industries. As with standard treatment facilities, the treatment plant is susceptible to shock loadings due to accidental spills.

Treatment Plant Operation

Raw sewage containing industrial wastes with a normal flow of 105-110 MGD and up to 4 MGD of mixed primary and secondary sludge from the Easterly Wastewater Treatment Plant are conveyed to the Southerly Wastewater Treatment Plant Screen Building where the flow passes through bar racks to two detritus tanks to remove grit and other debris. The flow is then ground in six comminutors, each with a capacity of 20 MGD.

The addition of new primary and secondary treatment facilities (completed in 1969) increased the plant capacity to 170 MGD However, recent process modifications, which are discussed in greater detail later in the text, have limited present capacity to 96 MGD in the primary settling tanks with a 34 MGD by-pass directly to the aeration units which provide 130 MGD capacity in the secondary treatment units of the activated sludge plant.

The aeration tanks are split into two separate units, aeration unit #1 and #2. The design capacities of these units are 55 MGD with 37 percent return sludge and 68 MGD with 27 percent return sludge, respectively. The aeration time varies between 4 and 8 hours. The clarified secondary effluent is disinfected with chlorine and discharged to the Cuyahoga River.

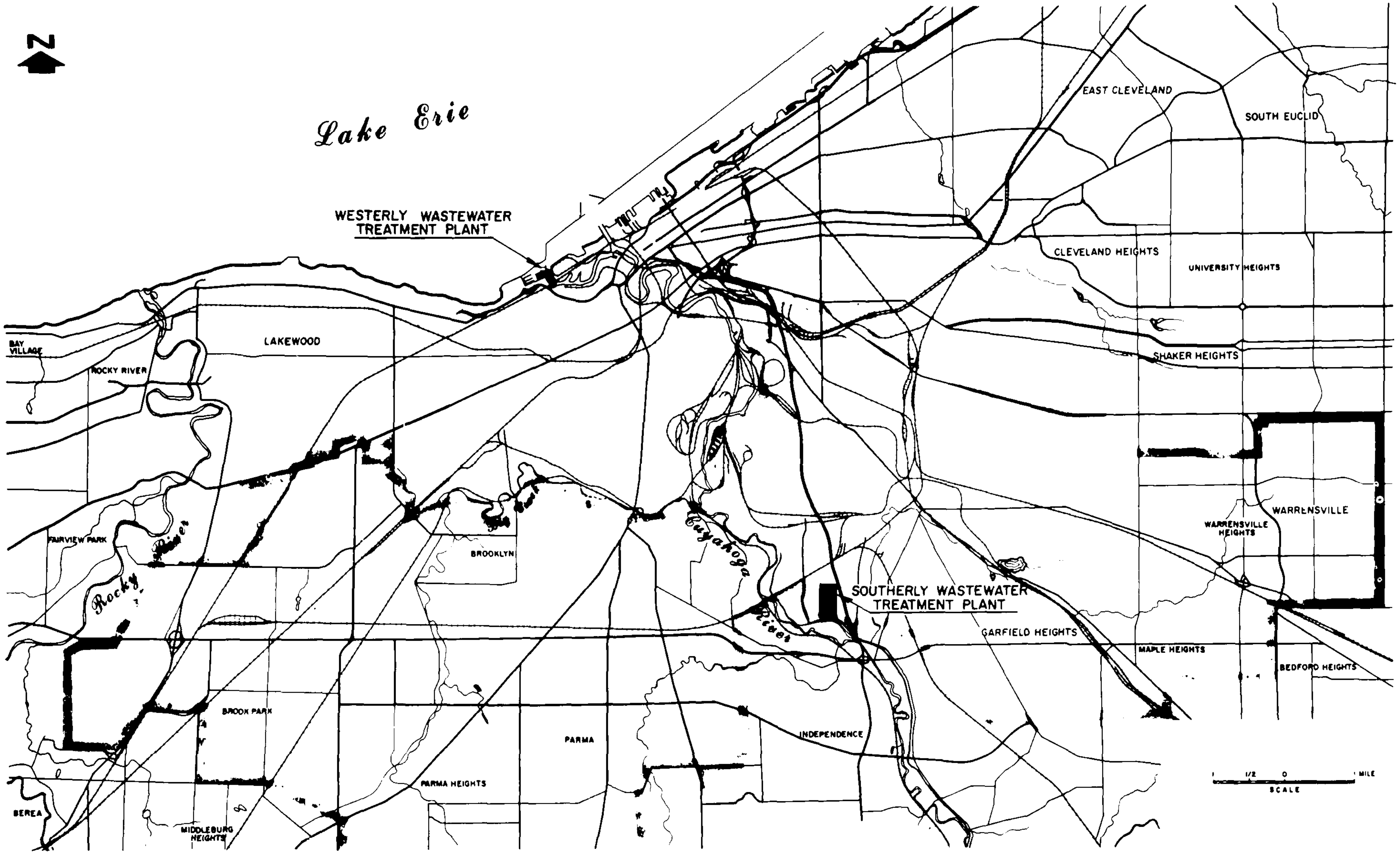


FIGURE I

SOUTHERLY WASTEWATER TREATMENT PLANT - LOCATION PLAN

The waste sludge from the final settling tanks is directed to a thickener. The thickened sludge is combined with primary sludge in a digestor and followed by an elutriation tank. Elutriated sludge is treated with ferric chloride and lime prior to vacuum filtration and incineration in a multi-hearth furance. The design capacity of the four multiple hearth incinerators is 800 tons per day. Previously, this plant produced 200 to 300 tons per day, but recently this production rate has been increased by a factor between 2 and 3.

Process Modification and Improvement

During the early part of 1970, plant operating personnel made process modifications and improvements to decrease the pollutional loads being discharged to the Cuyahoga River. These modifications included recycling the waste sludge from the final settling tanks serving aeration unit #1 to the primary settling tank influent channel and limiting the raw sewage flow to the primary settling tanks to 96 MGD. The final settling tank sludge improves the settling characteristics of the primary solids and the limitation of flow ensures a reasonable overflow rate.

The effluent from the primary settling tanks is split with 51 percent of the flow to aeration unit #1 and 49 percent to aeration unit #2. Flows in excess of 96 MGD, but less than 130 MGD, bypass the primary settling tanks and are conveyed to aeration unit #1 which can provide step aeration to effectively treat the increased loading.

The dissolved oxygen profile is held reasonably constant in each of the four aeration chambers by controlling the flow rate and maintaining a constant aeration rate of 1.2 cubic feet of air per gallon of mixed liquid. The first pass of the aeration tank is used to aerate the return sludge from the final settling tanks.

Due to the steel plants and other metal producing or processing industries which are tributary to the Southerly Wastewater Treatment Plant, the plant influent normally contains high iron concentrations, between 20-30 mg/l as Fe. This fact, coupled with the previously described plant modifications have enabled the plant to produce a good quality effluent with average characteristics as follows:

BOD	10-20 ppm
COD	50-90 ppm
TSS	10-20 ppm
TPO_4	5-10 ppm

With each successive process modification the treatment plant engineers made an in depth study to determine the effects and to define the controllable variables. It was finally determined that the controlling variable to produce high quality effluent was the rate of production of the total biological sludge within the system, which was optimal at a food-to-microorganism ratio of 0.2 to 0.5 (9).

Starting in late spring through November 1971 the plant encountered various operating and maintenance difficulties due primarily to a loss in solids handling capacity. With reference to the previously described method of control, this facility then began to store solids within the system by recycling the waste sludge to the head of the plant.

Throughout November and December of 1971 the plant was adjusting the total mass of sludge in the system to achieve a food-to-microorganism ratio of between 0.2 and 0.5. This was accomplished by juggling the incineration capacity of the plant. By mid-December the plant was again able to produce a satisfactory effluent which was maintained through the completion of the testing period.

Plant Influent and Effluent Water Quality

Tables 1 and 2 show the water quality of the influent raw sewage containing sludge from Easterly Wastewater Treatment Plant and the secondary effluent during the months of October, November and part of December 1971. A continuous 33 hour plant water quality survey on January 11 and 12, 1972 was undertaken and the results are presented on Figure 2.

TABLE 1

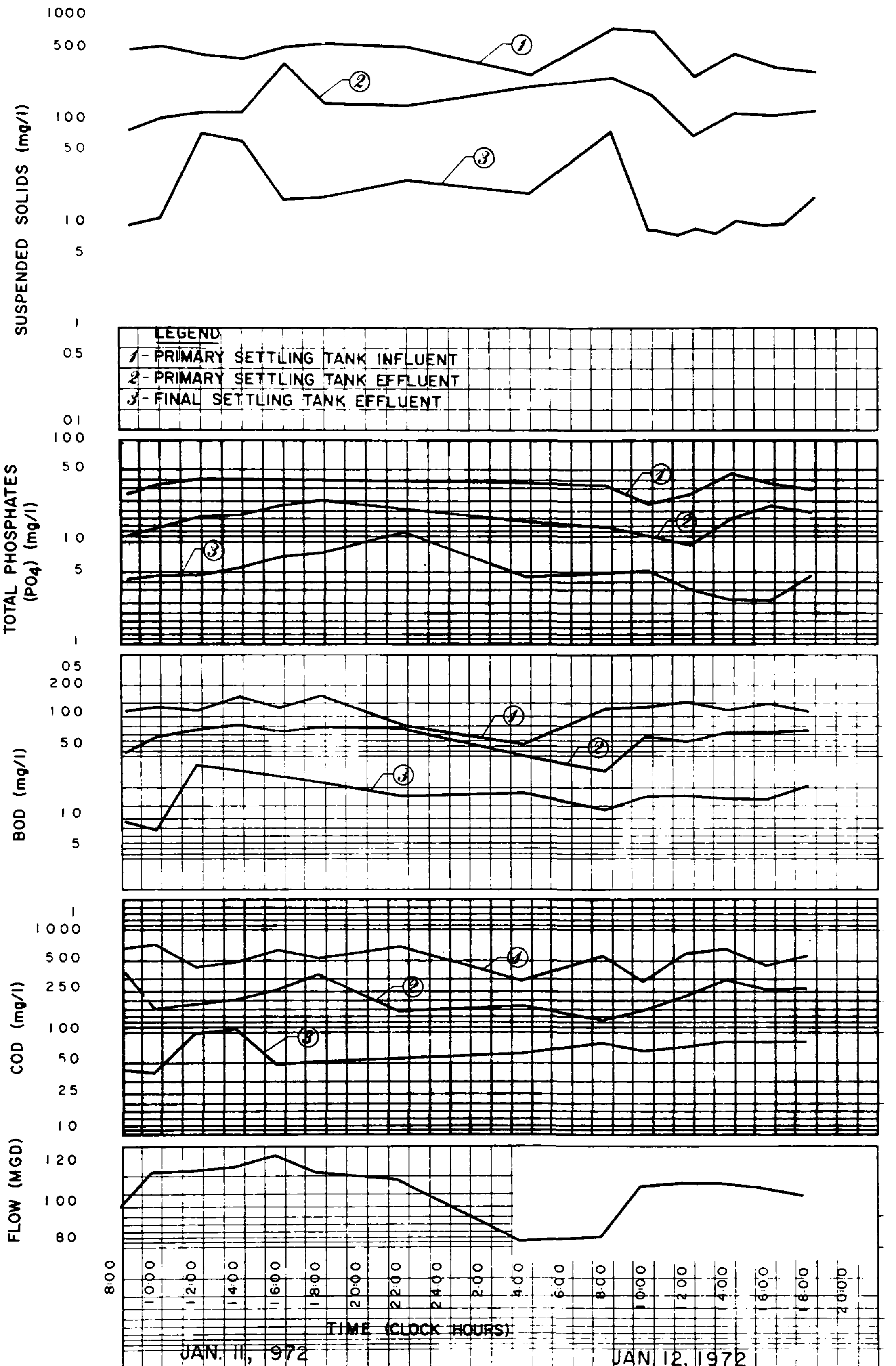
CHARACTERISTICS OF RAW SEWAGE
(OCTOBER THRU DECEMBER 1971)
SOUTHERLY WASTE WATER TREATMENT PLANT
CLEVELAND, OHIO

Month	pH			TSS (mg/l)			BOD (mg/l)			COD (mg/l)			T PO_4		
	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
Oct.	7.2	7.4	7.6	270	410	696	255	301	355	411	665	1169	13	32	44
Nov.	7.0	7.3	7.5	276	440	812	235	302	350	432	800	1204	25	36	60
Dec.	7.1	7.3	7.4	194	280	388	240	300	350	260	665	1260	12	19	33

TABLE 2

CHARACTERISTICS OF SECONDARY EFFLUENT
(OCTOBER THRU DECEMBER 1971)
SOUTHERLY WASTE WATER TREATMENT PLANT
CLEVELAND, OHIO

Month	pH			TSS (mg/l)			BOD (mg/l)			COD (mg/l)			T PO_4 (mg/l)		
	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.	Min.	Avg.	Max.
Oct.	7.7	7.9	8.1	5	22	57	18	25	31	28	58	129	3.1	16	20
Nov.	7.6	7.8	8.0	12	50	138	10	26	50	73	132	405	5.1	11	21
Dec.	7.5	7.7	7.9	15	20	30	15	19	45	56	73	85	2.5	5	5.5



TREATMENT PLANT - INFLUENT AND EFFLUENT WATER QUALITY PROFILE

FIGURE 2

SECTION V

TESTING PROGRAM AND PROCEDURE

Parameters

Two distinct types of test parameters were utilized and evaluated during this study. The first type of parameter can be called or described as design parameters, as they relate to the major features of the ultra high rate filtration system. The second type can be described as water quality parameters, which are essentially contaminant levels in and out of the filtration process.

The filtration system can be characterized and described by the following parameters:

Media Composition	Length of filter run
Media depth	Head loss
Filtration rate	Backwash procedure
Coagulant and flocculant addition	Backwash water volume

A definition of these elements allows the design and construction of a full scale facility.

Water quality parameters or analyses utilized are those normally associated with water quality criteria. Principal emphasis was given to the following analyses:

Total Suspended Solids
Total Phosphate
Biochemical Oxygen Demand
Chemical Oxygen Demand

Other water quality analyses were also performed to provide information as to process performance on a wide range of wastewater contaminants. Table 3 is a complete listing of all water quality analyses utilized.

The major water quality parameter for determining the effectiveness of the treatment process, since the proposed filtration process is essentially a solids removal process, is suspended solids. Insoluble BOD, simultaneously removed along with suspended solids, and soluble (ionizable) phosphates, rendered insoluble by the addition of coagulants, are also significant water quality parameters.

TABLE 3

WATER QUALITY ANALYSES

pH
Temperature
Turbidity
Total Suspended Solids
Total Solids
Biochemical Oxygen Demand
Chemical Oxygen Demand
Total Phosphate
Soluble Phosphate

Note: Analysis performed in accordance with "EPA Methods for Chemical Analysis of Water and Wastes", 1971.

Scope of Testing Program

The purpose of the testing program was to investigate operational and design parameters of the ultra high rate filtration process for the treatment of secondary effluent. The program could be viewed as three separate procedures, including: (a) bench scale testing of the effects of coagulants and flocculants, (b) preliminary coagulation-filtration testing with three-inch diameter filter columns, (c) collection of operational data from the principal experiments with six-inch diameter filter columns.

The bench scale tests consisted of a series of jar tests to evaluate a variety of coagulants and flocculants. The determination of the type and dosage of coagulants was based on floc formation, floc density and characteristics of agglutination.

The preliminary coagulation-filtration tests were conducted in a set of eight three-inch diameter filter columns. The tests evaluated four principal design variables: size of filter media, depth of filter bed, filtration rate and selection of coagulant and flocculant. These tests were performed under declining-flow conditions and were terminated when either the flow declined to fifty percent of initial rate or at the end of three hours, whichever was reached first. The testing programs are shown in Tables A-1 through A-4 in Appendix A.

The principal filtration experiments were performed in a set of three six-inch diameter filter columns with previously selected filter media, coagulant and flocculant. Filtration performance was evaluated in terms of the effluent water quality, the amount of water produced, length of filtration run, and total terminal head losses. Two methods of flux control, constant rate and declining rate, were also evaluated. The experimental program for the six-inch diameter filter columns is presented in Table A-5, in Appendix A.

Filtration Test Procedure

The testing apparatus and experience acquired in the research project for the treatment of combined sewer overflow (2) was used to establish the procedure for studying the treatment of the effluent from the Southerly Plant's secondary settling tanks. The testing procedure used to evaluate the filtration components was conducted primarily in two phases. First, evaluation and selection of system media and flux rates, and secondly, optimization of the process through the use of coagulant and flocculant additions prior to filtration.

The filtration media evaluated included four to five feet of anthracite over two to three feet of sand. The characteristics of the media are indicated as follows:

Media	Effective Size (mm)	Uniformity Coefficient
No. 3 Anthracite	4.0	1.5
No. 2 Anthracite	1.78	1.63
No. $1\frac{1}{2}$ Anthracite	0.98	1.73
No. 1 Anthracite	0.66	1.62
No. 612 Sand	2.0	1.32
No. 1220 Sand	0.95	1.41
No. 2050 Sand	0.45	1.33

Both media selection and coagulation-filtration testing were accomplished in the three-inch diameter filtration test apparatus, as shown in Figure 3. Referring to this figure, the two key points in the filtration system were sampling point #1 and sampling point #2. Sampling point #1 was at the head tank overflow, represented as filter influent, and sampling point #2 was at the filter column effluent. Grab samples were taken at thirty minute intervals for turbidity, pH, and temperature analyses. A composite sample was also collected at the influent and effluent. These samples were composited over a ten minute period at sixty minute intervals for a three hour duration. This composite sample was then analyzed for suspended solids concentration.

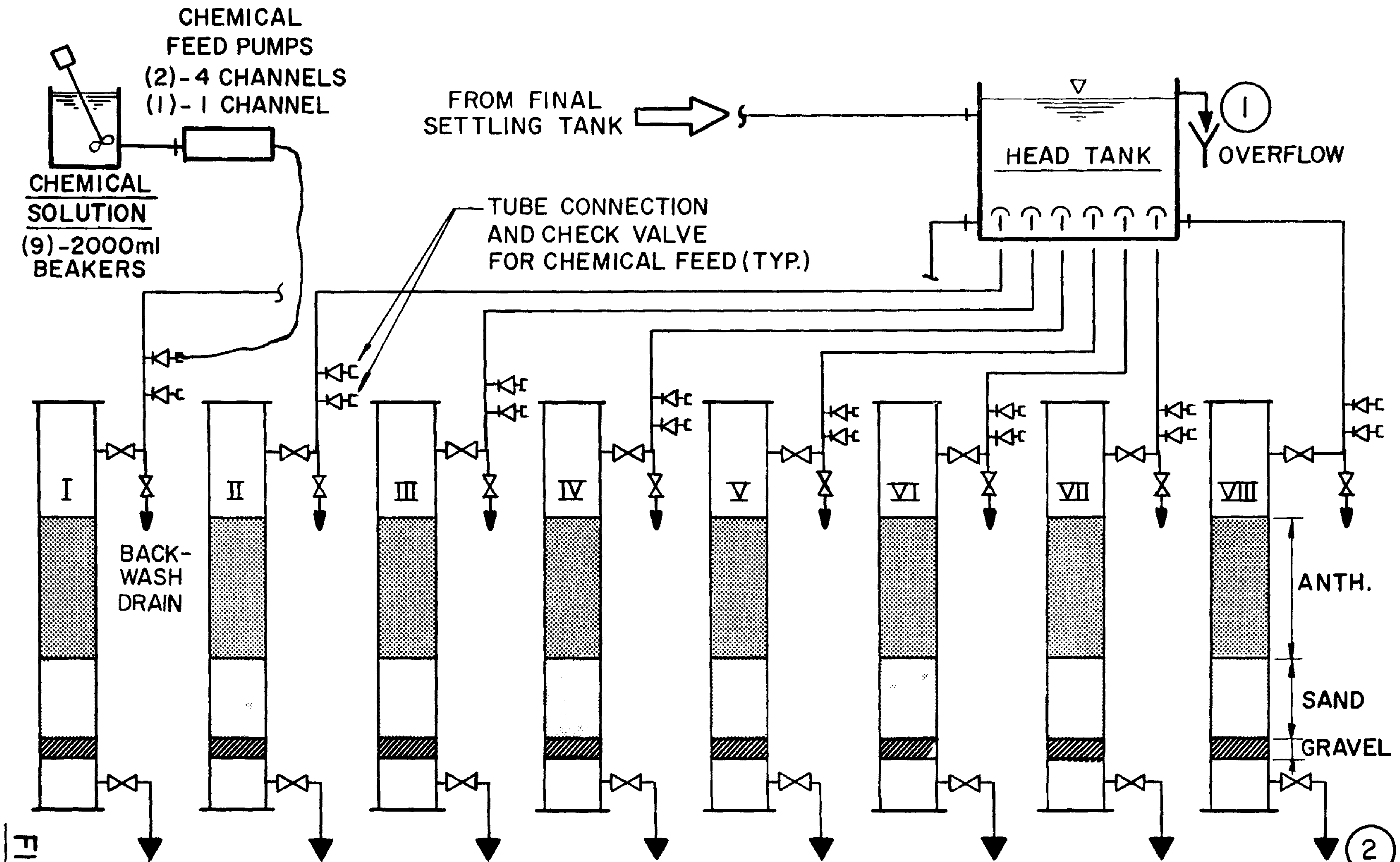


FIGURE 3

THREE INCH DIAMETER FILTER APPARATUS SCHEMATIC DIAGRAM

A typical test run applied seven different polymers at the same dosage to each of the various filter columns operated at the same filtration rate (one column was used as a reference). Based on effluent quality data, the efficiency of one polyelectrolyte versus another could be determined by suspended solids reduction. The various types of coagulants and flocculants evaluated in the preliminary tests were then used in the principal filtration test. A total of 30 polymers were evaluated for enhancing suspended solids removals, including 5 which are normally used to treat potable water. A list of polymers evaluated in this program is contained in Table 4.

The evaluation of ultra high rate filtration performance was conducted in six-inch diameter filter columns, as shown in Figure 4. Filter influent and effluent samples were taken every thirty minutes for turbidity, pH and temperature measurements; every hour for suspended solids determination; and every two hours for total phosphate, BOD and COD analyses.

The filtration columns were generally run for approximately 5 to 8 hours. The length of run was controlled by the extent of head loss (less than 20 ft proposed) and by effluent quality (turbidity less than 20 JTU). Head loss measurements were taken for each filter column by reading the various pressure gauges located along the side of the filter at one-half hour intervals, or more frequently, as required. These readings serve to identify and define the energy expended by the flow in overcoming friction during the filtration run.

The six-inch diameter filter columns were backwashed by using low pressure air followed by water. Initially, after the filtration run had terminated, the columns were scoured with low pressure air at a rate of approximately 15 scfm per sq ft for about 2 minutes. The air was then turned off, and water introduced at a rate of 25 to 75 gpm/sq ft for 5 to 15 minutes. Samples of the backwash effluent were collected during the filter backwash period. The samples provided information as to the nature of the backwash flow, both on an instantaneous and composite basis. Backwash effluent samples, when viewed in conjunction with a particular backwash procedure, could be used as a guide to the relative effectiveness of filter cleaning.

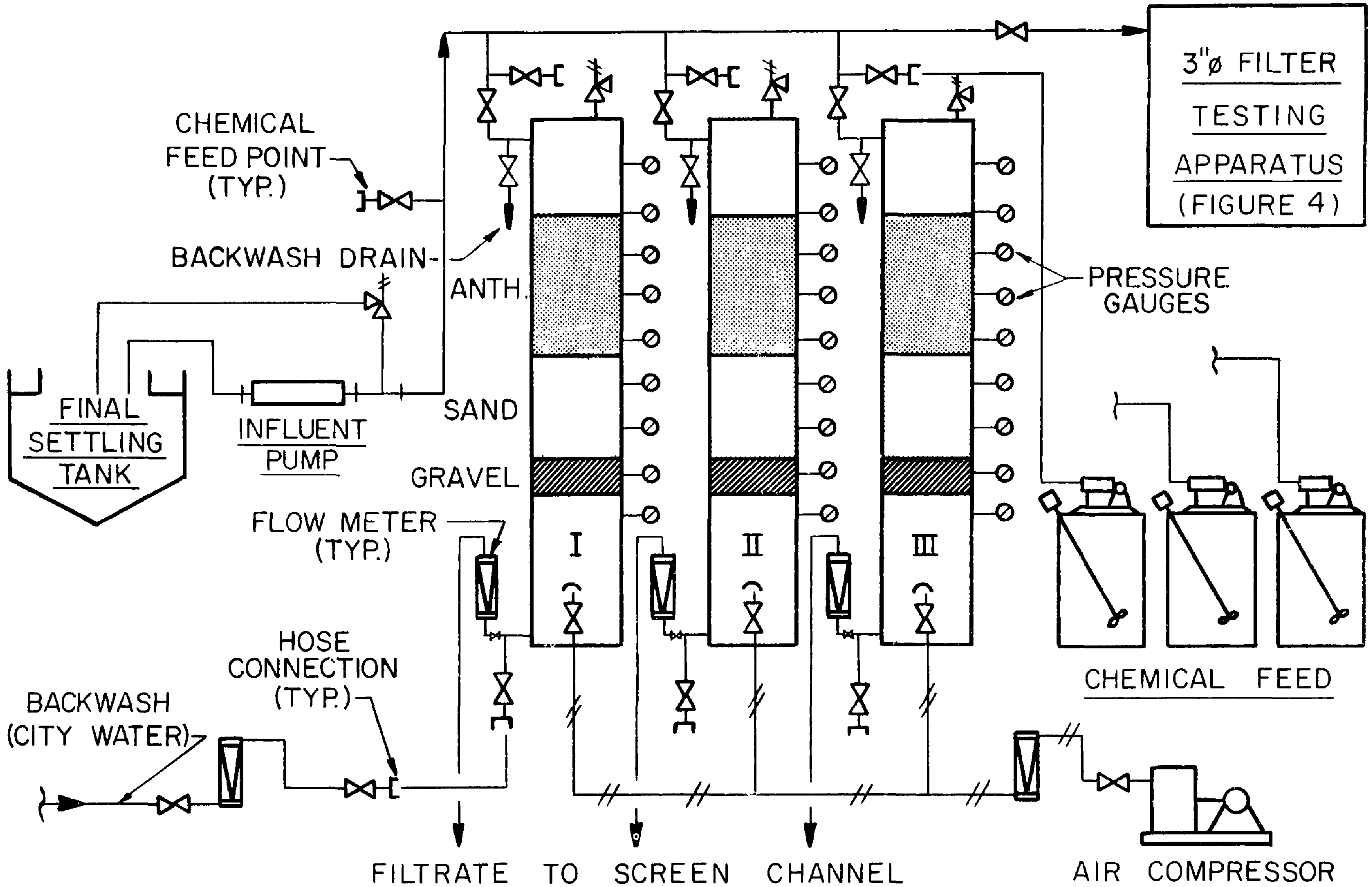


FIGURE 4

HIGH RATE FILTRATION PILOT PLANT SCHEMATIC DIAGRAM

TABLE 4

LIST OF POLYMERS

Chemical Industries	Type of Polyelectrolyte: Cationic	Nonionic	Anionic
Atlas Chemical Industries, Inc. Wilmington, Delaware 19899 (Atlasep)	105C	-	1A1, 2A2, 3A3, 4A4, 5A5
American Cyanamid Company Wayne, N.J. 07470 (Magnifloc)	570C* 560C	985N*	865A, 836A, 860A*
Calgon Corp. (Coagulant Aid) Pittsburgh, Pa. 15230	226, 228	-	25**, 240
The Dow Chemical Company Midland, Mich. 48640 (Purifloc)	C-31*	-	A-23*
Gamlen Chemical Co. (Gamafla) East Paterson, N.J. 07407	NC772	-	NA710
Hercules, Inc. (Hercofloc) Hopewell, Virginia 23860	810, 828.1	-	816
Nalco Chemical Co. (Nalcolyte) Chicago, Illinois 60601	-	671	672
Reichhold Chemicals, Inc. Tuscaloosa, Ala. 35401 (Aqua-Rid)	49-702 49-710	49-704	-
Stein-Hall Chem. (Polyhall) New York, New York 10016	-	-	295A
Swift and Company Oak Brook, Illinois 60521	-	-	X-400

* = Approved by EPA for Water Treatment (April 1971).
** = Polymer with Bentonite Clay.

SECTION VI

PILOT PLANT FACILITIES

Test Site

The pilot plant for testing the applicability of ultra high rate filtration for the treatment of secondary effluent was located at the Screen Building of the Southerly Wastewater Treatment Plant. This plant utilizes the activated sludge process for the treatment of combined domestic and industrial waste flows from the Cleveland area.

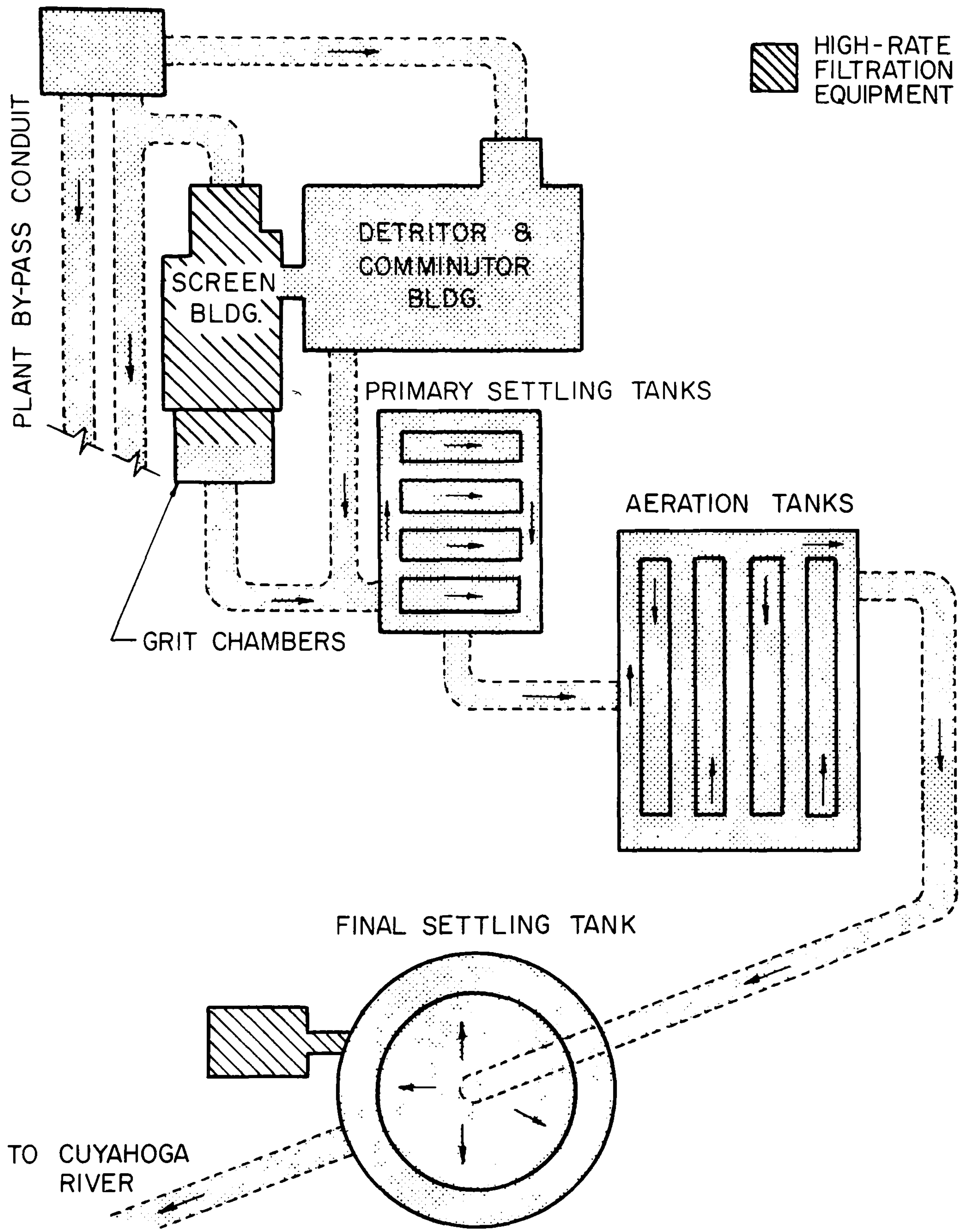
The pilot plant influent pump and backwash wastewater storage tanks were located outdoors. The filtration test columns, associated backwashing, chemical feed equipment, coagulation-filtration testing apparatus, laboratory and storage room, were located inside the Screen Building. Figure 5 shows the location of the pilot plant inside the Southerly Wastewater Treatment Plant. Figure 6 shows the pilot plant facilities. Only six of the eight three-inch columns are shown in the lower view of Figure 6.

Process Units

The secondary effluent was lifted from a final settling tank and pumped to the pilot plant site located in the Screen Building of the Southerly Wastewater Treatment Plant. Then, the flow was distributed into three six-inch diameter filter columns through a common manifold as shown in Figure 4. The flow also could be diverted to the three-inch diameter filtration apparatus, as shown in Figure 3, for preliminary, coagulation-filtration tests.

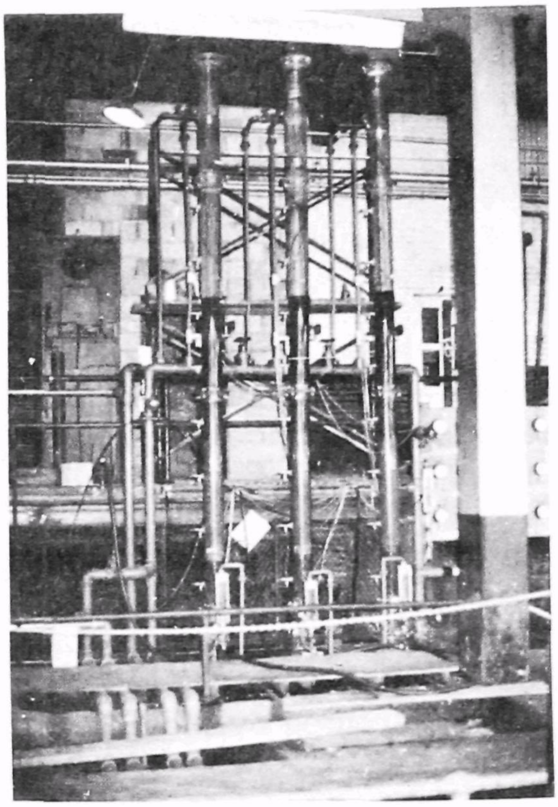
A total of eleven pilot filter columns were located in the test set-up. Three of the filter columns were six-inches in diameter and eight of the columns were three inches in diameter. All of the pilot columns were of sufficient size to provide reliable removal data in regard to the filtration process. The larger units gave a better indication of the effect of backwashing on the media. Three chemical feeding systems were provided for the six-inch diameter filter columns.

A preliminary coagulation-filtration apparatus was incorporated into the pilot plant equipment. This apparatus, as shown in Figure 3, permitted comparison of the effect and efficiency of various dosages of coagulants, and polyelectrolytes to improve process performance.

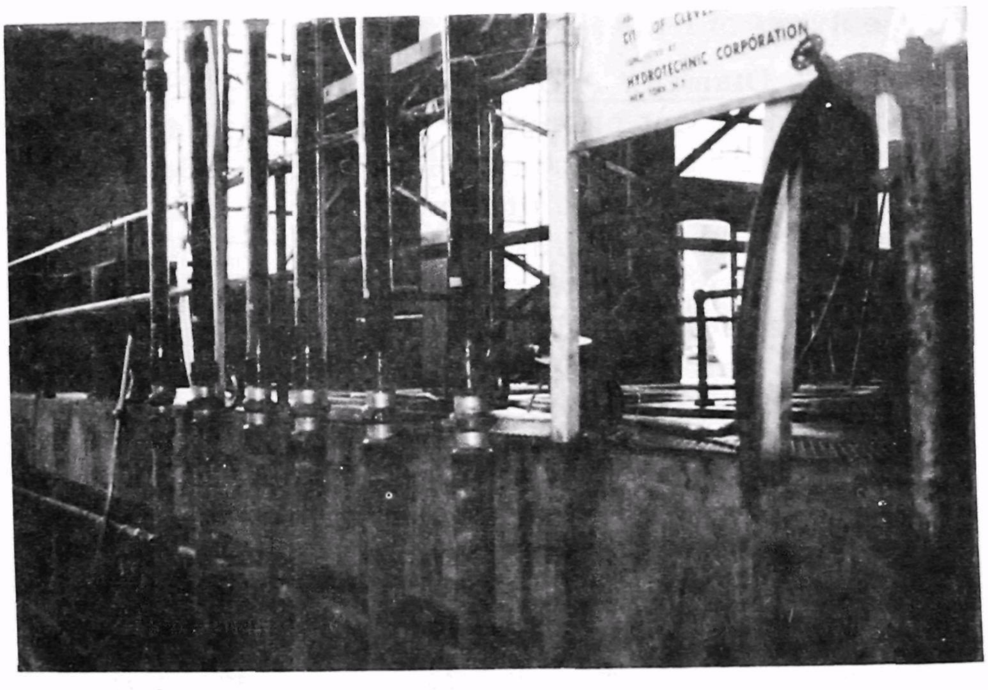


FILTRATION PILOT PLANT - LOCATION PLAN

FIGURE 5



6" Φ LUCITE FILTER COLUMNS



3" Φ LUCITE FILTER COLUMNS

PILOT PLANT FACILITIES FIGURE 6

Selected coagulants, polymers, and dosages were then utilized in the six-inch diameter pilot columns, from which operational data was obtained (length of run, head loss, etc.).

The flow volumes through each filtration column could be controlled by observing a flow meter and regulating a valve on the effluent from the filter. Pressure gauges were located along the sides of the pilot filtration columns to profile head losses throughout the filter depth. An air compressor was included at the test installation to provide a source of air for backwashing the filter columns. Backwash water was obtained from the existing service water system at the Southerly Wastewater Treatment Plant.

Major equipment at the pilot plant included the following:

1. Pilot Plant Influent Pump - A positive displacement self-priming pump was used for delivering secondary effluent to filtration testing site. The pump was manufactured by Moyno Pump Division, Robbins and Myers, Inc., Frame SWG 8 - Type CDQ. The unit was mounted on structural steel "L" type base plate and driven by "V" belts and pulleys covered by suitable belt guard (450 rpm). The pump was driven by a 3 HP TEFC motor, operating on 3 phase, 60 cycles, 230/460 volt current.

2. Three Six-Inch Diameter Pilot Filter Columns - The filter columns were made of transparent plexiglass tubing having an outside diameter of seven inches with a 3/8 inch wall thickness. Each filter was seventeen feet high and consisted of four sections. The four sections were connected by flanges using 1/4 inch bolts. Nine pressure taps, eighteen inches apart were provided along the column for measuring head loss development during filtration. Filter media was supported by a plexiglass plate with a plexiglass nozzle. Above the plate, an eighteen inch gravel layer was provided to support the filter media. A rotameter and valve were installed at the filter discharge end for measuring and controlling the rate of flow.

3. Backwash Air Compressor - The air compressor was a Model A490K8 - 103-80, oil free type, as manufactured by the Corken Pump Company. The compressor was mounted on an 80 gallon receiver, ASME Code 200 psig working pressure. The unit was complete with pressure gage, intake filter, hydrostatic relief valve and constant-speed unloaders. The compressor was driven by a 2 HP, drip proof, 1750 rpm motor operating at 230/460 volts.

4. Three Chemical Feed Systems - Each system consisted of a metering pump, a mechanical mixer and a chemical solution tank. The metering pumps were positive displacement, diaphragm type, with plastic ends, driven by 1/4 HP, single phase capacitor-start motors. The chemical solution tanks were polyethylene chemically resistant, each having a capacity of 50 gallons and equipped with covers. The mixers were driven by 1/4 HP totally enclosed motors and had stainless steel shafts and impellers. The pumps, chemical solution tanks and mixers were supplied by Wallace and Tiernan, Inc.

5. Backwash Effluent Storage Tank - A 1,000 gallon steel tank was used as the filter backwash effluent storage tank. The tank was made of carbon steel plate and equipped with outlet and drain connections.

6. Coagulation-Filtration Testing Apparatus -

a. Head Tank

To distribute flow to the eight filter columns - an eighteen inches in diameter, three-foot long, transparent plexiglass tube was used as a filter influent head tank. Overflow nozzles were installed to provide a constant head for the filter influent flow.

b. Filter Columns

Eight filter columns, made of three inch diameter transparent plexiglass tubing, were installed at the pilot plant site. Each filter column was eighteen feet high and consisted of three sections. The three sections were connected by two Victaulic couplings.

c. Chemical Feed System

Three peristalic pumps, with two rollers squeezing a flexible tubing, were installed. Two of the units were equipped with four channels each and one unit had a single channel. The pumps were capable of feeding nine different chemical solutions simultaneously to various inlets.

SECTION VII

ULTRA HIGH RATE FILTRATION RESULTS

Two groups of tests were programmed with the ultra high rate filtration pilot plant at the Southerly Wastewater Treatment Plant in Cleveland. The first group were preliminary tests to evaluate ultra high rate filtration operating and design variables for the treatment of secondary effluent. The preliminary test included the evaluation of various filter media as well as coagulants and flocculants. Various coagulants and flocculants were first tried in jar tests and these results were later used in determining the best coagulants and polymers for use in the three-inch diameter filters.

The second group of tests were principal tests, to determine the optimum parameters for operation of the ultra high rate filtration process. The principal filtration experiments were conducted in a six-inch diameter filter set. Rate of filtration, head loss, influent and effluent water quality, and backwash procedure were major investigative factors.

Preliminary Test

Four types of filter media were evaluated. The combinations of anthracite and sand in these media were as follows:

Type 1. Sixty inches of No. 3 Anthracite over thirty-six inches of No. 612 Sand.

Type 2. Sixty inches of No. 2 Anthracite over thirty-six inches of No. 1220 Sand.

Type 3. Sixty inches of No. 1 1/2 Anthracite over thirty six inches of No. 1220 Sand.

Type 4. Sixty inches of No. 1 Anthracite over thirty-six inches of No. 2050 Sand.

Based on the same operating condition, suspended solids concentration in the filter effluent, using these media, were similar. For instance, at a flux rate of 16 gpm/sq ft, with polymer addition, the effluent suspended solids were 3.0 mg/l, 2.0 mg/l, 1.85 mg/l and 2.2 mg/l for media type 1, 2, 3 and 4, respectively. Results on plain filtration test runs at 16 gpm/sq ft indicated that type 3 and 4 media were too fine, as the flux rate was reduced to fifty percent of the original flow within 180 minutes while the rate dropped only twenty percent in types 1 and 2. Table A-1, in Appendix A, illustrates these results. Based on the length of filter run, volume of water produced and filter effluent quality for the three testing modes, filter media type 2 was selected for further study.

For further evaluation of No. 2 Anthracite and No. 1220 Sand, four different combinations of filter bed depth were studied. These combinations of filter media were as follows:

Type 2. Sixty inches of No. 2 Anthracite over thirty-six inches of No. 1220 Sand.

Type 5. Sixty inches of No. 2 Anthracite over twenty-four inches of No. 1220 Sand.

Type 6. Forty-eight inches of No. 2 Anthracite over twenty-four inches of No. 1220 Sand.

Type 7. Seventy-two inches of No. 2 Anthracite over twenty-four inches of No. 1220 Sand.

The tests were conducted during two different periods. Filter media types 2 and 5 were evaluated in 1971 (early test period) with the 3-inch diameter filter columns, and under declining rate control for both plain filtration and for filtration with 1.0 mg/l of Calgon No. 25. Composite samples of the filter influent and effluent were collected at 30-minute intervals and were analyzed for suspended solids. Comparing these two types of media indicated in Table A-2, in Appendix A, type 5 showed lower suspended solids concentrations in the filter effluent, therefore this media (60" No. 2 Anthracite over 24" No. 1220 Sand) was mostly utilized throughout the test period.

After a long period of evaluating media type 5 with various chemical (alum and polymers) addition and filtration rates, it was discovered that variations in anthracite depth could improve the anthracite/sand combination. Therefore, filter media types 5, 6 and 7 were compared in early 1972. The results are summarized in Table 5. Grab samples for filter influent and effluent suspended solids determinations were collected every 30 minutes. Among the three media, type 7 produced the lowest suspended solids concentrations in the filtrate but was higher in head loss.

TABLE 5

EVALUATION OF FILTER BED DEPTH

Type of Media	Flux * Rate (gpm/sq ft)	Suspended Solids Average Influent (mg/l)	Suspended Solids Average Effluent (mg/l)	Removal (%)	Head Loss (ft)	Length of Run (min.)
1971 Test						
Plain Filtration						
2	24	8.5	4.5	47.0	-	240
5	24	8.5	3.5	59.0	-	240
With 1.0 mg/l of Calgon No. 25 Addition						
2	24	8.5	3.7	56.5	-	240
5	24	8.5	3.1	63.5	-	240
1972 Test						
With 15.0 mg/l of Alum and 1.0 mg/l of Calgon No. 226 Addition						
5	24	10.3	2.9	71.8	13.8	300
6	24	10.3	2.6	74.8	14.5	300
7	24	10.3	1.9	81.5	12.5	240
5	8	17.3	2.3	86.7	5.1	360
6	8	17.3	2.0	88.4	5.3	360
7	8	17.3	1.5	91.3	7.3	360

* Initial setting rate.

On October 18, 1971, the Southerly plant began operating in an abnormal condition due to mechanical failures in the sludge incineration building. The digested sludge was recycled to the primary tanks causing suspended solids and COD levels to increase in the secondary effluent. The suspended solids removal efficiency was sharply reduced during the abnormal period.

Table 6 shows the effect of the activated sludge plant operation on UHR filtration performance. It indicates the decrease in the filter efficiency from the initial normal activated sludge plant operation to the abnormal condition. Filtration runs 1SE-III and 2SE-III were conducted during the plant initial normal operation period. At the time the plant started to recycle digested sludge to the primary tanks, filtration runs 4SE-V and 4SE-VIII were in progress. Filtration runs 6ASE were conducted while the plant was operating under a completely abnormal condition in late October 1971.

In order to improve process efficiency under these abnormal plant conditions, a series of filter runs were performed with various types of polymers and with or without alum coagulants. The results show that alum with cationic polymer (Calgon No. 226) improved floc formation and, in turn, reduced suspended solids levels in the filter effluent as indicated in Table 7.

Thirty polymers were utilized in the preliminary testing work to evaluate the coagulation filtration performance. Nineteen polymers with alum, seven polymers with lime, and four polymers with alum or lime addition were compared for enhancing filtration efficiency. Results of the polymer comparison tests are presented in Tables A-3 and A-4, in Appendix A. These results show that certain polymers slightly improved the suspended solids removals, some seemed to have a negligible effect, and others seemed to cause a deteriorated performance. Neither polymer, nor alum plus polymer gave results significantly better than plain filtration based on tests in the eight parallel columns.

Among the thirty polymers, ten types were further evaluated with two levels of polymer dosage either with alum or lime addition. The test results are presented in Table A-4 in Appendix A.

Principal Test

Two basic modes of process operation were evaluated for removing suspended solids and other contaminants in suspended form: plain filtration and coagulation followed immediately by filtration. Coagulation-

TABLE 6

THE EFFECT OF ACTIVATED SLUDGE PLANT OPERATION TO UHR FILTRATION EFFICIENCY

Run No.	UHR Filtration Performance* Flux Rate (gpm/sq ft)	Suspended Solids Influent (mg/l)	Suspended Solids Effluent (mg/l)	Suspended Solids Removal (%)
Plain Filtration				
1SE-III	16	20.7	2.5	88.0
4SE-IV	16	8.5	3.4	60.0
6ASE-VIII	16	22.0	9.6	56.0
With 1.0 mg/l of Calgon No. 25 Addition				
2SE-III	16	8.1	2.0	75.5
4SE-VIII	16	8.5	2.2	72.2
6ASE-III	16	22.0	10.2	54.0

* Filter Media = 60" No. 2 Anth./24" No. 1220 Sand

TABLE 7

THE EFFECT OF ALUM AND POLYMER ADDITIONS ON UHR FILTRATION EFFICIENCY DURING ABNORMAL PLANT OPERATIONS

Flux Rate (gpm/sq ft)	Alum Feed (mg/l)	Polymer Feed (mg/l)	Suspended Solids Influent (mg/l)	Suspended Solids Effluent (mg/l)	Suspended Solids Removal (%)
24	0	1.0	66.25	30.0	55
8	0	1.0	66.25	16.5	75
24	15	1.0	63.0	6.7	90
8	15	1.0	63.0	5.1	93

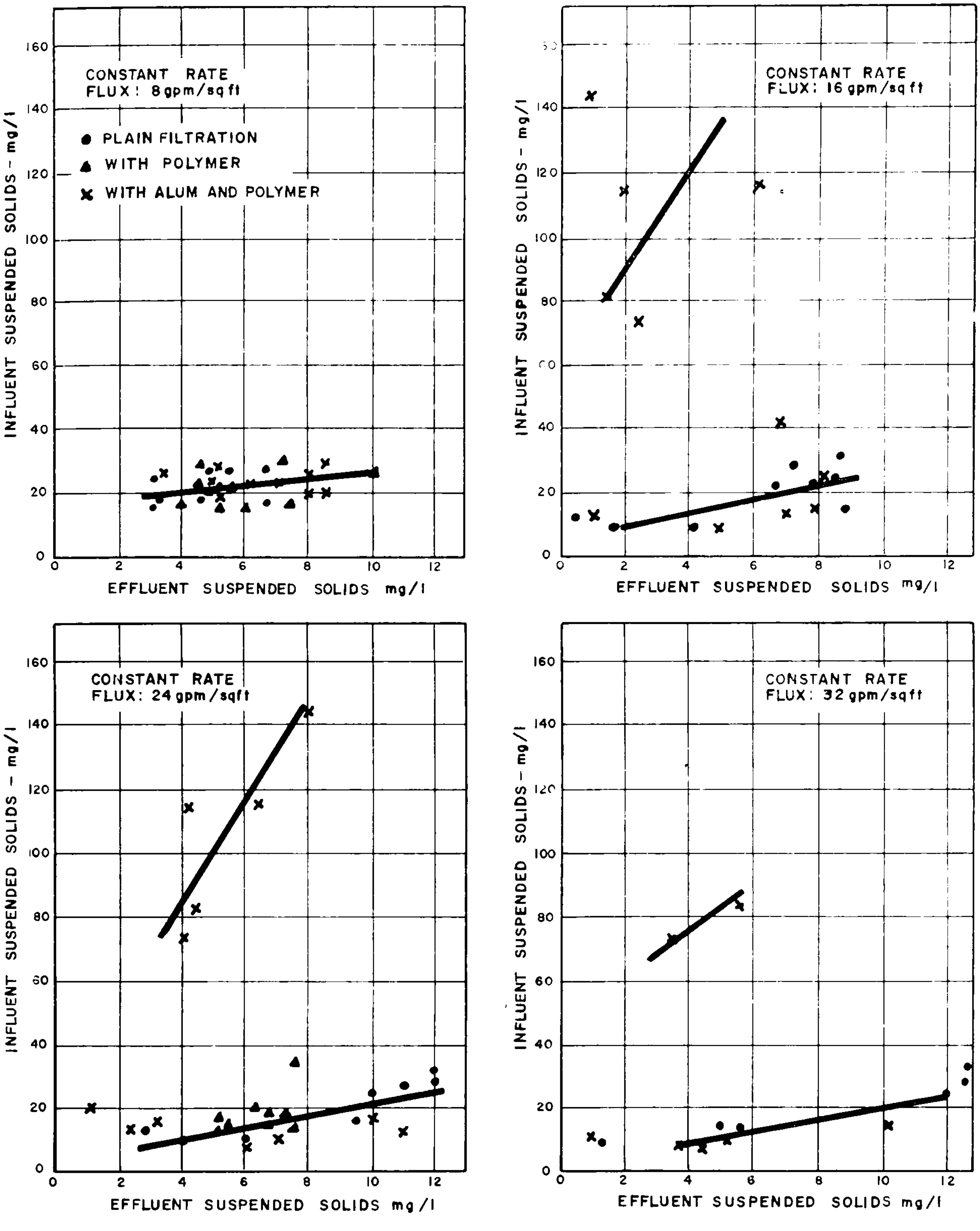
filtration was evaluated with alum and or cationic polymers, while plain filtration utilized no chemicals or other additions. Complete test results for all the filtration runs are presented in Table A-5 in the Appendix A. A total of sixty two filter runs were performed, including eleven plain filtration runs, ten with polymers and forty one with alum and polymers. Forty nine filter runs were conducted with the recommended filter media (60-inches of No. 2 Anthracite over 24-inches of No. 1220 Sand). Sets of filter performance curves for each run are presented in Figures B1 through B124, in Appendix B.

Figure 7 shows filter influent versus effluent suspended solids concentration at a filtration rate of 8, 16, 24 and 32 gpm/sq ft under constant rate control. This plot indicates that for filter influent suspended solids concentrations below 30 mg/l, the addition of chemicals (polymer or alum plus polymer) cannot be justified. On the other hand, the addition of alum and polymer enhances significantly, the filtration efficiency at influent suspended solids levels higher than 60 mg/l. Figure 7 also shows that filtration rate has little effect on the effluent suspended solids, which ranged between 1.0 mg/l and 12 mg/l.

Phosphate removals were calculated both as to percent removal and with respect to alum usage efficiencies. Although the molar ratio of aluminum to phosphorus is 1:1 to convert dissolved phosphate to aluminum phosphate ($AlPO_4$), the weight ratio is actually 0.87:1. The weight ratio of alum ($Al_2(SO_4)_3 \cdot 14H_2O$) to phosphorus is 9.67:1 and the weight ratio of alum to phosphate (PO_4) is 3.22:1. Plant results (10) indicate that an aluminum to phosphorus ratio up to 2:1 may be required for high (95 percent) phosphorus removal.

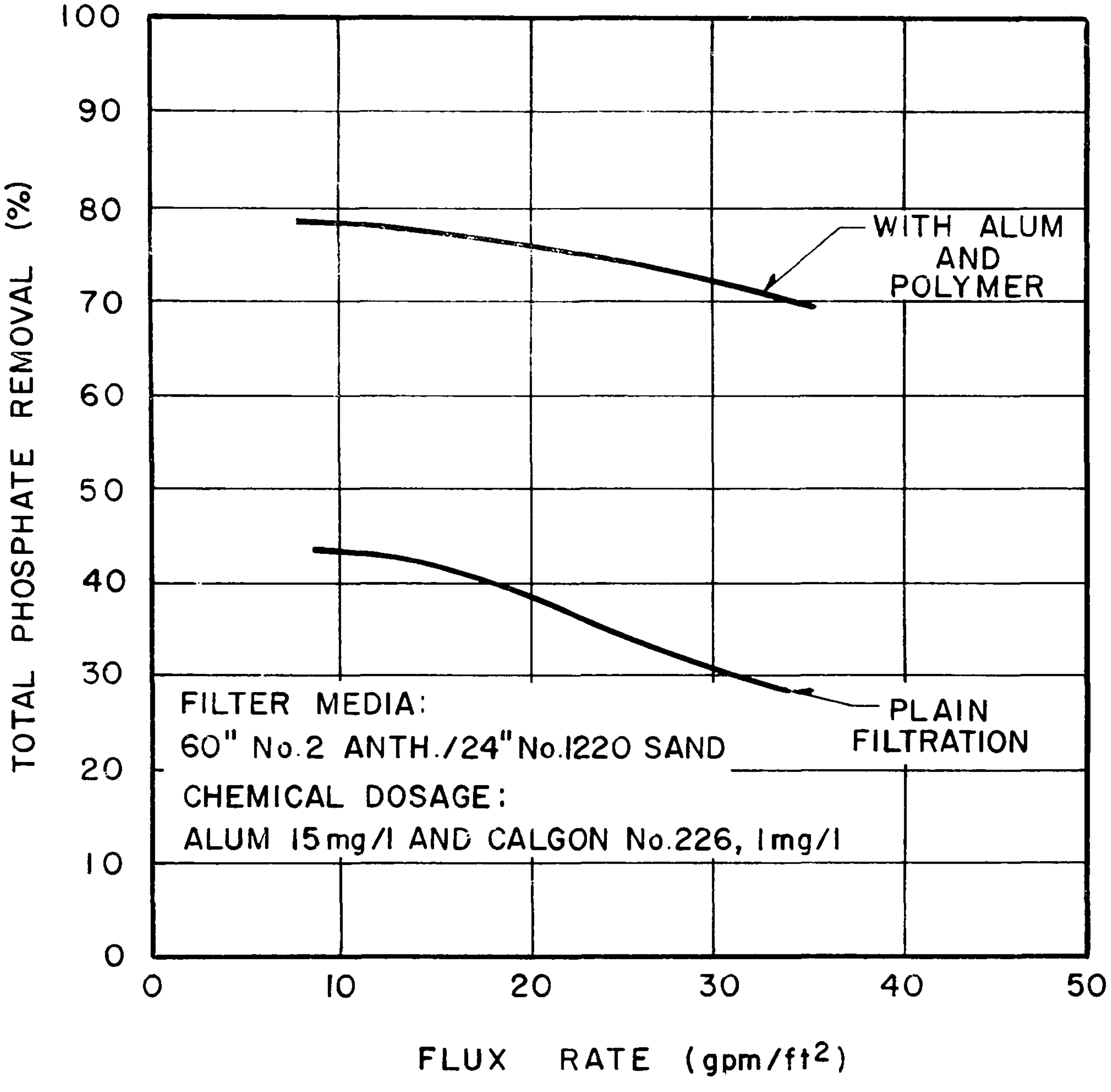
The range of total phosphate removals was 61.0 to 85.5% with filter flux rates between 24 and 16 gpm/sq ft. Figure 8 shows the average percent removals of total phosphate. The function of total phosphate removal by filtration is related to the effectiveness of reduction of suspended solids through the filter media. Figure 9 indicates the relationship between total phosphate and suspended solids removal.

BOD removals cover a variable range, both with and without alum and polymer addition to the filtration process. BOD levels in the filter effluent range between 3.8 and 14.4 mg/l with plain filtration at influent concentrations of 10.1 and 18.5 mg/l, respectively, between 1.8 and 13.4 mg/l with polymer addition at influent concentrations of 6.23 and 18.5 mg/l, respectively, and between 0.45 and 18.0 mg/l with alum and polymer at influent concentrations of 7.13 and 41.8 mg/l, respectively.



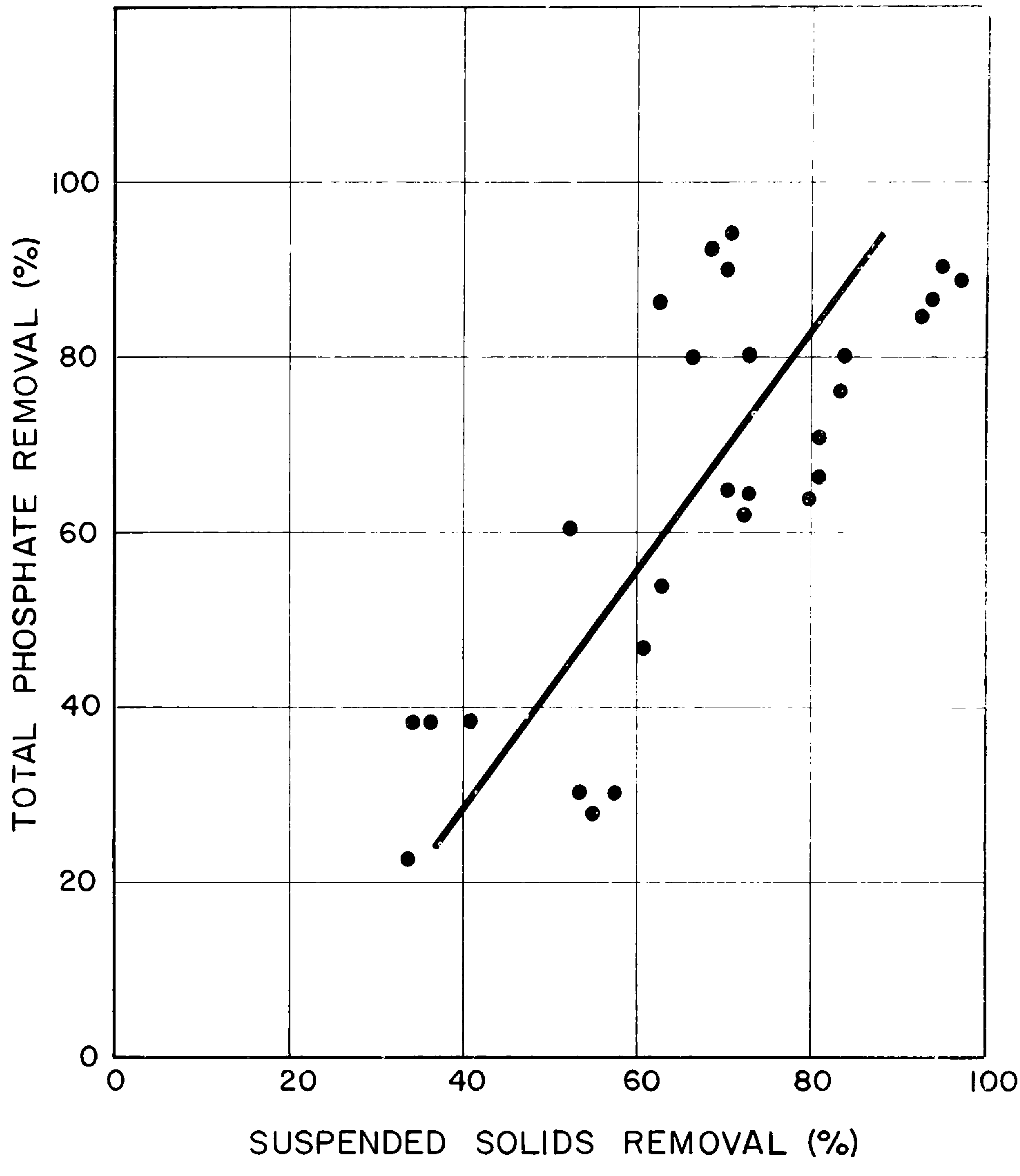
FILTER INFLUENT Vs EFFLUENT SUSPENDED SOLIDS

FIGURE 7



FILTER PERFORMANCE
TOTAL PHOSPHATE REMOVAL

FIGURE 8



RELATIONSHIP BETWEEN TOTAL PHOSPHATE AND SUSPENDED SOLIDS REMOVAL

FIGURE 9

Most of the BOD in the activated sludge plant secondary effluent was attributed to microbiological growth in suspended or colloidal form. The degree of BOD removal depended on the efficiency of coagulation and flocculation prior to filtration. In essence, the results, as shown in Table A-5, in Appendix A, indicate that there is no significant relationship between filtration rates and effluent BOD concentrations.

COD removal data, as shown in Table A-5 in Appendix A, indicates that better removals are experienced with alum and polymer addition. The ranges of COD removal were 16.3 to 56.7% with plain filtration, and 34.0 to 88.0% with alum and polymer addition. However, the COD concentrations in the filter effluent fell in a narrower range, 32.6 to 43.9 mg/l with plain filtration and 21.1 to 44.9 mg/l with alum and polymer addition.

The head loss in the filter media during each filtration test run is indicated on individual data curves in Appendix B. This head loss does not include pressure losses across the filter bottom. Generally, three curves are presented for each filter run: the top curve indicating the head loss that is experienced essentially through the whole filter media, and the curves indicating the head loss in a certain depth of the media, with the media depth measured from the top of the bed.

Two major factors caused an increase of head loss during filtration: one was surface cake formation and the second was filter bed clogging. Both deposition of floc on top of the filter bed and penetration of suspended solids into the lower filter media were observed. The depth of suspended solids penetration may be seen from the above mentioned head loss curves. The rate of head loss was dependent on filter influent suspended solids concentration, floc size related to coagulation and flocculation efficiency, filter media depth and size, rate of filtration and method of rate control. Head loss curves in Figure B-1 through B-124 in Appendix B indicate that head loss developed more slowly in the declining rate condition than with constant rate control, and more rapidly at a higher filtration rate and at higher influent suspended solids concentrations. The length of run and total head loss data are indicated on Table A-5 in Appendix A.

Table 8 illustrates the production volume of water at various filter operating conditions. The filter influent suspended solids of all runs shown was below 30 mg/l. For constant flux runs flux rates of 8, 16, 24 and 32 gpm/sq ft produced 14,400; 11,500; 10,370 and 9,600 gallons/sq ft, respectively. For coagulant and polymer addition runs, a flux of 16 gpm/sq ft yielded a higher production volume for

TABLE 8

PRODUCTION VOLUME OF WATER AT VARIOUS OPERATING CONDITIONS

Initial Flux (gpm/sq ft)	Average Flux (gpm/sq ft)	Rate Control	Length of Run (hours)	Total Head Loss (ft)	Length of Run at 15' Head Loss (hours)	Volume of Water Produced Thru 15' Head Loss (gal/sq ft)
Plain Filtration						
8	8	C	8	1.9	30*	14,400
16	16	C	8	6.4	12*	11,500
24	24	C	8	19.6	7.2	10,370
32	32	C	8	28.7	5.0	9,600
With 15 mg/l of Alum and 1.0 mg/l of Calgon No. 226						
8	8	C	13	37.5	7.0	3,360
16	16	C	5	15.2	4.9	4,740
24	24	C	3	17.0	2.8	4,030
Plain Filtration						
8	-	D	-	-	-	-
16	16	D	6	4.8	15*	14,400
24	22.2	D	6	7.5	12*	15,980
32	27.6	D	6	11.0	8*	13,260
With 15 mg/l of Alum and 1.0 mg/l of Calgon No. 226						
8	7.5	D	6	5.1	10*	4,500
16	13.3	D	6	13.4	7.5*	5,980
24	16.2	D	5	14.3	5.5*	5,340
32	18.0	D	4	17.6	3.5	3,780

* Estimated value from head loss curve projection.

constant rate control. Production levels are estimated for Declining Rate Control in the table, but were not actually determined during experimental period.

Backwash Considerations

Backwash water volume ranged between 1.12 to 9.27 percent of the total water filtered with the median at approximately 5 percent. A backwash rate in a range of 35 to 65 gpm/sq ft of water was needed. Air was introduced at a rate of 10 to 15 scfm prior to water flushing.

Suspended solids analyses on backwash effluents indicated the filters were relatively clean after 5 to 10 minutes of water flush. Suspended solids levels in the filter backwash water ranged from 4 to 4,000 mg/l. After backwash, the entire filter bed was carefully examined to insure that the bed was clean.

At the end of each run, with alum and polymer addition, an accumulation of a few inches of material was noted on the surface of the filter media, although visual observation indicated that solids had also penetrated throughout the depth of the media. No problems were experienced in backwashing this accumulation from the top of the media. In a filtration facility, utilizing the deep bed, high rate filtration process with the addition of appropriate alum and polymer, the backwash water requirements should be minimized by utilizing air agitation to dislodge the floc, then backwashing with water at a sufficient rate to allow these particulates to escape the granular bed.

SECTION VIII

DESCRIPTION OF ULTRA-HIGH RATE FILTRATION INSTALLATION

Process Sequence

Based on the results of the testing program, a conceptual schematic of a high rate filtration system for the treatment of activated sludge plant secondary effluent is presented on Figure 10.

Secondary effluent from an activated sludge plant could flow by gravity to a low lift pumping station. From there, the flow would be lifted into the influent channel to the filters. At first, alum solution would be introduced into the pump discharge pipe, then a selected polymer solution would be fed into filter influent to create desirable floc size and concentration.

As indicated previously, a gravity type design, that is, open filtration units, are proposed. The water would be introduced at the top of the filter and would flow downward through the filter bed.

The filtration building would be provided with low pressure air blowers as a source of backwash air. Backwash pumps would be located in the filtration facilities to deliver water to the filters for backwashing. Generally, filter effluent could serve as a source of water for backwashing filters, but for reducing the operating cost, filter influent could be utilized.

The treatment building would also include a control area, office space, alum feeding equipment, and a system for adding polymer to the filter influent. The high rate filtration facility could be designed for automatic operation, and the operator would be needed only for routine maintenance and periodic delivery of chemicals. In full size treatment systems, chlorine feed for disinfection could be incorporated into the filtration facilities, or tied into an existing chlorination tank in the activated sludge plant.

Backwash Solids Handling

Dirty backwash effluent from the filtration facilities would flow by gravity to a backwash effluent holding tank and then be bled at a controlled rate to the sewage treatment plant influent. The solids would settle in the primary tank and would be handled along with

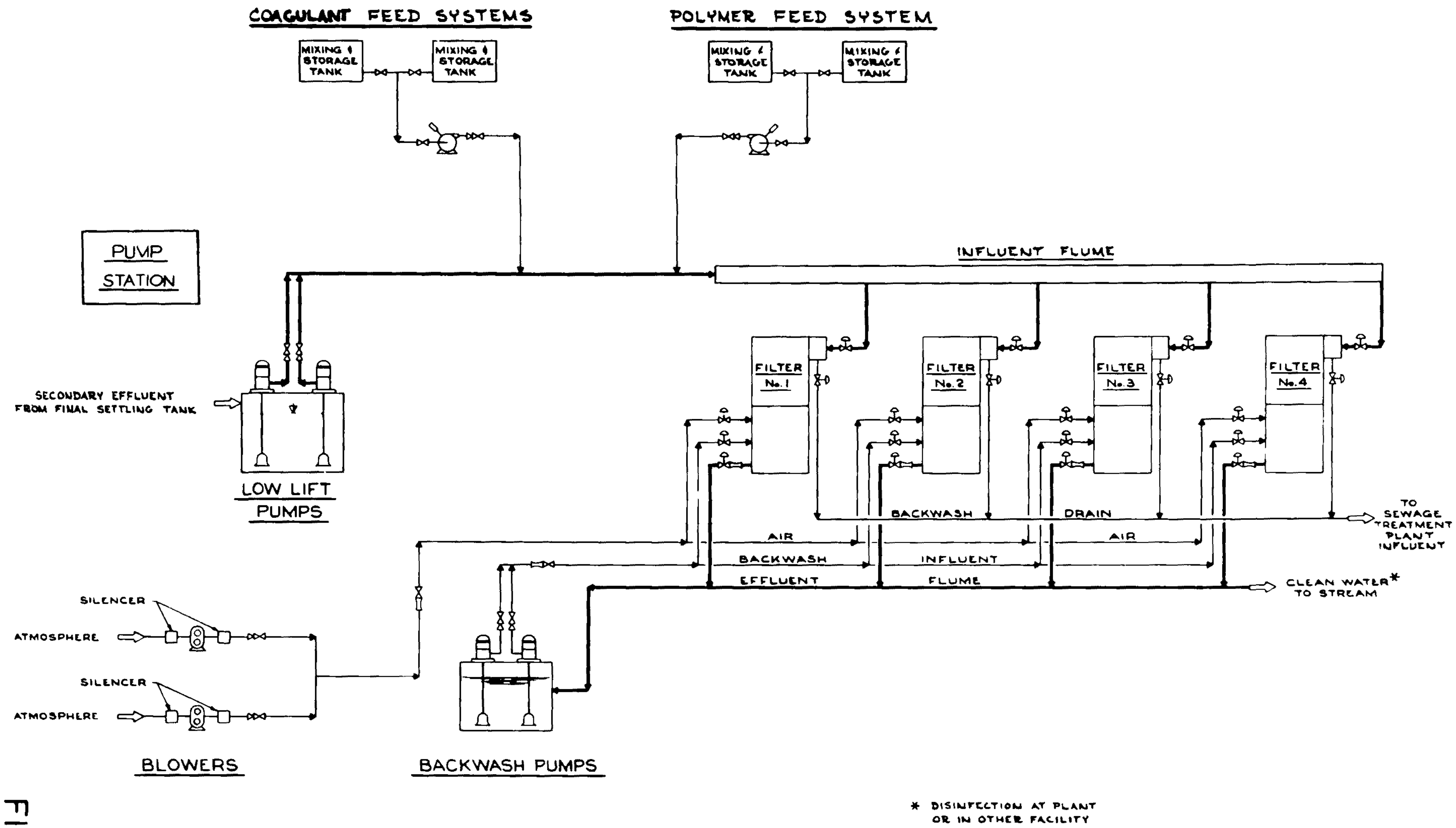


FIGURE 10

HIGH RATE FILTRATION INSTALLATION PROCESS FLOW DIAGRAM the primary sludge. The recycling of the backwash effluent, which contains alum sludge, could possibly improve the removal of suspended solids. Facilities for bleeding the backwash effluent into the plant influent should be considered.

Another possibility of handling the backwash solids would be to provide a complete sludge disposal system. The system would include a sludge thickener followed by a sludge dewatering process. The method of dewatering could be filter pressing, vacuum filtration or centrifuging. Under this alternate, the filter backwash effluent would be collected in a sludge thickening tank, the overflow would flow back to the primary settling tank at a controlled rate and the underflow would be pumped to a sludge dewatering facility. Many variables affect the selection of a sludge dewatering system. Some of these variables include concentration of aluminum hydroxide, solids concentration, temperature, pH, and sludge dewatering efficiency. For example, increasing alum feed in the system may cause the sludge to become more gelatinous. Dewatering of alum backwashing sludges can be efficiently accomplished in a filter press if a separate backwash disposal system is required (11).

Conceptual Design

For conceptual design purposes, the low lift pumping facility and the treatment plant have been incorporated into one site. Centralization and integration of pumping and treatment facilities is generally desirable. The 100 MGD system shown in Figures 11 and 12 is based on a filtration flux rate of 24 gpm/sq ft. The hydraulic capacity could be set at 20 percent greater than the design rate of the plant.

Figures 11 and 12 illustrate the general plan and a longitudinal section of a typical filter installation. The first level in the control building portion of the treatment facility includes the variable speed low lift pumping facilities, the chemical storage area, the alum and polymer feed equipment and the backwash pumps. The upper level of the plant includes electrical and control areas, and space allocations for office, service areas, etc.

Figure 13 shows a typical cross section of the filtration portion of the treatment plant with the filtration units arranged symetrically about the center line of the filter bay. Water is fed through the

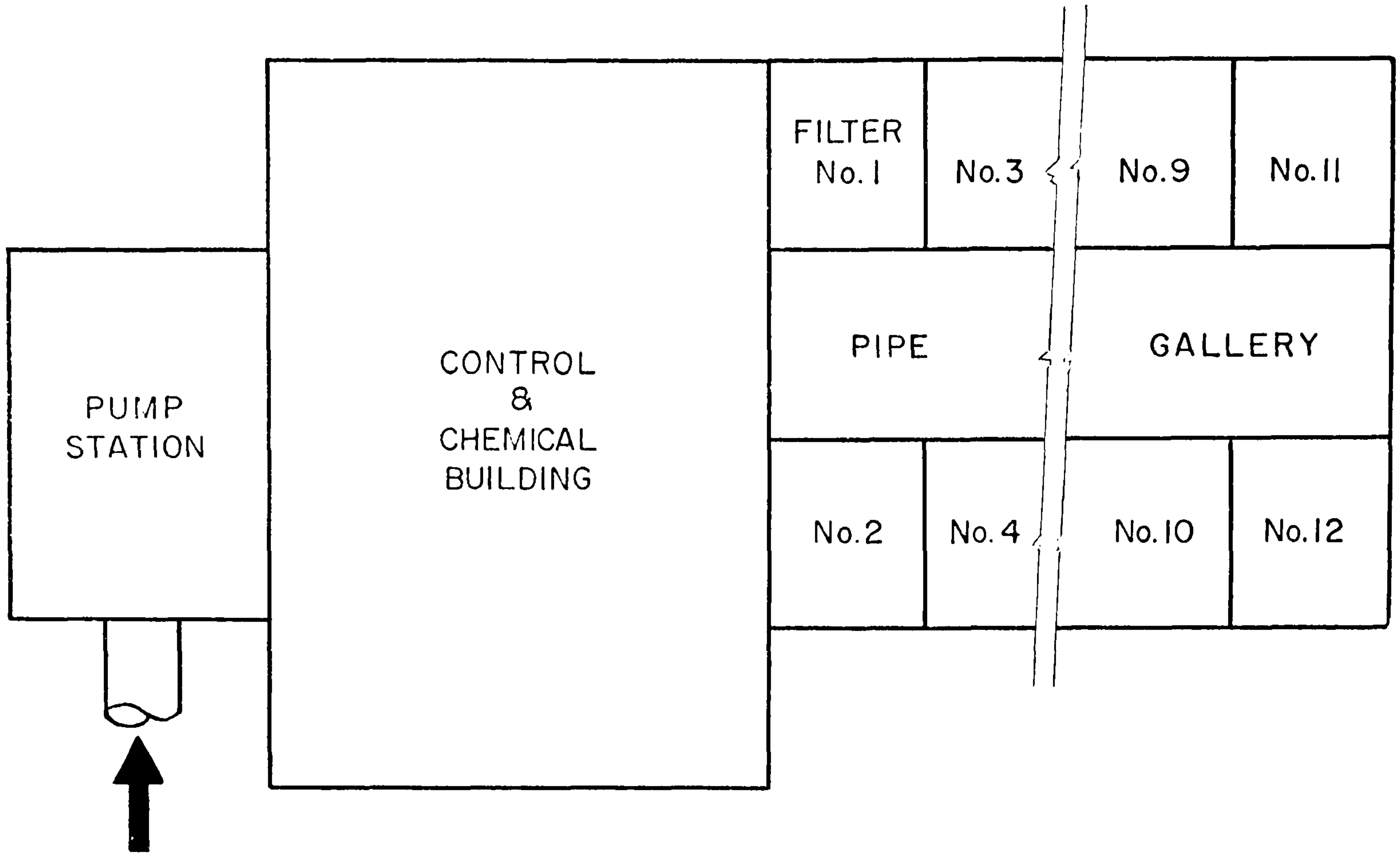


FIGURE 11

PLAN

HIGH RATE FILTRATION INSTALLATION (100 MGD)

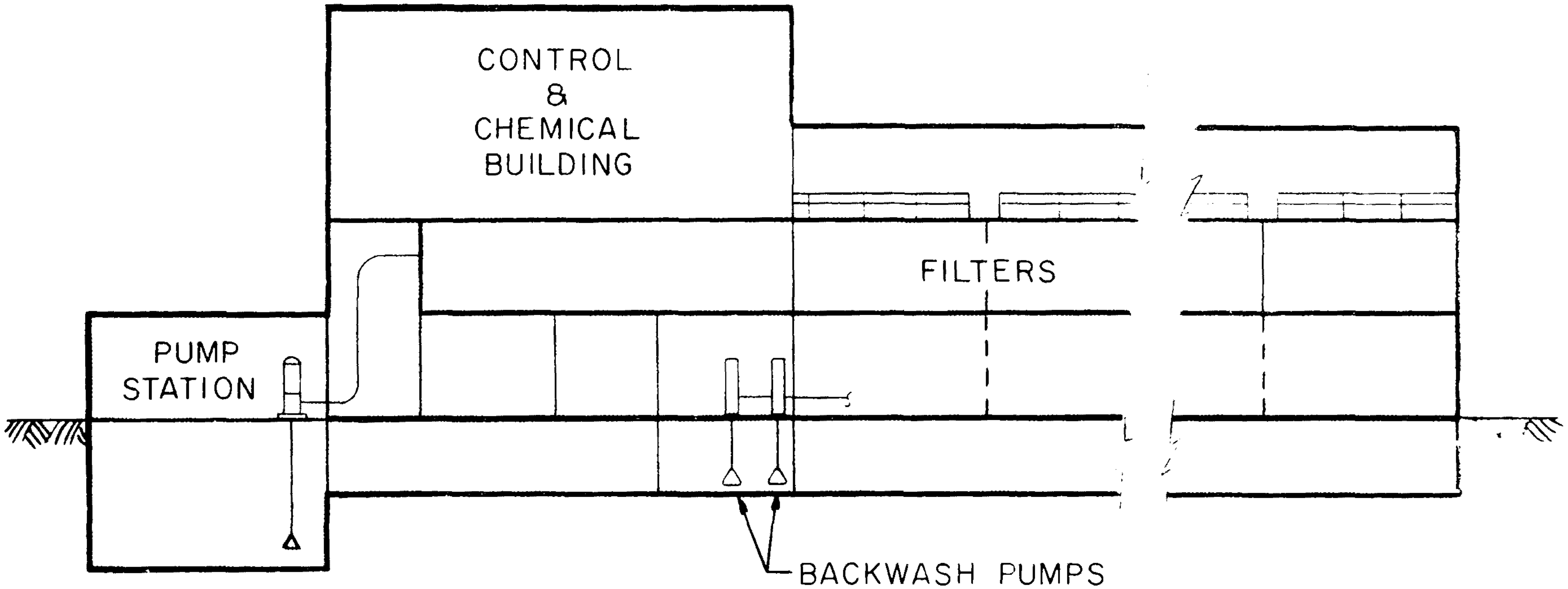
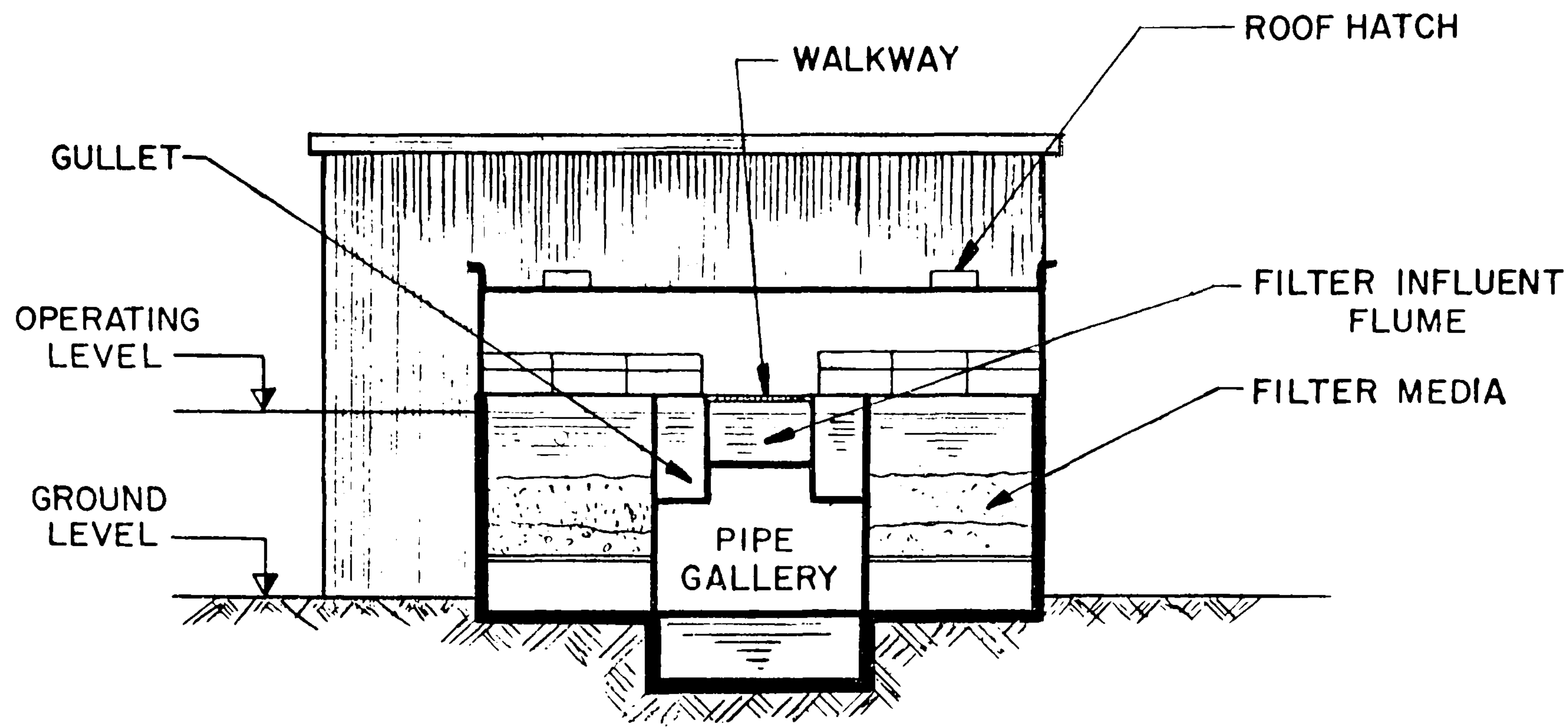


FIGURE 12

LONGITUDINAL SECTION

HIGH RATE FILTRATION INSTALLATION (100 MGD)



CROSS SECTION

HIGH RATE FILTRATION INSTALLATION (100 MGD)

FIGURE 13

filter influent flume then into each individual filter gullet and subsequently into the filter media bed. The filtered water flows downward through the media and filter bottom and out the filter effluent pipe, dropping into the plant effluent flume. The filter arrangement, as shown, is similar to a gravity filtration arrangement common to many potable water treatment plants, except that the depth of the media is much deeper.

SECTION IX

COST DATA

General

In developing unit cost estimates for a particular wastewater treatment process, a number of assumptions must be made to define a treatment plant which would be typical for many conditions. This has been accomplished in the preceding section. Depending on location, cost data developed for a particular treatment plant could be either high or low. This approach provides general order of magnitude information which can be utilized to determine what systems deserve consideration as potential treatment processes for suspended solids removal and other improvements in the quality of the secondary effluent from sewage treatment plants.

As noted in the preceding section, general designs were developed for a treatment facility to accommodate activated sludge effluent, including the integration of a low lift pump station with the treatment essentials. The cost of the influent pumping station has been included in the total cost of the facility, so that the costs will represent costs of the total project.

The treatment plant costs estimates presented in the summary curves contained in this section can be compared with alternate processes or engineering schemes, with associated cost-benefit relationships, for the required removals of pollutant loads necessary to achieve the degree of quality.

Capital Construction Costs

Cost estimates for filtration facilities for treating secondary effluent are presented for 25 to 200 mgd capacity plants. This range covers most areas of potential application. Estimated capital cost for different plant capacities are shown on Table 9 and Figure 14. Tables 10 through 13 contain detailed data on the capital cost estimates. These detailed breakdown costs were estimated for the ultra high rate filtration plant having design fluxes of 24 gpm/sq ft and 16 gpm/sq ft including alum and flocculant addition.

Capital cost estimates for the filtration plant include: the cost of equipment, installation and construction costs, and a 12 percent allowance for contingencies, plus a 10 percent allowance for engineering

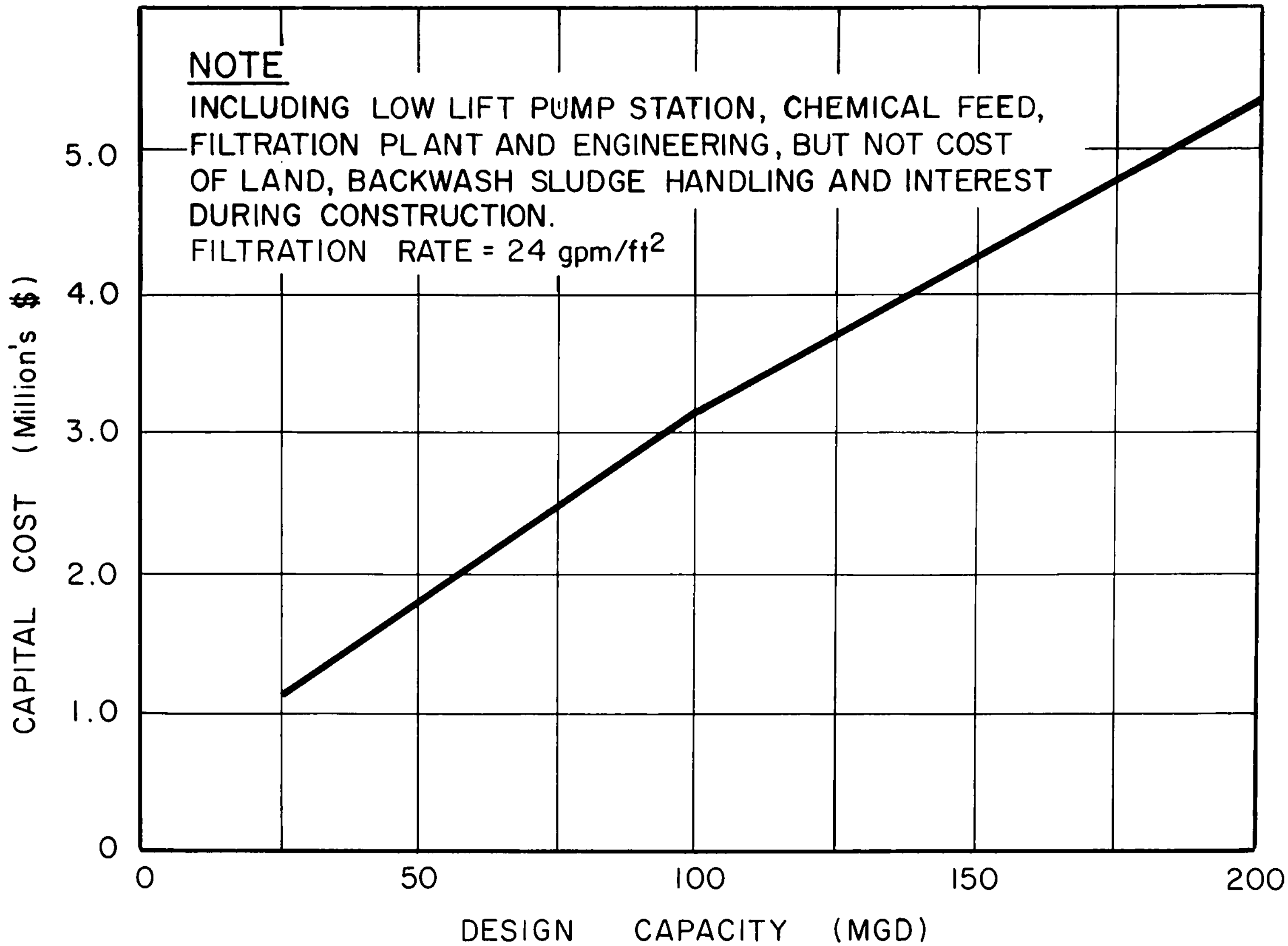


FIGURE 14

CAPITAL COST Vs. DESIGN CAPACITY (ENR=1682)

TABLE 9

SUMMARY OF CAPITAL CONSTRUCTION COST*

* Plant Capacity (MGD)	Capital Cost (ENR = 1,682)
25	$ 1,184,810
50	1,725,370
100	3,121,500
200	5,329,150

* Design Rate of 24 gpm/sq ft

TABLE 10

SUMMARY OF ESTIMATED PROJECT COSTS

FOR 25 MGD TREATMENT PLANT*

	Peak Filtration Rate Designed	
	24 gpm/sq ft	16 gpm/ sq ft
I. LOW LIFT PUMPING STATION		
Excavation and Backfill	$ 4,350	$ 4,350
Reinforced Concrete	44,100	44,100
Building	57,200	57,200
Pump	90,000	90,000
Piping	5,300	5,300
Heating and Ventilating	10,600	10,600
Electrical	42,500	42,500
Plumbing, Lighting, Interior & etc.	21,200	21,200
Sub-total	$ 275,250	$ 275,250
Construction Contingency (12%)	33,000	33,000
Sub-total Construction Cost	$ 308,250	$ 308,250
Engineering and Administration (10%)	31,000	31,000
Project Sub-total, Conveyance Portion	$ 339,250	$ 339,250

TABLE 10
(Continued)

	Peak Filtration Rate Designed	
	24 gpm/ sq ft	16 gpm/ sq ft
II. FILTRATION PLANT		
Excavation and Backfill	$ 9,160	$ 12,600
Reinforced Concrete	163,000	232,000
Building	92,300	105,200
Filter Media and Filter Bottom	21,200	31,800
Filter Backwash Pump	21,200	21,200
Air Blower	21,200	21,200
Piping	117,000	170,000
Polyelectrolyte Feed	21,200	21,200
Coagulant Feed	21,200	21,200
Chlorination Equipment	31,800	31,800
Heating and Ventilating	15,900	15,900
Electrical	53,000	53,000
Instrumentation	55,100	74,200
Plumbing, Lighting, Interior and etc.	42,400	47,700
Sub-total	$ 686,160	$ 859,000
Construction Contingency (12%)	82,400	103,000
Sub-total Construction Costs	$ 768,560	$ 962,000
Engineering and Administration (10%)	77,000	96,000
Project Sub-total Treatment Portion	$ 845,560	$1,058,000
III. TOTAL PROJECT COSTS	$1,184,810	$1,397,250

* Engineering News Record Construction Cost Index = 1682

TABLE 11

SUMMARY OF ESTIMATED PROJECT COSTS

FOR 50 MGD TREATMENT PLANT*

	Peak Filtration Rate Designed	
	24 gpm/ sq ft	16 gpm/ sq ft
I. LOW LIFT PUMPING STATION		
Excavation and Backfill	$ 4,350	$ 4,350
Reinforced Concrete	44,000	44,000
Building	57,200	57,200
Pump	148,500	148,500
Piping	10,600	10,600
Heating and Ventilating	12,720	12,720
Electrical	63,600	63,600
Plumbing, Lighting, Interior and etc.	26,500	26,500
Sub-total	$ 367,470	$ 367,470
Construction Contingency (12%)	44,000	44,000
Sub-total Construction Cost	$ 411,470	$ 411,470
Engineering and Administration (10%)	41,000	41,000
Project Sub-total, Conveyance Portion	$ 452,470	$ 452,470

TABLE 11
(Continued)

	Peak Filtration Rate Designed	
	24 gpm/sq ft	16 gpm/sq ft
II. FILTRATION PLANT		
Excavation and Backfill	$ 12,600	$ 16,100
Reinforced Concrete	288,000	420,000
Building	117,000	140,000
Filter Media and Filter Bottom	42,500	63,600
Filter Backwash Pump	21,200	21,200
Air Blower	21,200	21,200
Piping	225,000	333,000
Polyelectrolyte Feed	21,200	21,200
Coagulant Feed	21,200	21,200
Chlorination Equipment	31,800	31,800
Heating and Ventilating	19,100	19,100
Electrical	63,600	63,600
Instrumentation	95,500	127,200
Plumbing, Lighting, Interior & etc.	53,000	58,400
Sub-total	$ 1,032,900	$ 1,357,600
Construction Contingency (12%)	124,000	163,000
Sub-total Construction Costs	$ 1,156,900	$ 1,520,600
Engineering and Administration (10%)	116,000	152,000
Project Sub-total, Treatment Portion	$ 1,272,900	$ 1,672,600
III. TOTAL PROJECT COSTS	$ 1,725,370	$ 2,125,000

* Engineering News Record Construction Cost Index = 1682

TABLE 12

SUMMARY OF ESTIMATED PROJECT COSTS

FOR 100 MGD TREATMENT PLANT*

	Peak Filtration Rate Designed	
	24 gpm/ft ^{2}	16 gpm/ft ^{2}
I. LOW LIFT PUMPING STATION		
Excavation and Backfill	$ 6,100	$ 6,100
Reinforced Concrete	86,000	86,000
Building	128,200	128,200
Pump	270,000	270,000
Piping	15,900	15,900
Heating and Ventilating	21,200	21,200
Electrical	159,000	159,000
Plumbing, Lighting, Interior and etc.	31,800	31,800
Sub-total	$ 718,200	$ 718,200
Construction Contingency (12%)	86,100	86,100
Sub-total Construction Cost	$ 804,300	$ 804,300
Engineering and Administration (10%)	80,400	80,400
Project Sub-total, Conveyance Portion	$ 884,700	$ 884,700

TABLE 12
(Continued)

	Peak Filtration Rate Designed	
	24 gpm/ sq ft	16 gpm/ sq ft
II. FILTRATION PLANT		
Excavation and Backfill	$ 22,900	$ 23,600
Reinforced Concrete	539,000	820,000
Building	240,000	286,000
Filter Media and Filter Bottom	84,900	127,200
Filter Backwash Pump	38,200	38,200
Air Blower	38,200	38,200
Piping	441,000	657,000
Polyelectrolyte Feed	31,800	31,800
Coagulant Feed	31,800	31,800
Chlorination Equipment	47,600	47,600
Heating and Ventilating	31,800	31,800
Electrical	95,400	95,400
Instrumentation	100,700	138,000
Plumbing, Lighting, Interior and etc.	74,200	84,800
Sub-total	$ 1,815,500	$ 2,451,400
Construction Contingency (12%)	218,000	294,000
Sub-total Construction Costs	$ 2,033,500	$ 2,745,400
Engineering and Administration (10%)	203,300	274,600
Project Sub-total Treatment Portion	$ 2,236,800	$ 3,020,000
III. TOTAL PROJECT COSTS	$ 3,121,500	$ 3,904,700

Engineering News Record Construction Cost Index = 1682

TABLE 13

SUMMARY OF ESTIMATED PROJECT COSTS

FOR 200 MGD TREATMENT PLANT*

	Peak Filtration Rate Designed	
	24 gpm/sq ft	16 gpm/sq ft
I. LOW LIFT PUMPING STATION		
Excavation and Backfill	$ 12,250	$ 12,250
Reinforced Concrete	171,800	171,800
Building	254,000	254,000
Pump	509,000	509,000
Piping	26,500	26,500
Heating and Ventilating	31,800	31,800
Electrical	350,000	350,000
Plumbing, Lighting, Interior and etc.	63,600	63,600
Sub-total	$1,418,950	$1,418,950
Construction Contingency (12%)	170,000	170,000
Sub-total Construction Cost	$ 1,588,950	$ 1,588,950
Engineering and Administration (10%)	159,000	159,000
Project Sub-total Conveyance Portion	$ 1,747,950	$ 1,747,950

TABLE 13
(Continued)

		Peak Filtration Rate Designed	
		24 gpm/sq ft	16 gpm/sq ft
II.	FILTRATION PLANT		
	Excavation and Backfill	$ 45,800	$ 59,500
	Reinforced Concrete	915,000	1,282,000
	Building	458,000	538,000
	Filter Media and Filter Bottom	169,500	254,000
	Filter Backwash Pump	38,200	38,200
	Air Blower	38,200	38,200
	Piping	580,000	864,000
	Polyelectrolyte Feed	53,000	53,000
	Coagulant Feed	53,000	53,000
	Chlorination Equipment	68,900	68,900
	Heating and Ventilating	44,500	44,500
	Electrical	138,000	138,000
	Instrumentation	180,000	254,000
	Plumbing, Lighting, Interior and etc.	95,400	106,000
	Sub-total	$2,906,600	$ 3,791,300
	Construction Contingency (12%)	349,000	455,000
	Sub-total Construction Costs	$3,255,600	$ 4,246,300
	Engineering and Administration (10%)	325,600	424,600
	Project sub-total, Treatment Portion	$ 3,581,200	$ 4,670,900
III.	TOTAL PROJECT COSTS	$ 5,329,150	$ 6,418,850

* Engineering News Record Construction Cost Index = 1682

and administration of the proposed construction, but does not include the cost of land, backwash sludge handling and interest during construction. Construction cost estimates for a filtration plant for treating activated sludge secondary effluent range from $1,200,000 for 25 mgd capacity to $5,400,000 for 200 mgd capacity.

Total Annual Costs

Table 14 and Figure 15 present total annual costs for a high rate filtration plant. The estimated annual costs are based on plant operations for 365 days per year and include amortization, operation and maintenance. Tables 15 through 18 present breakdowns of these cost data.

These costs are based upon the following assumptions:

a. Interest at six percent for 25 years.

b. Maintenance at three percent of mechanical equipment cost and at two percent of electrical and instrumentation cost.

c. Labor at $15,000 per man year, including overhead and benefits.

d. Chemical application of polymer to filter influent at 1.0 mg/l and coagulant at 15 mg/l before filtration.

e. After filtration chlorination to provide disinfection before discharge to the receiving body of water at 5 mg/l of chlorine.

f. Unit costs of chemicals are:

Polymer	=	$1.50/lb	Alum	=	2.5¢/lb
Chlorine	=	5¢/lb			

g. Unit cost of electricity supplied through Consolidated Edison of New York, March 1972 as follows:

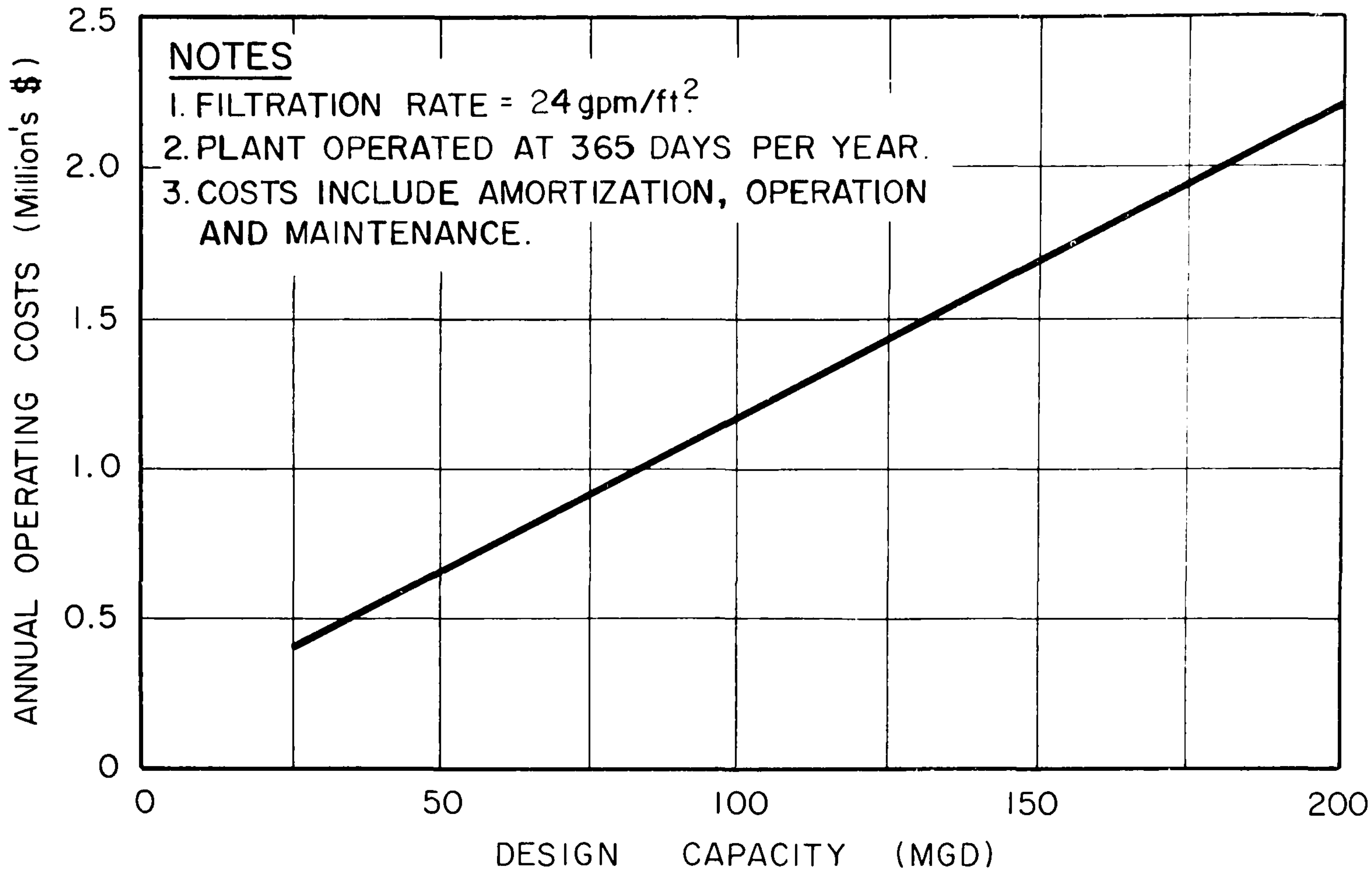
0-3000 Kw-hr	2.25¢
3000 - 150,000 Kw-hr	1.7 ¢
150,000 - 450,000 Kw-hr	1.55¢
450,000 - 1,450,000 Kw-hr	1.4 ¢
1,450,000 - 2,950,000 Kw-hr	1.25¢
2,950,000 - inclusive Kw-hr	1.15¢

TABLE 14

SUMMARY OF TOTAL ANNUAL COST*

Plant Capacity (MGD)	Annual Costs
25	$ 394,110
50	627,790
100	1,161,735
200	2,164,610

* Design Rate of 24 gpm/sq ft



TOTAL ANNUAL COST Vs. DESIGN CAPACITY

FIGURE 15

TABLE 15

SUMMARY OF ESTIMATED ANNUAL COSTS

FOR 25 MGD TREATMENT PLANT

	Peak Filtration Rate Designed	
	24 gpm/sq ft	16 gpm/sq ft
I. AMORTIZATION		
6 percent Interest Rate for 25 years	$ 92,600	$ 109,200
II. OPERATING COSTS		
Labor (Includes Overhead & Benefits)	$ 80,000	$ 80,000
Maintenance		
Mechanical Equipment (3% of Equipment Cost)	$ 7,630	$ 7,945
Electrical and Instrumentation (2% of Equipment Cost)	$ 3,010	$ 3,395
Piping (1% of Piping Cost)	$ 1,220	$ 1,750
Utilities		
Electrical (see schedule)	$ 37,800	$ 37,800
Chemicals		
Chlorine (5 mg/l)	18,750	18,750
Coagulant (15 mg/l)	28,100	28,100
Polymer (1.0 mg/l)	125,000	125,000
Operating Costs Sub-total	$ 301,510	$ 302,740
Total Annual Costs	$ 394,110	$ 411,940

TABLE 16

SUMMARY OF ESTIMATED ANNUAL COSTS

FOR 50 MGD TREATMENT PLANT

	Peak Filtration Rate Designed	
	24 gpm/sq ft	16 gpm/sq ft
I. AMORTIZATION		
6 percent Interest Rate for 25 years	$ 135,000	$ 166,500
II. OPERATING COSTS		
Labor (Includes Overhead & Benefits)	$ 80,000	$ 80,000
Maintenance		
Mechanical Equipment (3% of Equipment Cost)	$ 10,180	$ 10,815
Electrical and Instrumentation (2% of Equipment Cost)	$ 4,455	$ 5,090
Piping(1% of Piping Cost)	$ 2,355	$ 3,435
Utilities		
Electrical (see schedule)	$ 72,800	$ 72,800
Chemicals		
Chlorine (5 mg/l)	38,000	38,000
Coagulant (15 mg/l)	57,000	57,000
Polymer (1.0 mg/l)	228,000	228,000
Operating Costs Sub-total	$ 492,790	$ 495,140
Total Annual Costs	$ 627,790	$ 661,640

TABLE 17

SUMMARY OF ESTIMATED ANNUAL COSTS

FOR 100 MGD TREATMENT PLANT

	Peak Filtration Rate Designed	
	24 gpm/ sq ft	16 gpm/ sq ft
I. AMORTIZATION		
6 percent Interest Rate for 25 years	$ 244,000	$ 306,000
II. OPERATING COSTS		
Labor (Includes Overhead & Benefits)	$ 140,000	$ 140,000
Maintenance		
Mechanical Equipment (3% of Equipment Cost)	$ 17,865	$ 19,135
Electrical and Instrumentation (2% of Equipment Cost)	$ 7,100	$ 7,850
Piping (1% of Piping Cost)	$ 4,570	$ 6,910
Utilities		
Electrical (see schedule)	$ 112,200	$ 112,200
Chemicals		
Chlorine (5 mg/l)	$ 76,000	$ 76,000
Coagulant (15 mg/l)	104,000	104,000
Polymer (1.0 mg/l)	456,000	456,000
Operating Costs Sub-total	$ 917,735	$ 922,095
Total Annual Costs	$1,161,735	$ 1,228,095

TABLE 18

SUMMARY OF ESTIMATED ANNUAL COSTS

FOR 200 MGD TREATMENT PLANT

	Peak Filtration Rate Designed	
	24 gpm/sq ft	16 gpm/ sq ft
I. AMORTIZATION		
6 percent Interest Rate for 25 years	$ 416,000	$ 502,000
II. OPERATING COSTS		
Labor (Includes Overhead & Benefits)	$ 200,000	$ 200,000
Maintenance		
Mechanical Equipment (3% of Equipment Costs	$ 30,180	$ 32,720
Electrical and Instrumentation (2% of Equipment Cost)	$ 13, 360	$ 14,840
Piping(1% of Piping Cost)	$ 6,070	$ 8,900
Utilities		
Electrical (see schedule)	$ 227,000	$ 227,000
Chemicals		
Chlorine (5 mg/l)	$ 152,000	$ 152,000
Coagulant (15 mg/l)	208,000	208,000
Polymer (1.0 mg/l)	912,000	912,000
Operating Costs Sub-total	$ 1,748,610	$ 2,035,460
Total Annual Costs	$ 2,164,610	$2,537, 460

Annual operating cost estimates range from $394,110 per year for a 25 MGD capacity plant to $2,164,610 per year for a 200 MGD capacity plant. The largest contributions to annual treatment costs for the high rate filtration process are interest and amortization charges and chemical treatment requirements. Some savings may be realized through the purchase of bulk shipments of polymer which could represent a significant reduction in total costs.

As evidenced in the previous section, the filtration plant design and the associated housing for process units, would be suitable for a cold climate. In warmer areas, and in locations where local engineering practices permit a more compressed equipment arrangement, the enclosure could be removed from the filter portion and from some of the related process equipment. It may also be possible to compress the site requirements, especially in the building, resulting in a reduction of both capital and operating costs on the order of 10 to 20 percent.

Treatment System Comparison

A cost comparison between an ultra high rate and a conventional filtration system was estimated on the basis of similar process units but different design criteria. The cost comparison was based on data from listed references (12, 13) and from experience in the design of such treatment units. In all cases, capital costs were adjusted to reflect an Engineering News Record (ENR) Construction Cost Index of 1,682 for March 1972. Costs of land acquisition were not included. The rate of filtration was assumed to be 4 gpm/sq ft for conventional filters and 24 gpm/sq ft for UHR filters with equal effluent quality.

The comparison of annual cost estimates for a 25 mgd plant, including amortization, operation and maintenance, indicated an approximate savings of as much as 40% for the UHR filtration system. This was primarily due to reduced construction area and fewer filtration units required for UHR filtration. Operation and maintenance costs for both UHR and conventional filters were comparable even though UHR filtration requires more power than conventional filters. Estimated power costs for both a conventional and an ultra high rate filtration system are presented in Table 19.

Estimated power costs for both a conventional and an ultra high rate filtration system are presented in Table 19.

TABLE 19

ESTIMATED POWER COSTS FOR UHR AND CONVENTIONAL

FILTRATION SYSTEMS

Design	Annual Cost		Cost/MG		Cost of Power/1000 gal	
Capacity	UHRF	Conventional	UHRF	Conventional	UHR	Conventional
25	$37,800	$21,400	$4.14	$2.35	$0.414	$0.235
50	72,800	40,200	3.99	2.53	0.399	0.253
100	112,200	94,000	3.08	2.57	0.308	0.257
200	227,000	194,000	3.10	2.65	0.31	0.265

The estimated power costs for UHR and conventional filtration systems as shown in Table 19 are based on the power consumed by influent pumps, backwashing, and instrumentation and control units. The charges for power utilization are based on Consolidated Edison of New York's schedule of rates. The annual power costs range from $37,800 to $227,000 for UHR filtration capacities of 25 and 200 MGD, respectively. For a conventional filtration system, these costs are $21,400 and $194,000 per year for 25 and 200 MGD facilities, respectively.

Area requirements for both processes are estimated and compared in Table 20. Area requirements for conventional and UHR filtration systems include filters, filter gallery, control and chemical building, backwashing facilities, and a low lift pumping station, but not including backwash wastewater handling facilities.

TABLE 20

ESTIMATED TREATMENT SYSTEM AREA REQUIREMENTS

Design Capacity (MGD)	Area Required: UHR* (Sq ft)	Area Required: Conventional** (Sq ft)
25	3,000	7,600
50	4,600	13,000
100	9,300	27,000
200	16,500	50,000

*Design Rate of 24 gpm/sq ft
**Design Rate of 4 gpm/sq ft

SECTION X

ACKNOWLEDGEMENTS

This project was undertaken and implemented through a joint effort of the U.S. Environmental Protection Agency and Hydrotechnic Corporation of New York with the cooperation of the City of Cleveland, Ohio. The USEPA offices involved in this project are:

U.S. Environmental Protection Agency
Municipal Technology Branch
1901 N. Ft. Meyer Drive
Rosslyn, Virginia
Telephone: 703-522-0811

Advanced Waste Treatment Laboratory
4676 Columbia Parkway
Cincinnati, Ohio 45226
Telephone: 513-871-1820

Acknowledgement is made to Mr. W.A. Rosenkranz, Chief, Municipal Technology Branch and Mr. Francis Condon, Municipal Pollution Technology Section. Special acknowledgement is due to Dr. S.A. Hannah and Mr. J.F. Kreissl, Project Officer, of the Advanced Waste Treatment Laboratory in Cincinnati, Ohio for the invaluable advice which was given on many aspects of this project. We wish to express our gratitude to Mr. Richard Field, Chief, Storm and Combined Sewer Technology Branch for permission to use the pilot plant. The city departments in Cleveland involved in this project are:

City of Cleveland, Ohio
Department of Public Utilities
Division of Water Pollution Control
1825 Lakeside Avenue
Cleveland, Ohio 44114
Telephone: 216-694-2750

Southerly Wastewater Treatment Plant
6000 Canal Road
Cleveland, Ohio 44125
Telephone: 216-641-3200

Acknowledgement is made to Mr. W.S. Gaskill, past Director of Public Utilities and Mr. R.A. Kadukis, Director of Public Utilities and to Mr. C.A. Crown, Commissioner of Water Pollution Control. Thanks are also due to Messrs. R.A. Roth, Assistant Commissioner of Water Pollution Control, Nabil Ghoubrial, Sewage Treatment Plant Superintendent and J.N. Donahue, who together with other members of the Southerly Wastewater Treatment Plant staff enabled this program to be a success. The project was conducted by a consulting engineering firm:

Hydrotechnic Corporation
641 Lexington Avenue
New York, New York 10022
Telephone: 212-752-4646

The project was conceived by Mr. Ross Nebolsine, President, who provided general guidance and high level review throughout its duration.

The project was managed, for most of its duration, by Mr. Ivan Pouschine, Jr., Vice President. In the initial stages the project was managed by Mr. P.J. Harvey, Division Engineer.

General consultation and review were provided by Dr. J.C. Eck, Consultant, and Mr. H.J. Kohlmann, Manager of Engineering. Dr. Eck contributed many valuable engineering suggestions throughout the duration of this project. Mr. Chi-Yuan Fan, Principal Engineer, was in charge of the daily technical aspects of the project, supervising a field team and an office staff.

The on-site field testing program was directed by Mr. R. Morales and later by Mr. E.F. Neubauer.

SECTION XI

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SECTION XII

PUBLICATION

R. Nebolsine and J.C. Eck, "Tertiary Treatment of Sewage by the Ultra High Rate Filtration Process," Paper presented at 44th Annual Meeting of the New York Water Pollution Control Association, New York, January, 1972.

SECTION XIII

APPENDICES

Table A-1

Experimental Program for Comparison of Filter Media Size

Run No.	Type of Media (1)	Flux (2) (gpm/sq ft)	Coagulant Feed (3) (mg/l)	Polymer Feed (4) (mg/l)	Filter Performance: Influent S.S. (mg/l)	Filter Performance: Effluent S.S. (mg/l)	Filter Performance: Removal (%)	Volume (5) Water Produced (gal/sq ft)	Total (6) Length of Run (min.)
1SE - I	1	16	-	-	20.7	1.0	94.5	2351	240
1SE - II	1	8	-	-	20.5	1.0	95.0	825	180*
1SE - III	2	16	-	-	20.7	2.5	88.0	2506	240
1SE - IV	2	8	-	-	20.7	1.2	94.0	1005	240
1SE - V	4	16	-	-	16.0	1.0	93.0	1946	180*
1SE - VI	4	8	-	-	16.0	1.5	91.0	880*	120*
1SE - VII	3	16	-	-	16.0	1.0	93.0	1958	180*
1SE - VIII	3	8	-	-	20.5	1.0	95.0	970	210*
2SE - I	1	16	-	1.0	8.1	3.0	63.0	2144	240
2SE - II	1	8	-	1.0	8.1	2.6	68.0	1155	240
2SE - III	2	16	-	1.0	8.1	2.0	75.5	2402	240
2SE - IV	2	8	-	1.0	8.1	1.7	79.0	1224	240
2SE - V	4	16	-	1.0	8.1	1.85	80.0	2099	240
2SE - VI	4	8	-	1.0	8.1	2.05	75.0	1185	240
2SE - VII	3	16	-	1.0	8.1	2.20	74.0	2342	240
2SE - VIII	3	8	-	1.0	8.1	1.85	80.0	1374	240
3SE - I	1	16	15.0	1.0	3.0	1.9	35.0	1967	180*
3SE - II	1	8	15.0	1.0	3.3	1.3	60.0	1095	240
3SE - III	2	16	15.0	1.0	3.3	1.2	62.5	2232	240
3SE - IV	2	8	15.0	1.0	3.3	1.0	69.0	1122	240
3SE - V	4	16	15.0	1.0	3.0	2.0	35.0	873*	120*
3SE - VI	4	8	15.0	1.0	3.0	0.7	76.0	702*	120*
3SE - VII	3	16	15.0	1.0	1.6	0.5	69.0	1446*	90*
3SE - VIII	3	8	15.0	1.0	3.1	2.2	40.0	948	180*

NOTES:

(1) Type of Media = Type 1: 60" No. 3 Anth./36" No. 612 Sand, Type 2: 60" No. 2 Anth./36" No. 1220 Sand
Type 3: 60" No. 1 1/2 Anth./36" No. 1220 Sand, Type 4: 60" No. 1 Anth./36" No. 2050 Sand

(2) Declining rate operation. Indicated as initial rate of filtration.

(3) Coagulant = $FeCl_3$

(4) Polymer = Calgon No. 25

(5) Volume of water produced is the weighted average through 180 minutes of filtration time. Where marked with asterisk the filtration time is as indicated in the right hand column.

(6) Length Of Run Based On 240 Minutes Of Filtration Time Or 50 Percent Of Flow Declined Marked With Asterisk (*).

Table A-2

Experimental Program for Comparison of Filter Bed Depth

Run No.	Type of Media (1)	Flux (2) (gpm/sq ft)	Coagulant Feed (3) (mg/l)	Polymer Feed (4) (mg/l)	Filter Performance: Influent S.S. (mg/l)	Filter Performance: Effluent S.S. (mg/l)	Filter Performance: Removal (%)	Volume (5) Water Produced (gal/sq ft)	Total (6) Length of Run (min.)
4SE - I	2	24	-	-	8.5	4.5	47.0	4037	240
4SE - II	2	16	-	-	8.5	2.5	70.6	2232	240
4SE - III	5	24	-	-	8.5	3.5	59.0	3335	240
4SE - IV	5	16	-	-	8.5	3.4	60.0	2541	240
4SE - V	2	24	-	A-1.0	8.5	3.7	56.5	3712	240
4SE - VI	2	16	-	A-1.0	8.5	2.3	73.0	2504	240
4SE - VII	5	24	-	A-1.0	8.5	3.1	63.6	3285	240
4SE - VIII	5	16	-	A-1.0	8.5	2.2	72.2	2429	240
6FSE - I	5	24	-	A-1.0	39.25	18.3	53.4	3236	180
6FSE - II	5	8	-	A-1.0	66.25	6.9	89.6	907	180
6FSE - III	5	24	-	B-1.0	66.25	30.0	54.6	2987	180
6FSE - IV	5	8	-	B-1.0	66.25	16.5	73.5	1116	180
6FSE - V	8	20	-	A-1.0	66.25	8.3	87.4	2017*	120*
6FSE - VI	8	8	-	A-1.0	66.25	6.8	89.7	1240	180
6FSE - VII	8	20	-	B-1.0	66.25	20.3	69.4	2457*	120*
6FSE - VIII	8	8	-	B-1.0	66.25	13.8	79.8	942	180
6GSE - I	5	24	15.0	A-1.0	51.5	5.6	89.1	1385*	90*
6GSE - II	5	8	15.0	A-1.0	63.0	4.0	93.6	1144	180
6GSE - III	5	24	15.0	B-1.0	63.0	6.7	89.4	2480	120*
6GSE - IV	5	8	15.0	B-1.0	63.0	5.1	91.9	979	180
6GSE - V	8	24	15.0	A-1.0	47.0	6.2	86.8	400*	60*
6GSE - VI	8	8	15.0	A-1.0	63.0	3.5	94.4	860*	120*
6GSE - VII	8	24	15.0	B-1.0	47.0	7.1	84.9	77*	30*
6GSE - VIII	8	8	15.0	B-1.0	51.5	5.1	90.1	539*	60*

NOTES:

(1) Type of Media:
Type 2: 60" No. 2 Anth./36" No. 1220 Sand
Type 5: 60" No. 2 Anth./24" No. 1220 Sand
Type 8: 60" No. 2 Anth./24" No. 2050 Sand

(2) Declining rate operation. Indicated as initial rate of filtration.

(3) Coagulant: Alum

(4) Polymer: Type A: Calgon No. 25 Type B: Calgon No. 226

(5) Volume of water produced is the weighted average through 180 minutes of filtration time. Where marked with asterisk the filtration time is as indicated in the right hand column.

(6) Length Of Run Based On 180 And 240 Minutes Of Filtration Time, Or 50 Percent Of Flow Declined Marked With Asterisk (*).

Table A-3

Experimental Program for Comparison of Polymers

Run No.	Type of Media (1)	Flux (2) (gpm/sq ft)	Coagulant Feed (mg/l)	Polymer Feed (3) (mg/l)	Filter Performance: Influent S.S. (mg/l)	Effluent S.S. (mg/l)	Removal (%)	Volume (4) Water Produced (gal/sq ft)	Total (5) Length of Run (min.)
6ASE - I	5	16	-	Magnifloc 985A	22.0	15.2	31	2184	180
6ASE - II	5	16	-	Calgon No 226	22.0	10.9	51	1980	180
6ASE - III	5	16	-	Calgon No 25	22.0	10.2	54	2043	180
6ASE - IV	5	16	-	Swift X-400	22.0	18.5	16	1980	180
6ASE - V	5	16	-	Purifloc A23	21.5	23.0	0	1359	120
6ASE - VI	5	16	-	Purifloc C31	22.0	11.5	48	1974	180
6ASE - VII	5	16	-	Atlas 3A3	22.0	22.2	0	1836	180
6ASE - VIII	5	16	-		22.0	9.6	56	2187	180
6CSE - I	5	16	Alum - 10.0	Calgon No 25	32.2	10.8	66	2197	180
6CSE - II	5	16	Alum - 10.0	Calgon No 226	32.2	18.0	43	2094	180
6CSE - III	5	16	Alum - 10.0	Purifloc C31	32.2	15.6	52	2043	180
6CSE - IV	5	16	Alum - 10.0	Magnifloc 985N	32.2	19.6	39	2361	180
6CSE - V	5	16	Alum - 10.0	Atlas 3A3	30.6	21.3	30	1309*	90*
6CSE - VI	5	16	Alum - 10.0	Atlas 2A2	30.6	21.6	29	951*	90*
6CSE - VII	5	16	Alum - 10.0	Swift X-400	32.0	19.7	38	1601*	120*
6CSE - VIII	5	16	Alum - 10.0		32.2	11.4	65	1959	180
6DSE - I	5	16	Alum - 10.0	Magnifloc 836A	13.2	13.2	0	549*	60*
6DSE - II	5	16	Alum - 10.0	Polyhall 295	13.7	16.2	0	1617	180
6DSE - III	5	16	Alum - 10.0	Hercofloc 816	13.6	18.2	0	1283*	120*
6DSE - IV	5	16	Alum - 10.0	Nalco 671	13.7	15.5	0	1943	180
6DSE - V	5	16	Alum - 10.0	Jaguar 22A	13.7	14.6	0	2189	180
6DSE - VI	5	16	Alum - 10.0	Aquarid 49-704	13.7	9.6	30	2288	180
6DSE - VII	5	16	Alum - 10.0	Aquarid 49-702	13.7	9.9	28	2052	180
6DSE - VIII	5	16	Alum - 10.0		13.7	10.2	26	1919	180
8BSE - I	5	16	Alum - 15.0	Hercofloc 828	37.6	6.8	82	2665	180
8BSE - II	5	16	Alum - 15.0	Aquarid 49-710	37.6	5.7	85	2773	180
8BSE - III	5	16	Alum - 15.0	Magnifloc 570C	37.6	8.1	78	2405	180
8BSE - IV	5	16	Alum - 15.0	Gamlenne 722	37.6	7.7	80	2199	180
8BSE - V	5	16	Alum - 15.0	Calgon No 228	37.6	9.2	76	2077	180
8BSE - VI	5	16	Alum - 15.0	Herocloc 810C	26.5	7.8	71	1324*	150*
8BSE - VII	5	16	Alum - 15.0	Atlas 109-C	26.5	8.7	65	1102*	120*
8CSE - I	5	16	Lime - 50.0	Atlas 1A1	14.0	5.1	64	2920	180
8CSE - II	5	16	Lime - 50.0	Magnifloc 860A	14.0	3.6	74	2294	180
8CSE - III	5	16	Lime - 50.0	Gamlen NA710	14.0	4.8	66	2460	180
8CSE - IV	5	16	Lime - 50.0	Magnifloc 865A	14.0	5.4	61	2471	180
8CSE - V	5	16	Lime - 50.0	Polyhall M-295	14.0	5.1	64	2424	180
8CSE - VI	5	16	Lime - 50.0	Nalco 672	8.0	3.8	52	2051	180
8CSE - VII	5	16	Lime - 50.0	Calgon No.240	14.0	5.1	64	2596	180
8CSE - VIII	5	16	Lime - 50.0	Atlas 5A5	14.0	7.1	50	2145	180

NOTES:

(1) Type Of Media: Type 5: 60" No. 2 Anth./24" No. 1220 Sand

(2) Declining rate operation. Indicated as initial rate of filtration.

(3) Polymer Feed At 1.0 mg/l Concentration.

(4) Volume of water produced is the weighted average through 180 minutes of filtration time. Where marked with asterisk the filtration time is as indicated in the right hand column.

(5) Length Of Run Based On 180 Minutes Of Filtration Time, Or 50 Percent Of Flow Declined Marked With Asterisk (*).

Table A-4

Experimental Program for Comparison of Polymers

at Two Levels Concentration

Run No.	(1) Type of Media	Flux (2) (gpm/sq ft)	Coagulant Feed (mg/l)	Polymer Feed (mg/l)	Filter Performance Influent S.S. (mg/l)	Effluent S.S. (mg/l)	Removal (%)	Volume (3) Water Produced (gal/sq ft)	Total (4) Length of Run (min.)
6SE - I	5	24		Mag.985N - 1.0	44.5	35.2	21	3236	180
6SE - II	5	16		Mag.985N - 1.0	41.3	13.6	67	907	120*
6SE - III	5	24		Cal. 226 - 1.0	41.3	30.0	27	2987	120*
6SE - IV	5	16	-	Cal. 226 - 1.0	43.0	27.4	36	1116	180
6SE - V	5	24	-	Mag.985N - 0.5	41.7	29.6	19	2017	60*
6SE - VI	5	16		Mag.985N - 0.5	43.0	27.8	35	1240	180
6SE - VII	5	24		Cal. 226 - 0.5	43.0	30.0	30	2457	180
6SE - VIII	5	16	-	Cal. 226 - 0.5	43.0	36.8	15	942	180
7SE - I	5	24		Mag.985N - 1.0	36.3	23.3	36	4450	180
7SE - II	5	24	-	Mag.985N - 0.5	36.3	20.9	42	3950	180
7SE - III	5	24	-	Purif.C31 - 1.0	36.3	22.8	37	4590	180
7SE - IV	5	24		Purif.C31 - 2.0	36.3	23.3	36	4250	180
8ASE - I	5	16	Alum - 15.0	Mag.985N - 1.0	46	20.4	56	2440	180
8ASE - II	5	16	Lime - 50.0	Mag.985N - 1.0	46	12.4	73	2450	180
8ASE - III	5	16	Alum - 15.0	Purif.C31 - 2.0	46	9.4	80	2055	180
8ASE - IV	5	16	Lime - 50.0	Purif.C31 - 2.0	46	11.3	75	2230	180
8SE - I	5	24	Alum - 15.0	Cal. 25 - 2.0	12.3	5.3	57	3730	180
8SE - II	5	16	Alum - 15.0	Cal. 25 - 2.0	12.3	5.2	58	2210	180
8SE - III	5	24	Alum - 15.0	Cal. 226 - 1.0	12.3	5.3	57	3180	180
8SE - IV	5	16	Alum - 15.0	Cal. 226 - 1.0	12.3	6.2	50	2560	180
8SE - V	5	24	Alum - 15.0	Cal. 25 - 1.0	12.3	4.5	64	3410	180
8SE - VI	5	16	Alum - 15.0	Cal. 25 - 1.0	12.3	5.0	60	2520	180
8SE - VII	5	24	Alum - 15.0	Cal. 226 - 0.5	12.3	6.6	46	4000	180
8SE - VIII	5	16	Alum - 15.0	Cal. 226 - 0.5	12.3	6.6	46	2290	180
8DSE - I	6	24	Alum - 30.0	Mag.560C - 0.5	12.3	4.6	63	3020	180
8DSE - II	6	16	Alum - 30.0	Mag.560C - 0.5	12.3	4.4	64	2150	180
8DSE - III	6	24	Alum - 30.0	Aqu.49-710-1.0	12.3	7.2	42	3290	180
8DSE - IV	6	16	Alum - 30.0	Aqu.49-710-1.0	12.3	4.1	67	2200	180
8DSE - V	6	24	Alum - 30.0	Mag.560C-0.25	12.3	4.0	68	2870	180
8DSE - VI	6	16	Alum - 30.0	Mag.560C-0.25	12.3	5.1	59	2000	180
8DSE - VII	6	24	Alum - 30.0	Aqu.49-710-1.0	12.3.	6.3	47	3090	180
8DSE - VIII	6	16	Alum - 30.0	Aqu.49-710-1.0	12.3	4.1	67	1960	180
9SE - I	5	24	Alum - 15.0	Aqu.49-710-1.0	14.3	4.4	69	3480	180
9SE - II	5	16	Alum - 15.0	Aqu.49-710-1.0	14.3	3.2	78	2410	180
9SE - III	5	24	Alum - 15.0	Hercf.828-1-1.0	14.3	4.0	72	3020	180
9SE - IV	5	16	Alum - 15.0	Hercf.828-1-1.0	14.3	3.8	74	2190	180
9SE - V	5	24	Alum - 15.0	Aqu.49-710-0.5	14.3	4.3	70	3630	180
9SE - VI	5	16	Alum - 15.0	Aqu.49-710-0.5	14.3	2.6	82	2350	180
9SE - VII	5	24	Alum - 15.0	Hercf. 828-1-0.5	14.3	3.8	74	3490	180
9SE - VIII	5	16	Alum - 15.0	Hercf. 828-1-0.5	14.3	3.2	78	2030	180
10SE - I	5	24	Lime - 50.0	Cal. 25 -2.0	9.0	3.8	58	4400	180
10SE - II	5	16	Lime - 50.0	Cal. 25 -2.0	9.0	3.6	60	2720	180
10SE - III	5	24	Lime - 50.0	Mag.860A-1.0	9.0	3.4	62	3820	180
10SE - IV	5	16	Lime - 50.0	Mag.860A-1.0	9.0	3.3	63	2760	180
10SE - V	5	24	Lime - 50.0	Cal. 25 -1.0	9.0	2.9	68	4310	180
10SE - VI	5	16	Lime - 50.0	Cal. 25 -1.0	9.0	1.2	87	2380	180
10SE - VII	5	24	Lime - 50.0	Mag.860A-0.5	9.0	5.3	41	4360	180
10SE - VIII	5	16	Lime - 50.0	Mag.860A-0.5	9.0	4.0	56	2220	180
11SE - I	5	24	Lime - 50.0	Nal. 672 - 1.0	45.6	24.2	47	3740	180
11SE - II	5	16	Lime - 50.0	Nal. 672 -1.0	45.6	14.1	69	2430	180
11SE - III	5	24	Lime - 50.0	Nal. 672 -0.5	45.6	20.0	56	3540	180
11SE - IV	5	16	Lime - 50.0	Nal. 672 -0.5	45.6	6.3	86	2130	180
11SE - V	5	24	Lime - 50.0	-	45.6	19.3	58	3720	180
11SE - VI	5	16	Lime - 50.0	-	45.6	13.5	70	3090	180
11SE - VII	5	24	Lime - 50.0	Cal. 240 -1.0	45.6	9.6	79	3110	180
11SE - VIII	5	16	Lime - 50.0	Cal. 240 -1.0	45.6	4.8	90	1650	180

NOTES:

(1) Type of Media: Type 5: 60" No. 2 Anth./24" No. 1220 Sand

(2) Declining Rate Operation, Indicated As Initial Filtration Rate.

(3) Volume of water produced is the weighted average through 180 minutes of filtration time. Where marked with asterisk the filtration time is as indicated in the right hand column.

(4) Length Of Run Based On 180 Minutes Of Filtration Time, Or 50 Percent Of Flow Declined Marked With Asterisk (*).

TABLE A-5

HIGH-RATE DEEP-BED FILTRATION OF ACTIVATED SLUDGE PLANT EFFLUENT

Run No.	Filter Media	Average Flux Rate (gpm/ft²)	Rate * Control	Coagulant Feed (mg/l)	Polymer Feed (mg/l)	pH	Temp. (°F)	Suspended Solids Influent (mg/l)	Suspended Solids Effluent (mg/l)	Suspended Solids % Removal (@95% C.I.)	Turbidity Avg. Inf. (JU) (mg/l)	Turbidity Avg. Eff. (JU) (mg/l)	Turbidity % Removal (@95% C.I.)
12SE-I	60" NO. 2 ANTHRACITE / 24" NO. 1220 SAND	32.0	C	0	Cal. 1.0	6.96	53.1	15.7	5.7	63.7 ± 5.4	26.3	10.9	46.3 ± 2.4
12SE-II		16.0	C	0	Cal. 1.0	6.96	53.1	15.5	6.1	60.6 ± 1.9	26.3	10.2	46.3 ± 2.4
12SE-III		24.0	C	0	Cal. 1.0	6.96	53.1	17.5	5.9	66.2 ± 5.0	26.3	12.6	51.8 ± 1.9
13SE-I		32.0	C	0	Mag. 0.5	6.74	50.9	23.7	11.5	51.5 ± 6.7	31.1	17.2	41.2 ± 10.7
13SE-II		16.0	C	0	Mag. 0.5	6.74	50.9	22.5	8.6	60.9 ± 3.1	32.3	19.2	45.1 ± 3.0
13SE-III		24.0	C	0	Mag. 0.5	6.74	50.9	21.2	9.8	53.5 ± 5.2	32.3	16.7	46.3 ± 1.5
14SE-I		8.0	C	0	Mag. 1.0	7.0	52.3	22.2	5.0	77.7 ± 1.7	29.2	11.4	67.8 ± 1.9
14SE-II		8.0	C	0	Cal. 1.0	7.0	52.3	21.7	4.6	78.7 ± 3.5	29.2	11.3	62.8 ± 0.8
14SE-III		8.0	C	0	0	7.0	52.3	20.2	4.7	76.6 ± 2.4	29.2	14.0	57.1 ± 1.7
15SE-I		24.0	C	Alum 15.0	Cal. 1.0	6.83	56.3	16.6	1.4	91.1 ± 2.6	29.2	9.9	77.8 ± 3.5
15SE-II		15.0	C	Alum 15.0	Cal. 1.0	6.83	56.3	28.0	0.2	95.7 ± 0.7	31.8	8.2	76.6 ± 2.7
15SE-III		19.0	C	Alum 15.0	Cal. 1.0	6.85	56.3	28.0	0.2	95.7 ± 0.7	28.2	9.6	65.1 ± 7.6
16SE-I		24.0	C	Alum 15.0	Mag. 0.5	6.85	57.1	41.7	12.0	71.2 ± 13.9	30.9	12.0	62.2 ± 2.5
16SE-II		16.0	C	Alum 15.0	Mag. 0.5	6.82	56.9	16.4	11.1	32.4 ± 9.5	34.5	10.6	65.1 ± 1.3
16SE-III		24.0	C	Alum 15.0	Mag. 0.5	6.82	56.9	42.2	11.6	72.5 ± 19.3	33.6	11.9	62.6 ± 4.1
17SE-I		8.0	C	Alum 15.0	Mag. 0.5	7.06	54.7	18.8	7.8	58.1 ± 2.2	25.7	9.9	62.1 ± 4.3
17SE-II		8.0	C	Alum 15.0	Cal. 1.0	7.06	54.7	20.7	7.9	61.8 ± 5.5	25.7	7.4	69.2 ± 5.2
18SE-I		32.0	C	0	0	6.80	51.3	29.0	13.9	52.2 ± 1.6	28.7	18.5	34.7 ± 1.0
18SE-II		16.0	C	0	0	6.80	51.3	26.7	8.0	70.1 ± 2.8	28.7	13.4	54.5 ± 2.1
18SE-III		24.0	C	0	0	6.80	51.3	23.0	9.3	59.7 ± .69	28.7	16.6	45.2 ± 2.7
										% Removal			% Removal
19SE-I		16.2	D	Alum 15.0	Cal. 1.0	6.71	53.3	9.2	.88	90.4	18.1	5.1	71.8
19SE-II		13.3	D	Alum 15.0	Cal. 1.0	6.71	53.3	9.2	.37	96.0	18.1	6.0	67.0
19SE-III		18.0	D	Alum 15.0	Cal. 1.0	6.71	53.3	9.2	.31	96.6	18.1	5.2	71.2
20SE-I		22.2	D	0	0	6.96	54.9	10.7	2.6	75.6	16.1	10.0	37.8
20SE-II		16.0	D	0	0	6.96	54.9	10.7	2.1	80.8	16.1	9.4	41.6
20SE-III		27.6	D	0	0	6.96	54.9	10.7	3.5	67.3	16.1	10.2	36.7
21SE-I	60" NO.3 ANTHRACITE 24" NO. 612 SAND	8.0	C	Alum 15.0	Cal. 1.0	6.93	51.7	7.9	3.6	54.4	13.9	3.7	73.4
21SE-II		16.0	C	Alum 15.0	Cal. 1.0	6.93	51.7	7.9	3.0	62.0	13.9	3.7	73.4
21SE-III		24.0	C	Alum 15.0	Cal. 1.0	6.93	51.7	7.9	3.4	57.0	13.9	3.9	71.8
22SE-I		7.5	D	Alum 15.0	Cal. 1.0	7.1	52.3	10.3	1.2	84.4	15.2	4.1	73.0
22SE-II		16.6	D	Alum 15.0	Cal. 1.0	7.1	52.3	10.3	1.2	88.4	15.2	5.0	67.2
22SE-III		22.4	D	Alum 15.0	Cal. 1.0	7.1	52.3	10.3	2.2	78.6	15.2	5.6	63.2
23SE-I		24	D	0	0	7.15	52.0	13.1	6.0	54.2	13.7	6.2	54.7
23SE-II		16	D	0	0	7.15	52.0	13.1	4.0	69.5	13.7	5.7	58.4
23SE-III		8	D	0	0	7.15	52.0	13.1	3.8	70.9	13.7	4.5	67.2
25SE-I	60" NO. 2 ANTHRACITE - 24" NO. 1220 SAND	16.4	D	Alum 15.0	Cal. 1.0	6.84	47.8	17.6	5.1	71.0	23.5	8.6	63.4
25SE-II		15.5	D	Alum 15.0	Cal. 1.0	6.91	48.0	17.6	5.2	70.4	23.8	11.0	53.8
25SE-III		23.0	D	Alum 15.0	Cal. 1.0	6.91	48.0	17.6	5.2	70.4	23.5	9.0	61.7
26SE-I		14.5	D	Alum 15.0	Cal. 1.0	6.99	48.5	9.4	1.15	87.7	20.3	1.83	91.0
26SE-II		13.5	D	Alum 15.0	Cal. 1.0	6.99	48.5	9.4	2.58	72.6	20.3	2.33	88.5
26SE-III		20.0	D	Alum 15.0	Cal. 1.0	6.99	48.5	9.4	3.10	67.0	20.3	2.6	87.2
27SE-I		20.0	D	Alum 15.0	Cal. 0.5	6.95	47.5	18.9	3.1	83.6	27.4	5.1	81.4
27SE-II		13.4	D	Alum 15.0	Cal. 0.5	6.95	47.5	18.9	2.3	87.8	27.4	5.0	81.7
27SE-III		18.6	D	Alum 15.0	Cal. 0.5	6.95	47.5	18.9	2.5	86.8	27.4	4.8	82.4
28SE-I		24.0	C	Alum 15.0	Cal. 0.5	6.85	46	104.6	13.7	86.8	115.2	17.4	84.9
28SE-II		16.0	C	Alum 15.0	Cal. 0.5	6.85	46	104.6	3.4	96.7	115.2	5.4	95.3
28SE-III		32.0	C	Alum 15.0	Cal. 0.5	6.65	45.6	80.4	13.0	83.9	89.6	14.0	84.4
29SE-I		24.0	C	Alum 15.0	Cal. 1.0	6.62	46	114.1	3.4	97.0	111.0	6.0	94.6
29SE-II		16.0	C	Alum 15.0	Cal. 1.0	6.62	46	114.1	2.6	97.7	111.0	2.9	97.4
29SE-III		32.0	C	Alum 15.0	Cal. 1.0	6.61	46	112.7	2.6	97.8	108.2	6.6	93.2
30SE-I	(1)	16.3	D	Alum 15.0	Cal. 1.0	6.77	43.7	10.3	2.9	71.8	20.1	3.9	80.3
30SE-II	(2)	17.3	D	Alum 15.0	Cal. 1.0	6.77	43.7	10.3	2.6	74.8	20.1	3.9	81.1
30SE-III	(3)	14.0	D	Alum 15.0	Cal. 1.0	6.77	43.7	10.3	1.9	81.5	20.1	3.7	81.6
31SE-I	(1)	7.5	D	Alum 15.0	Cal. 1.0	6.70	45.9	17.3	2.3	86.7	20.7	4.9	76.3
31SE-II	(2)	7.3	D	Alum 15.0	Cal. 1.0	6.70	45.9	17.3	2.0	88.4	20.7	4.1	80.4
31SE-III	(3)	7.0	D	Alum 15.0	Cal. 1.0	6.70	45.9	17.3	1.5	91.3	20.7	3.6	82.7
34SE-I	60" NO. 2 ANTH. 24" NO. 1220 SAND	24	C	Alum 15.0	Cal. 1.0	6.66	44.2	23.7	5.6	76.4	20.2	1.4	93.1
34SE-II		16	C	Alum 15.0	Cal. 1.0	6.66	44.2	23.7	5.7	76.0	20.2	1.4	93.1
34SE-III		32	C	Alum 15.0	Cal. 1.0	6.66	44.2	23.7	6.0	74.6	20.2	1.5	92.6
35SE-I		23.6	D	0	Cal. 1.0	6.84	45.8	22	8.7	60.4	21.7	9.5	56.2
35SE-II		23.6	D	0	Cal. 0.5	6.84	45.8	22	8.4	62.0	21.7	9.7	55.4
35SE-III		23.6	D	0	0	6.84	45.8	22	10.8	51.0	21.7	14.3	34.0

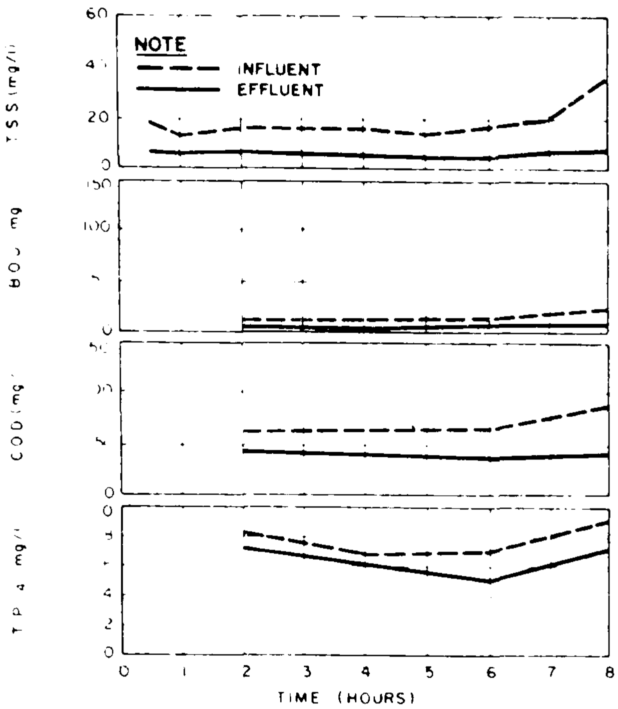
(1) 60" No. 2 Anthracite/24" No. 1220 Sand (2) 48" No. 2 Anthracite/24" No. 1220 Sand (3) 72" No. 2 Anthracite/24" No. 1220 Sand

* C: Constant Rate Control, D: Declining Rate Control

TABLE A-5

HIGH RATE DEEP BED FILTRATION OF ACTIVATED SLUDGE PLANT EFFLUENT

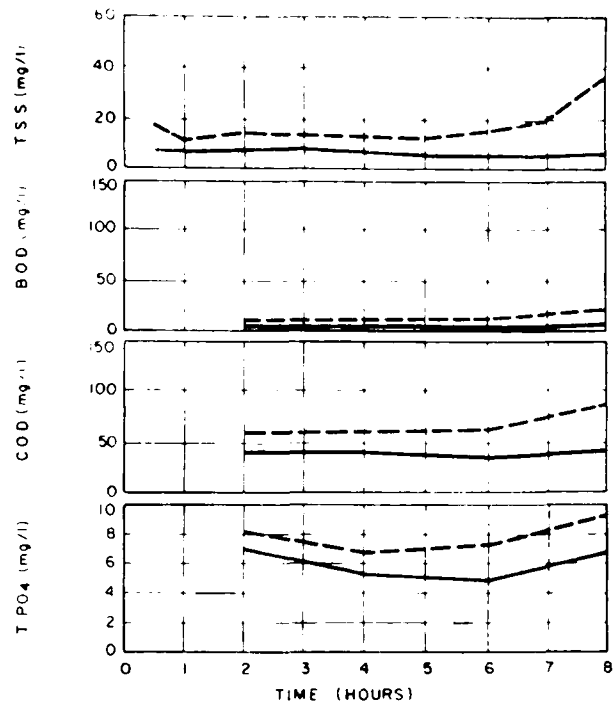
Total Phosphate (PO_4)			B O D_5			C O D						
Avg. Influent (mg/l)	Avg. Effluent [illegible]	% Removal ± 95% C.I.	Avg. Influent [illegible]	Avg. Effluent [illegible]	% Removal ± 95% C.I.	Avg. Influent (mg/l)	Avg. Effluent (mg/l)	% Removal ± 95% C.I.	Length of Run (hours)	Total Head Losses (feet)	Volume of Water Produced [illegible]	Backwash Water Volume [illegible]	Percent of Backwash ( )
7.8	6.3	17.8 ± 15.0	12.4	3.8	66 ± 14.4	69.4	41.9	39.5 ± 14.4	8	20.8	15,360	155	[illegible]
7.7	5.9	23.1 ± 15.6	12.4	2.6	77.5 ± 6.4	69.4	41.0	39.7 ± 15.2	8	7.2	7,680	177	2.30
7.8	6.1	21.7 ± 12.5	12.4	3.7	67.7 ± 16.0	69.4	41.9	39.8 ± 13.2	8	18.6	11,520	403	3.49
6.9	4.7	31.7 ± 39.8	17.9	9.0	47.0 ± 26.9	73.7	50.9	30.3 ± 7.6	6	37.8	11,520	300	2.60
6.5	4.3	33.7 ± 19.2	17.9	9.0	44.7 ± 28.1	73.2	48.0	34.7 ± 5.2	8	12.7	7,680	296	3.85
6.5	4.4	31.5 ± 19.8	17.9	10.7	48.5 ± 31.3	73.2	50.7	30.6 ± 4.0	8	36.4	11,520	620	5.39
7.2	4.6	36.1 ± 5.8	18.5	13.4	40.3 ± 10.6	62.0	42.0	32.1 ± 3.1	8	7.3	3,840	155	4.04
6.9	3.4	49.1 ± 30.1	18.5	12.6	46.2 ± 42.2	62.6	37.7	39.6 ± 15.1	8	9.7	3,840	325	8.46
6.9	4.1	41.3 ± 10.6	18.5	14.4	25.0 ± 12.9	62.6	43.9	30.0 ± 13.4	8	1.9	3,840	124	3.23
6.2	1.7	71.7 ± 27.4	30.7	10.4	69.3 ± 7.4	55.7	29.0	47.9 ± 17.1	5	40.9	7,200	---	---
8.7	1.0	88.6 ± 3.5	27.2	12.4	55.0 ± 5.6	75.3	25.6	65.8 ± 1.2	10	39.6	9,000	---	---
6.9	1.0	85.5 ± 11.2	27.7	12.2	55.7 ± 7.0	62.4	25.2	59.6 ± 13.2	6	44.6	6,840	---	---
6.3	3.3	51.9 ± 16.5	36.4	8.8	71.0 ± 21.0	75.6	44.9	37.7 ± 15.8	6	44.0	8,640	---	---
6.3	3.4	46.0 ± 13.3	41.9	18.0	56.9 ± 17.7	75.6	43.0	40.5 ± 16.9	9	41.1	8,640	---	---
6.3	3.7	41.3 ± 10.6	29.5	12.4	58.5 ± 4.0	75.6	44.3	38.0 ± 20.3	7	31.7	10,080	---	---
15.4	10.9	29.1 ± 6.9	30.7	11.1	70.0 ± 4.6	61.1	41.7	31.7 ± 2.2	17	43.5	9,160	103	1.26
15.0	9.1	39.4 ± 7.3	27.7	12.4	55.2 ± 7.6	60.0	34.6	42.2 ± 1.4	13	37.5	6,240	562	9.00
2.3	1.7	26.1 ± 9.7	9.3	6.7	34.0 ± 10.5	46.9	39.2	16.3 ± 2.4	8	28.7	15,360	279	1.82
2.8	1.5	46.4 ± 7.3	9.3	4.9	50.7 ± 3.7	47.4	32.7	30.8 ± 7.8	8	6.4	7,680	266	3.46
2.5	1.6	35.2 ± 6.4	9.3	6.1	35.1 ± 7.4	47.4	35.9	24.0 ± 8.6	8	19.6	11,520	279	2.42
		% Removal			% Removal			% Removal					
3.1	.29	90.6	7.9	1.3	83.5	44.4	23.0	48.0	5	14.3	4,860	449	9.23
3.1	.23	92.6	7.9	1.4	82.2	44.4	21.9	50.4	6	13.4	4,788	444	9.27
3.1	.18	94.2	7.9	1.5	81.0	44.4	21.3	50.8	4	17.6	4,320	---	---
1.8	1.1	38.8	9.1	5.9	35.2	75.3	33.4	55.6	6	7.5	7,992	403	5.04
1.8	1.1	38.8	9.1	5.3	41.7	75.3	32.6	56.7	6	4.8	5,760	311	5.40
1.8	1.1	38.8	9.1	6.4	29.6	76.0	34.2	55.2	6	11.0	9,936	201	2.02
4.5	1.6	64.5	9.4	3.3	65.0	33.9	22.9	32.5	8	3.5	3,840	403	---
4.5	1.7	62.2	9.4	3.7	60.6	33.9	22.4	33.8	8	5.6	7,680	311	4.05
4.5	1.6	64.4	9.4	3.4	63.8	33.9	23.1	31.8	8	11.9	11,520	232	2.01
3.9	.75	80.7	9.1	2.1	77.0	40.2	22.5	43.8	7	2.6	3,150	186	5.90
3.9	.75	80.8	9.1	1.6	82.4	40.2	24.3	39.5	7	5.1	6,972	266	3.91
3.9	.52	86.6	9.1	1.8	80.2	40.2	23.9	40.5	7	9.6	9,408	248	2.64
3.3	2.3	30.2	6.5	5.3	18.5	50.4	35.4	29.6	7	2.5	10,080	---	---
3.3	2.3	30.2	6.5	4.9	25.0	50.4	37.4	25.9	7	3.3	6,720	---	---
3.3	2.5	24.0	6.5	4.8	26.2	50.4	35.9	28.8	7	1.2	3,360	---	---
2.93	1.66	54.6	15.8	4.3	72.8	45.0	27.5	38.9	2	10.7	1,968	---	---
3.2	1.25	60.9	15.8	3.7	76.6	44.4	28.7	35.4	6	11.5	5,580	---	---
2.93	1.53	47.8	15.8	4.0	74.7	45.0	27.7	38.5	3	12.4	4,080	---	---
2.18	1.01	53.7	14.4	5.9	59.0	48.5	29.4	39.4	3	13.7	2,610	---	---
2.18	.98	55.0	14.4	3.33	76.8	48.5	32.1	34.0	6	10.2	4,860	---	---
2.18	1.03	52.8	14.4	5.0	65.3	48.5	32.6	33.8	4	14.7	4,800	---	---
4.01	1.35	66.3	7.1	.91	87.2	47.0	25.6	45.6	6	15.1	7,200	590	8.19
4.01	1.13	71.8	7.13	0.65	90.9	47.0	24.8	47.7	7	11.6	5,628	354	---
4.01	1.18	70.6	7.13	0.45	93.7	47.0	24.9	47.0	6	15.9	6,696	534	7.97
14.0	2.71	80.6	48	7.3	84.7	150	30	80.0	4	38.9	5,760	359	6.23
14.0	1.4	90.0	48	2.9	93.9	150	24.2	83.8	4	37.6	3,840	---	---
10.7	2.52	76.4	51.5	7.3	85.8	127	33.9	73.3	4	43.3	7,680	456	5.94
15.7	2.1	86.7	56.5	3.8	93.3	175.5	21.1	88.0	2	34.2	2,880	---	---
15.7	1.62	89.6	56.5	1.3	97.7	175.5	23.5	86.6	3	42.5	2,880	---	---
14.2	2.1	85.2	54.2	3.3	93.9	151	25.8	82.8	2	40.8	3,840	---	---
11.1	4.0	64.0	6.2	1.8	71.0	60.8	24.9	59.0	5	13.8	4,890	---	---
11.1	3.7	66.6	6.2	1.4	77.4	60.8	28.6	53.0	5	14.5	5,190	372	7.17
11.1	3.8	65.6	6.2	1.5	75.8	60.8	24.1	60.4	4	12.5	3,360	196	5.83
11.6	6.6	43.2	9.3	2.1	77.4	51.8	27.6	46.7	6	5.1	2,700	---	---
11.6	6.0	48.3	9.3	2.05	78.0	51.8	28.3	45.2	6	5.3	2,629	---	---
11.6	6.0	48.3	9.3	2.3	75.2	51.5	26.7	48.2	6	7.3	2,520	---	---
2.71	1.06	61.0	3.3	1.0	70.0	39.6	21.7	45.3	3	17.0	4,320	---	---
2.71	1.00	63.2	3.3	1.0	70.0	39.6	22.3	43.7	5	15.2	4,800	381	7.94
2.71	1.04	61.6	3.3	1.0	70.0	39.6	21.9	55.2	4	13.8	7,680	342	4.45
4.8	3.3	31.4	10.1	1.8	82.2	45.2	32.5	28.1	3	5.2	4,248	236	5.55
4.8	3.4	29.2	10.1	3.0	70.2	45.3	32.0	28.1	3	4.2	4,248	204	4.80
4.8	3.7	23.0	10.1	3.8	42.3	45.2	36.4	19.5	3	4.6	4,248	---	---



FILTER MEDIA 60 in No 2 ANTH /24 in No 1220 SAND
DATE 12-2-71 FLUX RATE 32.0 gpm/ft^2 COAG — mg/l
POLY CAL 226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No 12-SE-I

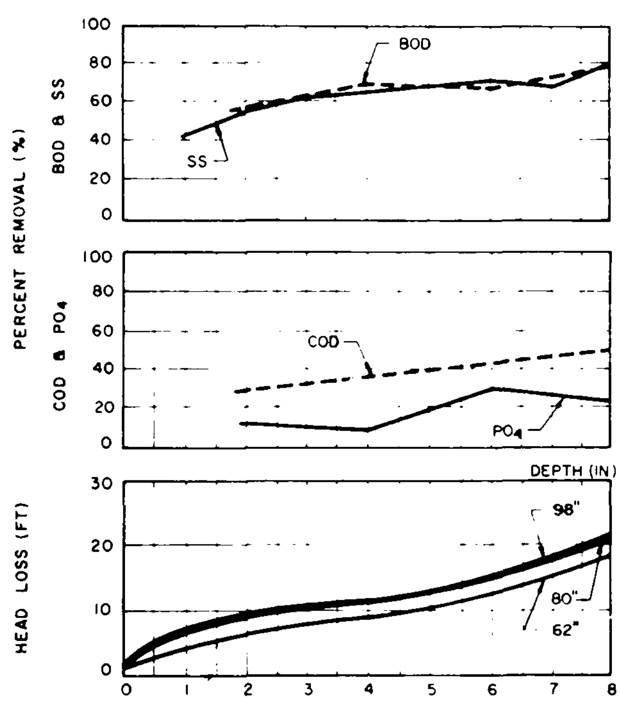
FIGURE B1



FILTER MEDIA 60 in No 2 ANTH /24 in No 1220 SAND
DATE 12-2-71 FLUX RATE 16.0 gpm/ft^2 COAG — mg/l
POLY CAL 226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No 12-SE-II

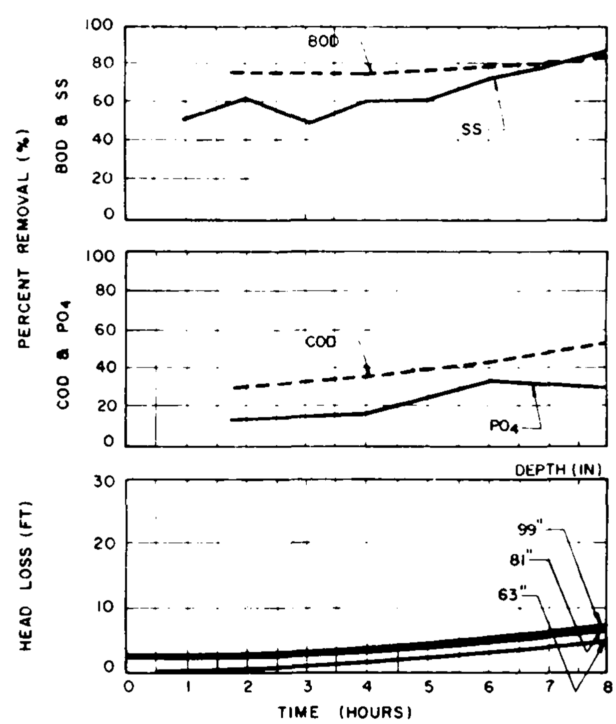
FIGURE B3



FILTER MEDIA: 60 in No. 2 ANTH /24 in No 1220 SAND
DATE 12-2-71 FLUX RATE 32.0 gpm/ft^2 COAG — mg/l
POLY CAL 226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.12-SE-I

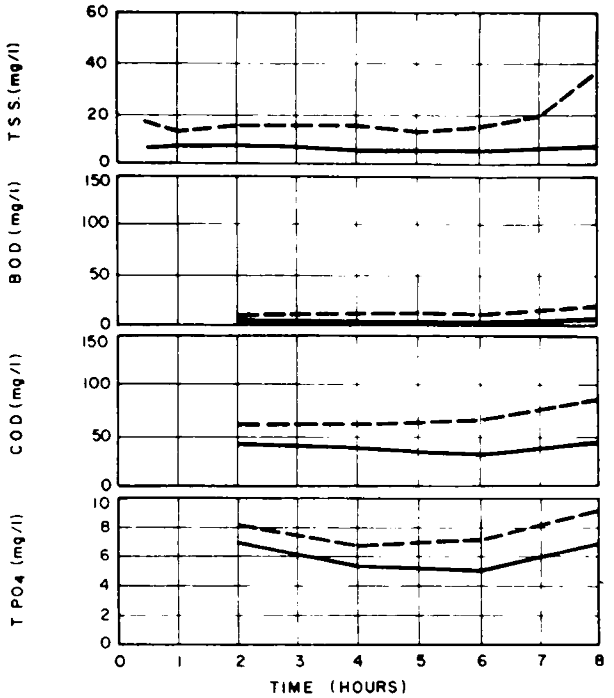
FIGURE B2



FILTER MEDIA 60 in No. 2 ANTH /24 in No 1220 SAND
DATE 12-2-71 FLUX RATE 16.0 gpm/ft^2 COAG — mg/l
POLY CAL 226-1.0 mg/l

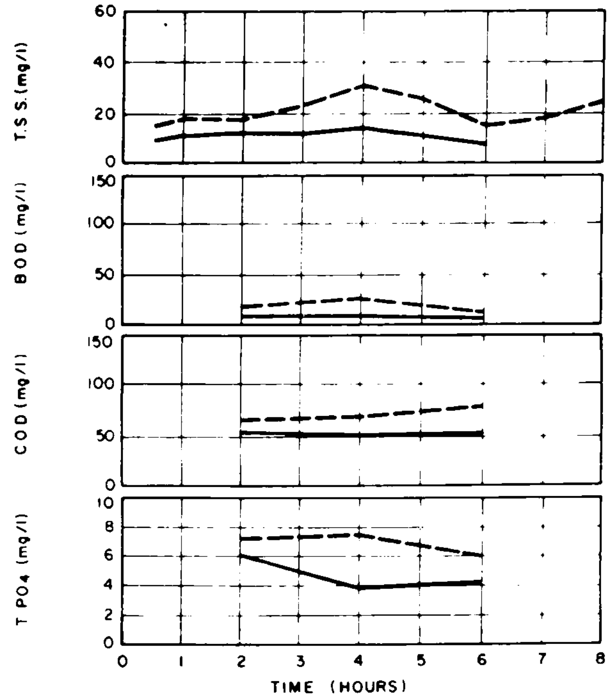
HIGH RATE DEEP BED FILTRATION TEST No.12-SE-II

FIGURE B4



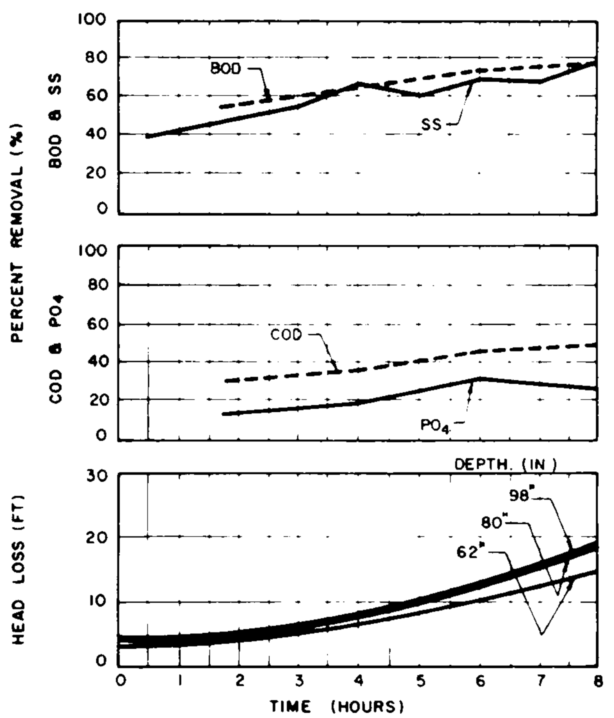
FILTER MEDIA: 60 in No 2 ANTH./24 in No 1220 SAND
DATE 12-2-71 FLUX RATE 24.0 gpm/ft^2 COAG. – mg/l
POLY CAL 226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.12-SE-III
FIGURE B-5



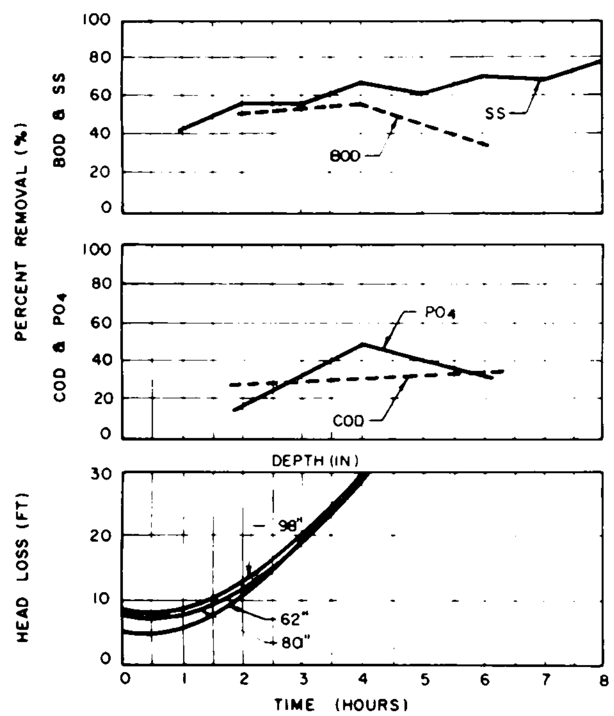
FILTER MEDIA: 60 in No 2 ANTH./24 in No 1224 SAND
DATE 12-6-71 FLUX RATE 32.0 gpm/ft^2 COAG – mg/l
POLY MAG 560C 0.5 mg/l

HIGH RATE DEEP BED FILTRATION TEST No 13-SE-I
FIGURE B-7



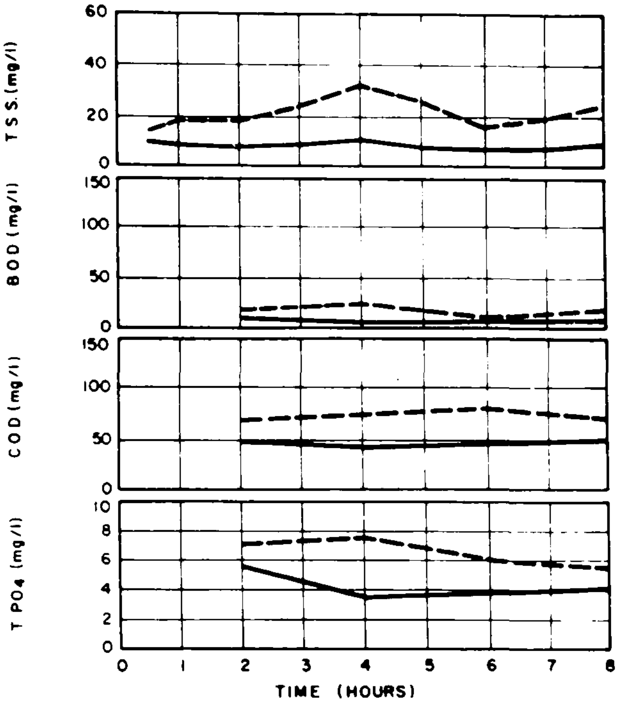
FILTER MEDIA 60 in No. 2 ANTH /24 in No 1220 SAND
DATE 12-2-71 FLUX RATE 24.0 gpm/ft^2 COAG – mg/l
POLY CAL 226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.12-SE-III
FIGURE B6



FILTER MEDIA 60 in No. 2 ANTH /24 in No 1224 SAND
DATE 12-6-71 FLUX RATE 32.0 gpm/ft^2 COAG – mg/l
POLY MAG. 560C 0.5 mg/l

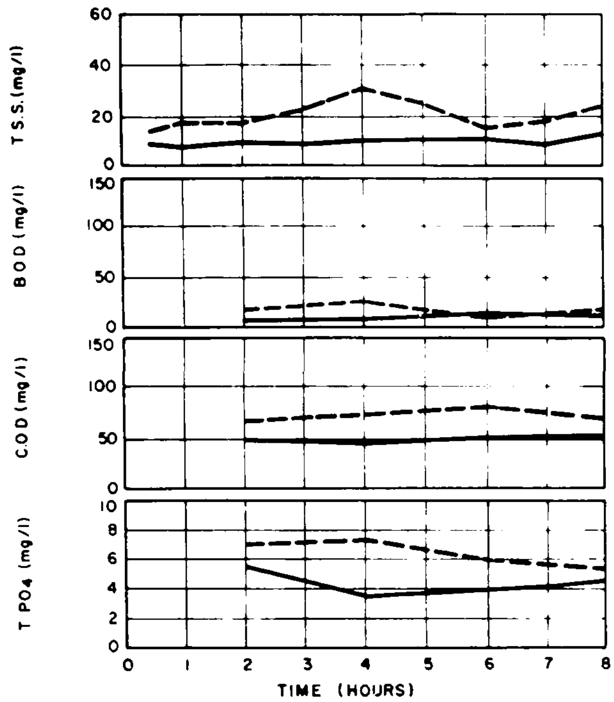
HIGH RATE DEEP BED FILTRATION TEST No.13-SE-I
FIGURE B8



FILTER MEDIA: 60 in No. 2 ANTH./24 in No 1220 SAND
DATE 12-6-71 FLUX RATE 16.0 gpm/ft² COAG. – mg/l
POLY. MAG. 560C-0.5 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.13-SE-II

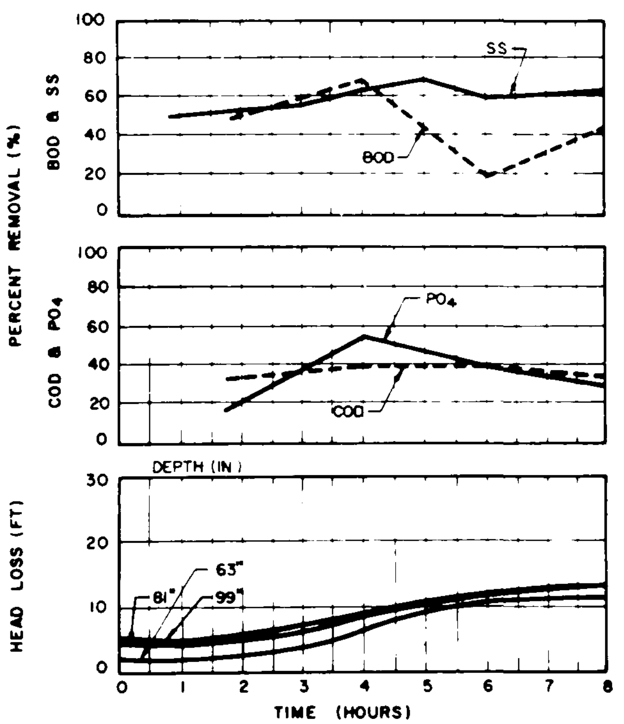
FIGURE B 9



FILTER MEDIA: 60 in No. 2 ANTH./24 in No 1220 SAND
DATE 12-6-71 FLUX RATE 24.0 gpm/ft² COAG – mg/l
POLY MAG. 560C-0.5 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.13-SE-III

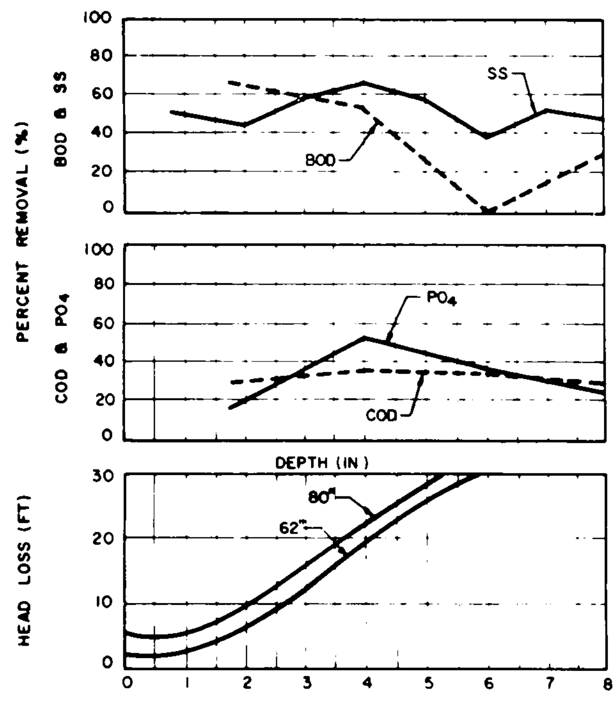
FIGURE B 11



FILTER MEDIA: 60 in No. 2 ANTH./24 in No. 1220 SAND
DATE 12-6-71 FLUX RATE 16.0 gpm/ft² COAG – mg/l
POLY MAG. 560C 0.5 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.13-SE-II

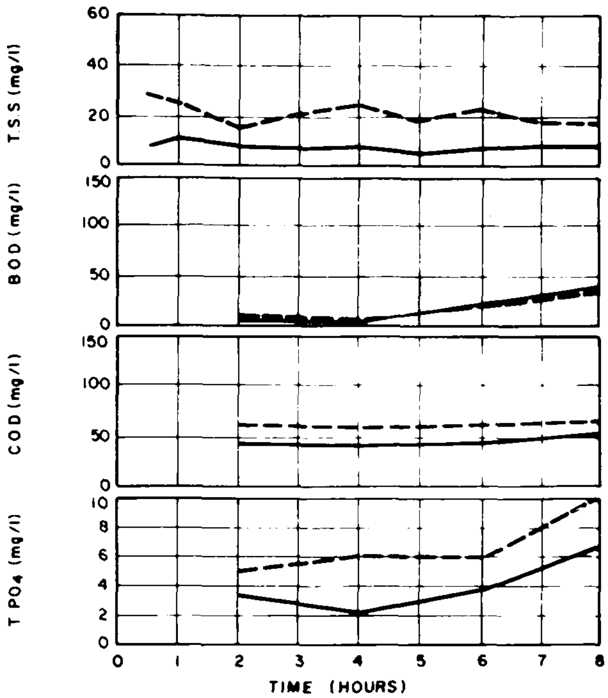
FIGURE B10



FILTER MEDIA: 60 in No. 2 ANTH./24 in No 1220 SAND
DATE 12-6-71 FLUX RATE 24.0 gpm/ft² COAG – mg/l
POLY MAG. 560C 0.5 mg/l

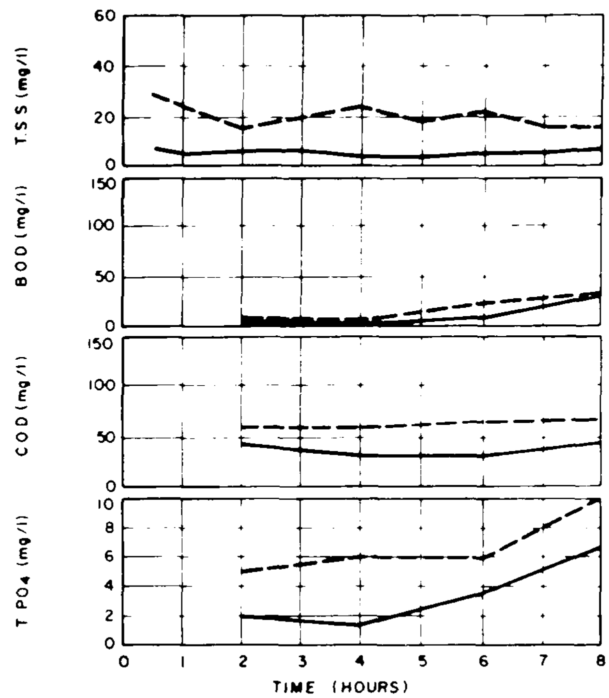
HIGH RATE DEEP BED FILTRATION TEST No.13-SE-III

FIGURE B12



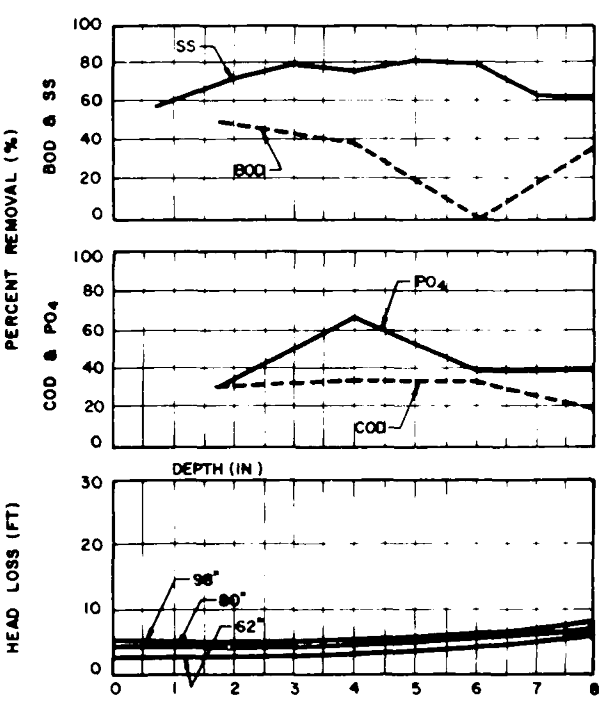
FILTER MEDIA: 60 in No. 2 ANTH./24 in No 1220 SAND
DATE 12-1-71 FLUX RATE 8.0 gpm/ft^2 COAG. - mg/l
POLY. MAG.560- 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.14-SE-I
FIGURE B 13



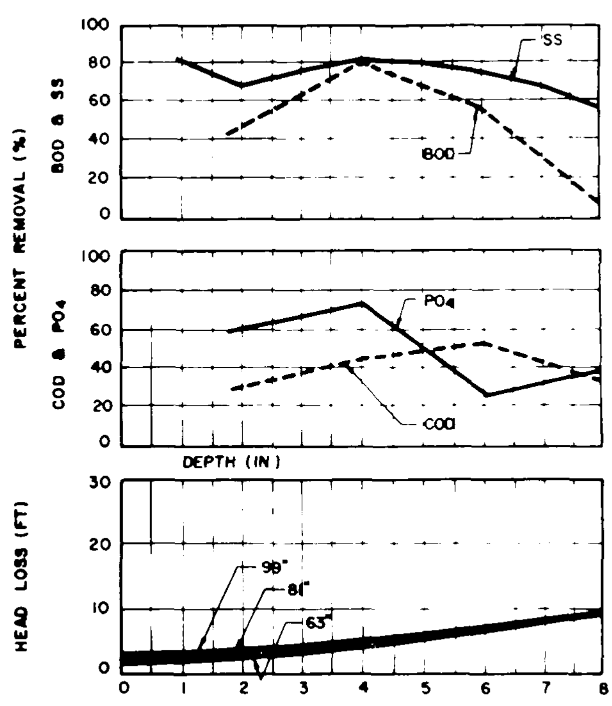
FILTER MEDIA: 60 in No 2 ANTH./24 in No 1220 SAND
DATE 12-1-71 FLUX RATE 8.0 gpm/ft^2 COAG — mg/l
POLY CAL.226 - 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No 14-SE-II
FIGURE B 15



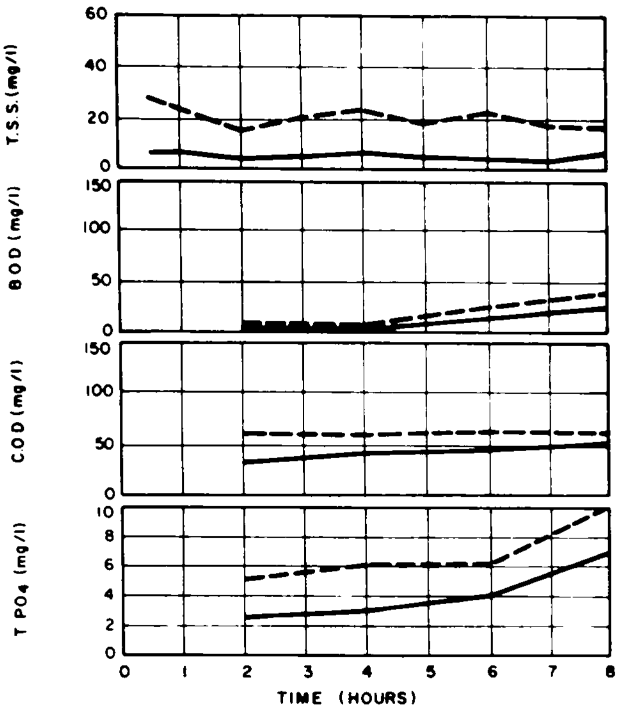
FILTER MEDIA: 60 in No. 2 ANTH./24 in No 1220 SAND
DATE 12-1-71 FLUX RATE 8.0 gpm/ft^2 COAG — mg/l
POLY MAG.560C 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.14-SE-I
FIGURE B14



FILTER MEDIA: 60 in No. 2 ANTH./24 in No 1220 SAND
DATE 12-1-71 FLUX RATE 8.0 gpm/ft^2 COAG — mg/l
POLY CAL.226-1.0 mg/l

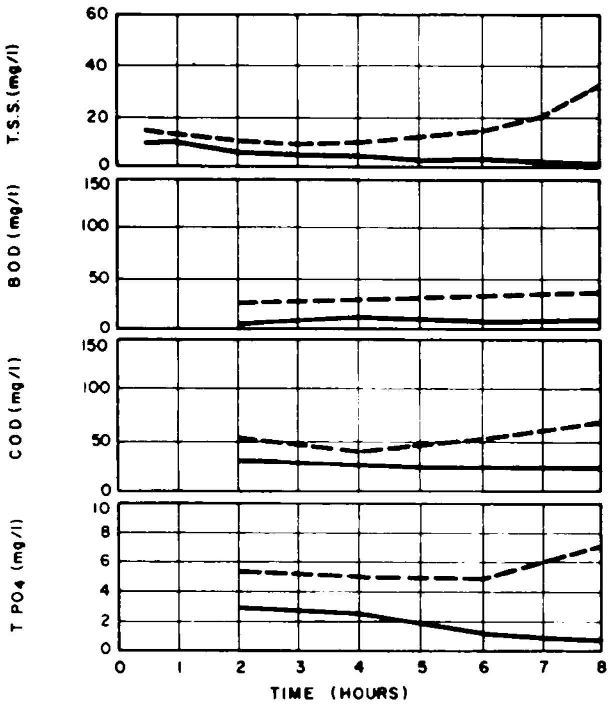
HIGH RATE DEEP BED FILTRATION TEST No.14-SE-II
FIGURE B16



FILTER MEDIA: 60 in No. 2 ANTH./24 in No 1220 SAND
DATE 12-1-71 FLUX RATE 8.0 gpm/ft^2 COAG. — mg/l
POLY. — mg/l

HIGH RATE DEEP BED FILTRATION TEST No. 14-SE-III

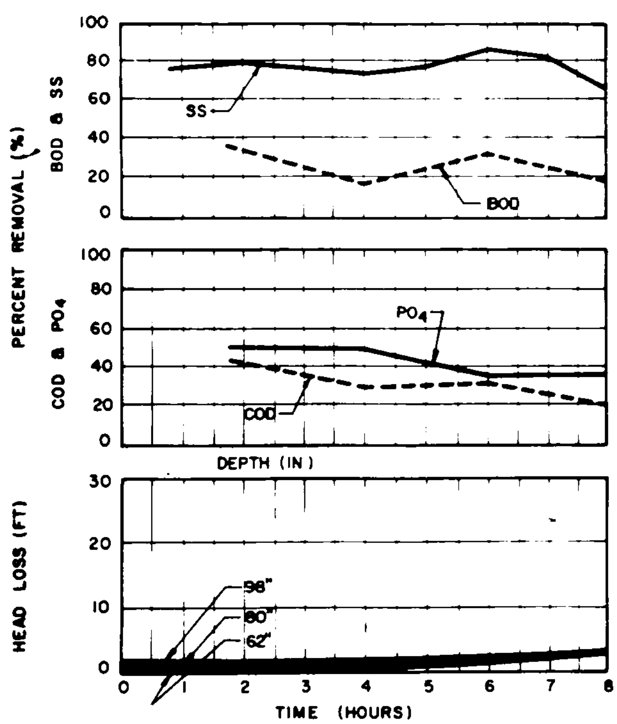
FIGURE B 17



FILTER MEDIA: 60 in No. 2 ANTH./24 in No 1220 SAND
DATE 11-23-71 FLUX RATE 23.5 gpm/ft^2 COAG. ALUM 15 mg/l
POLY. CAL. 226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No. 15-SE-I

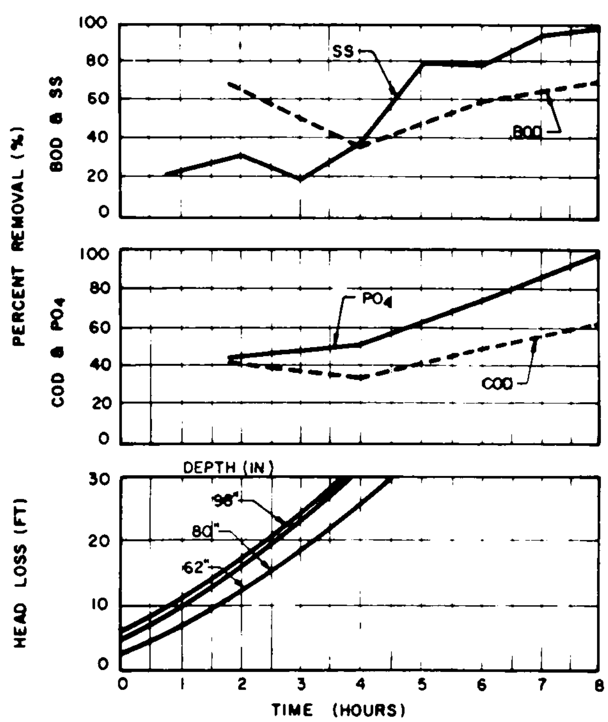
FIGURE B 19



FILTER MEDIA: 60 in No. 2 ANTH./24 in No 1220 SAND
DATE 12-1-71 FLUX RATE 8.0 gpm/ft^2 COAG — mg/l
POLY. — mg/l

HIGH RATE DEEP BED FILTRATION TEST No. 14-SE-III

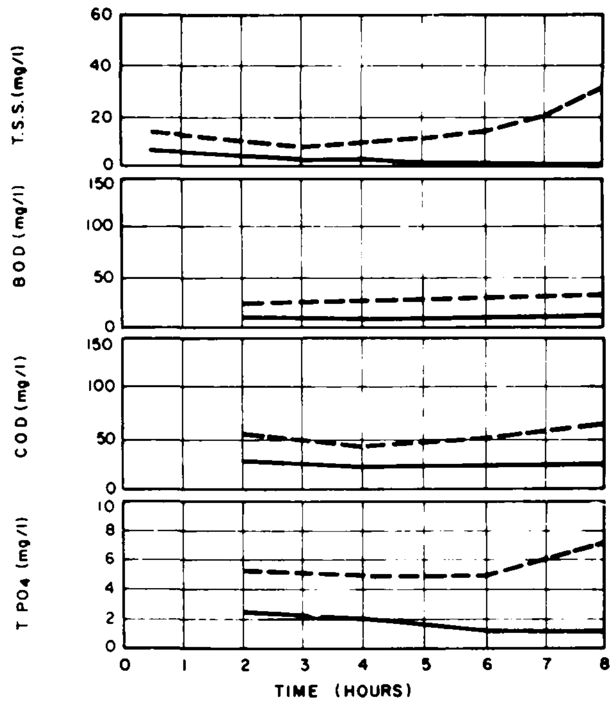
FIGURE B18



FILTER MEDIA: 60 in No. 2 ANTH./24 in No. 1220 SAND
DATE 11-23-71 FLUX RATE 23.5 gpm/ft^2 COAG ALUM 15 mg/l
POLY CAL. 226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No. 15-SE-I

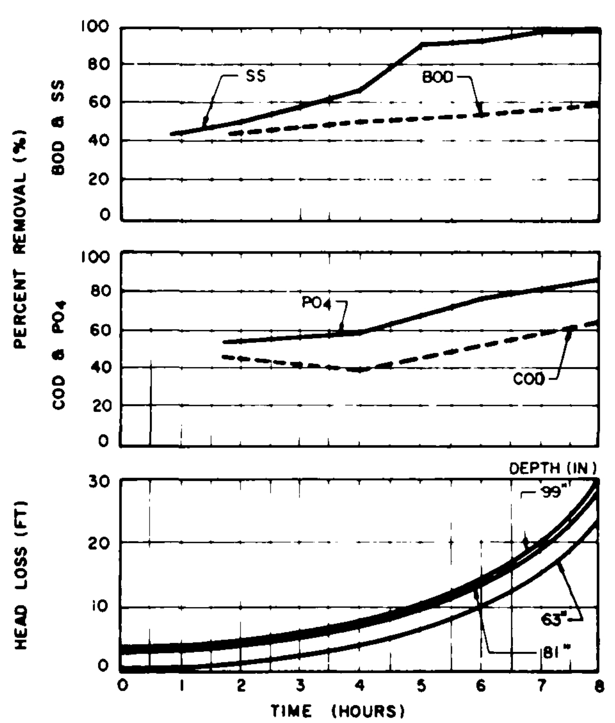
FIGURE B20



FILTER MEDIA: 60 in No. 2 ANTH./24 in No 1220 SAND
DATE 11-23-71 FLUX RATE 15.0 gpm/ft^2 COAG. ALUM 15 mg/l
POLY. CAL. 226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.15-SE-II

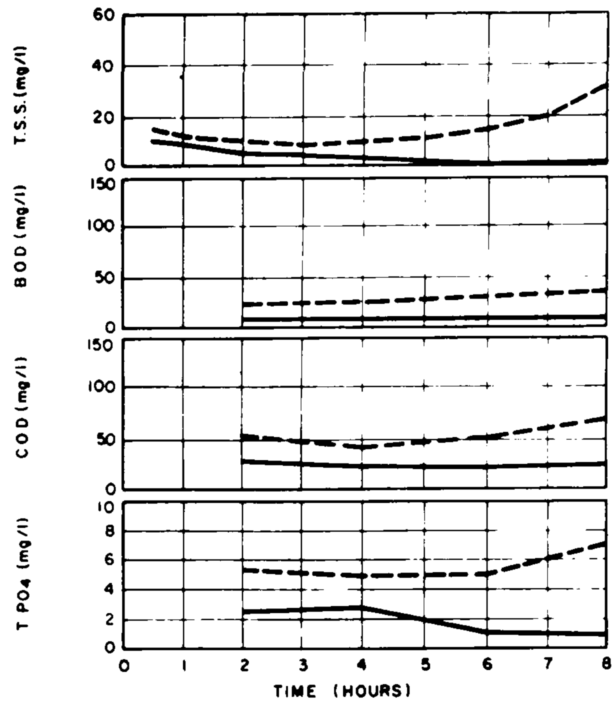
FIGURE B 21



FILTER MEDIA: 60 in No. 2 ANTH./24 in No 1220 SAND
DATE 11-23-71 FLUX RATE 15.0 gpm/ft^2 COAG ALUM 15 mg/l
POLY CAL. 226 - 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.15-SE-II

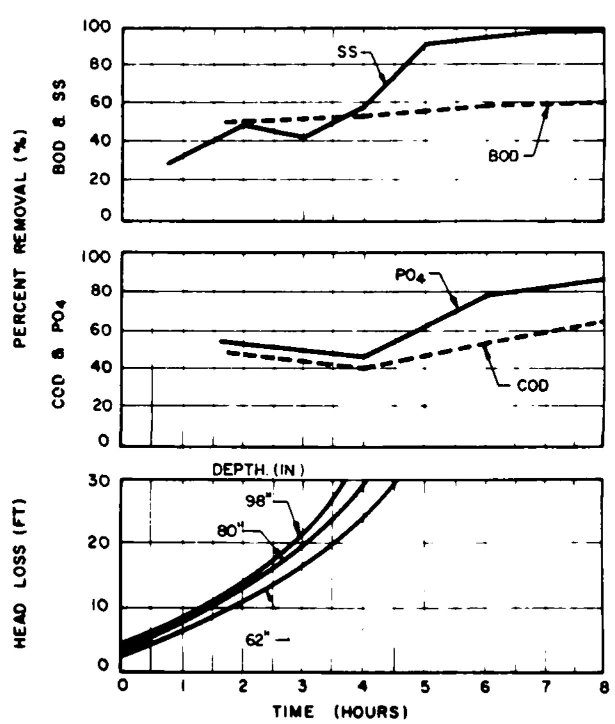
FIGURE B22



FILTER MEDIA: 60 in No. 2 ANTH./24 in No 1220 SAND
DATE 11-23-71 FLUX RATE 19.0 gpm/ft^2 COAG. ALUM 15 mg/l
POLY. CAL. 226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.15-SE-III

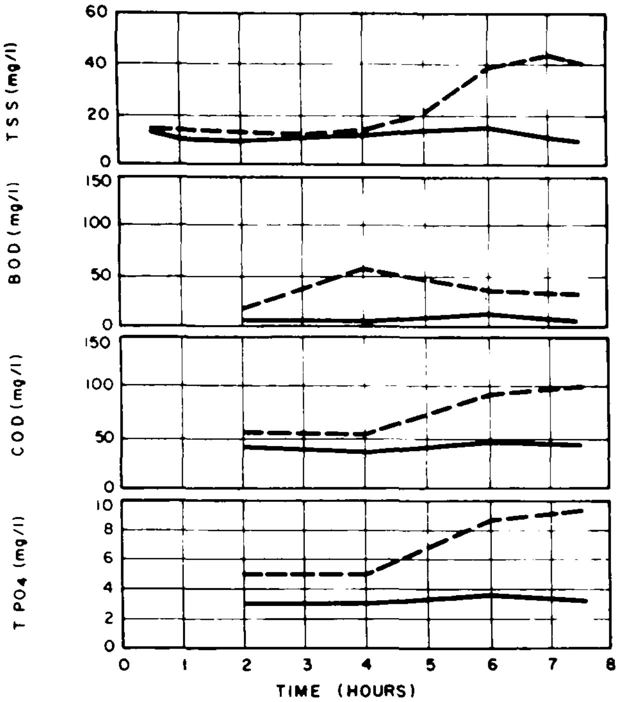
FIGURE B 23



FILTER MEDIA: 60 in No. 2 ANTH./24 in No. 1220 SAND
DATE 11-23-71 FLUX RATE 19.0 gpm/ft^2 COAG ALUM 15 mg/l
POLY CAL. 226 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.15-SE-III

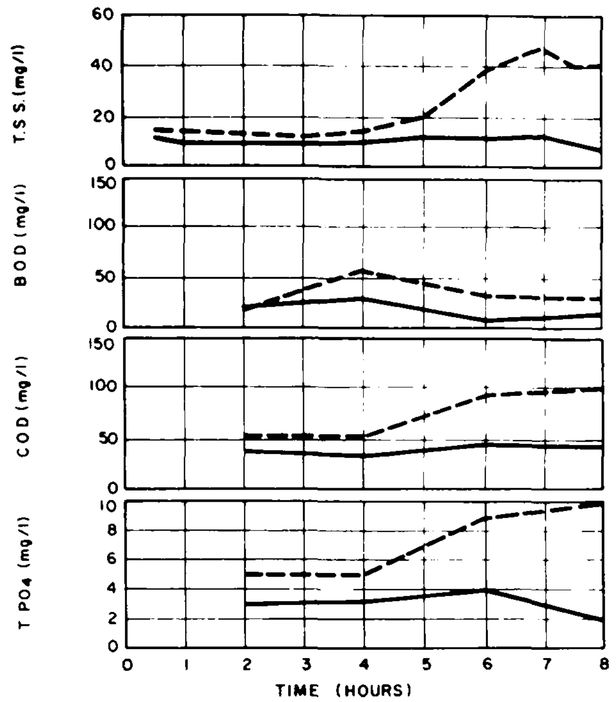
FIGURE B24



FILTER MEDIA: 60 in No 2 ANTH./24 in No 1220 SAND
DATE 11-24-71 FLUX RATE 24.6 gpm/ft² COAG. ALUM 15 mg/l
POLY MAG. 560C 0.5 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.16-SE-I

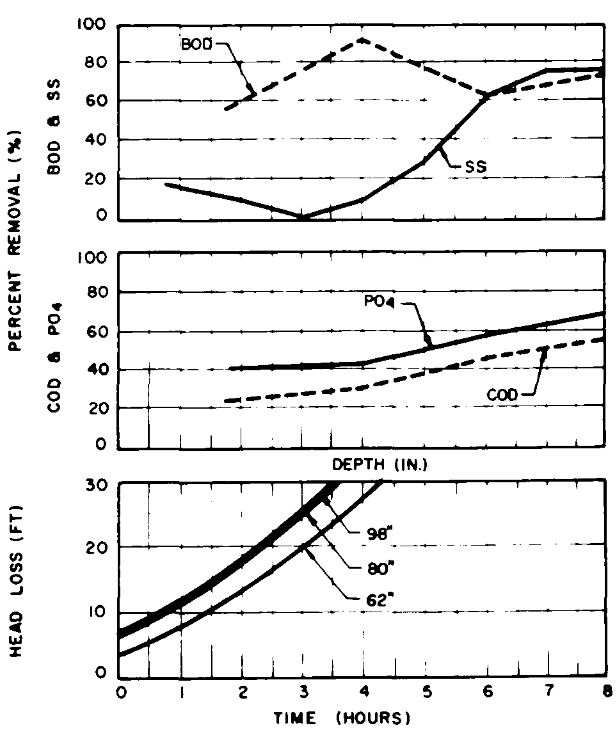
FIGURE B 25



FILTER MEDIA: 60 in No 2 ANTH./24 in No 1220 SAND
DATE 11-24-71 FLUX RATE 16.0 gpm/ft² COAG. ALUM 15 mg/l
POLY MAG 560C 0.5 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.16-SE-II

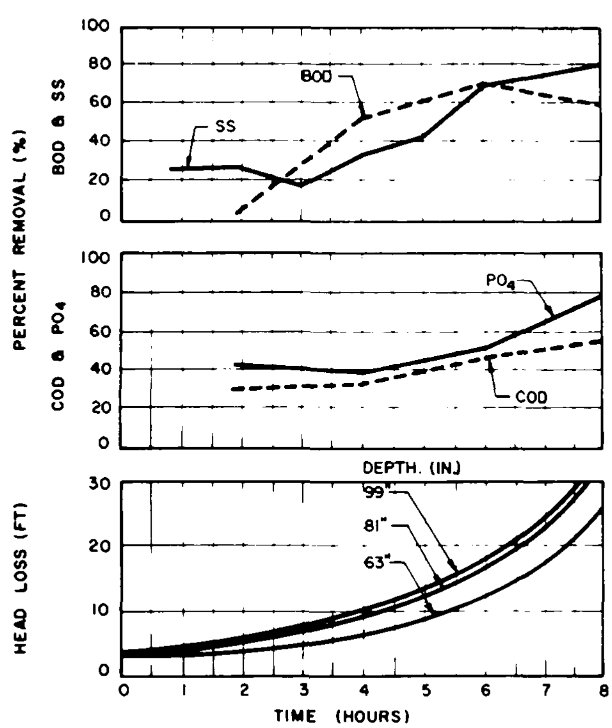
FIGURE B 27



FILTER MEDIA: 60 in No 2 ANTH /24 in No 1220 SAND
DATE 11-24-71 FLUX RATE 24.6 gpm/ft² COAG ALUM 15 mg/l
POLY MAG. 560C 0.5 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.16-SE-I

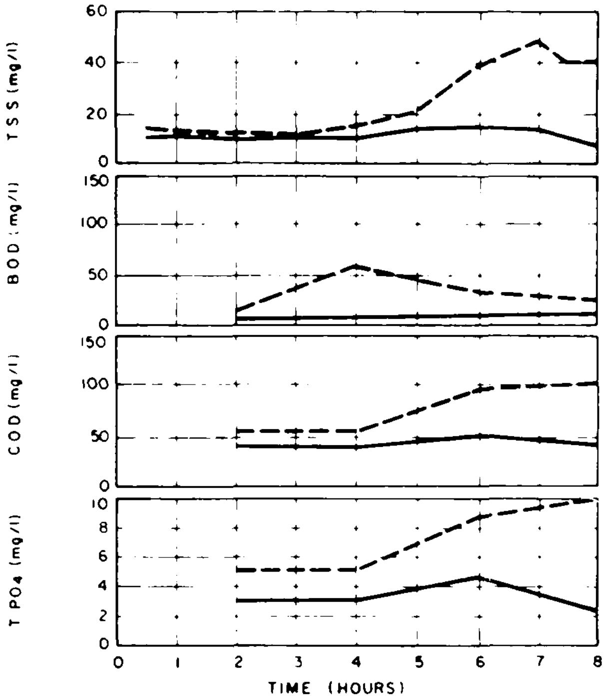
FIGURE B 26



FILTER MEDIA: 60 in No 2 ANTH /24 in No 1220 SAND
DATE 11-24-71 FLUX RATE 16.0 gpm/ft² COAG ALUM 15 mg/l
POLY MAG. 560C 0.5 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.16-SE-II

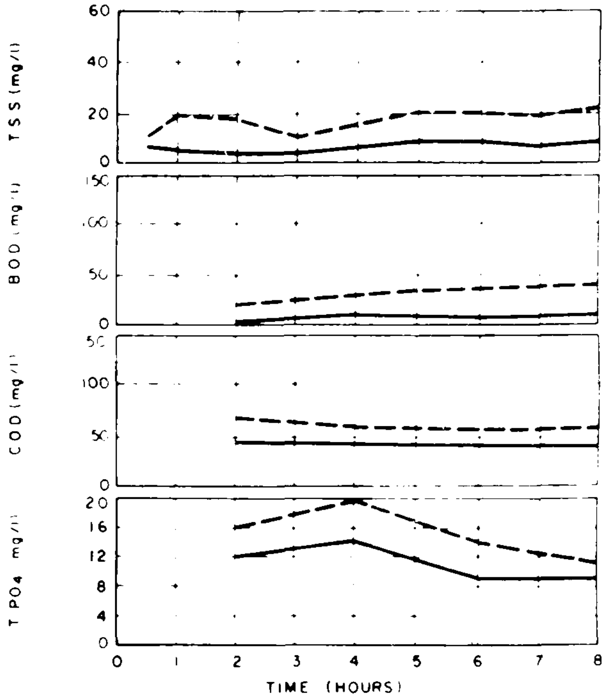
FIGURE B 28



FILTER MEDIA: 60 in No 2 ANTH./24 in No 1220 SAND
DATE 11-24-71 FLUX RATE 24.0 gpm/ft² COAG ALUM 15 mg/l
POLY MAG 560C 0.5 mg/l

HIGH RATE DEEP BED FILTRATION TEST No 16-SE-III

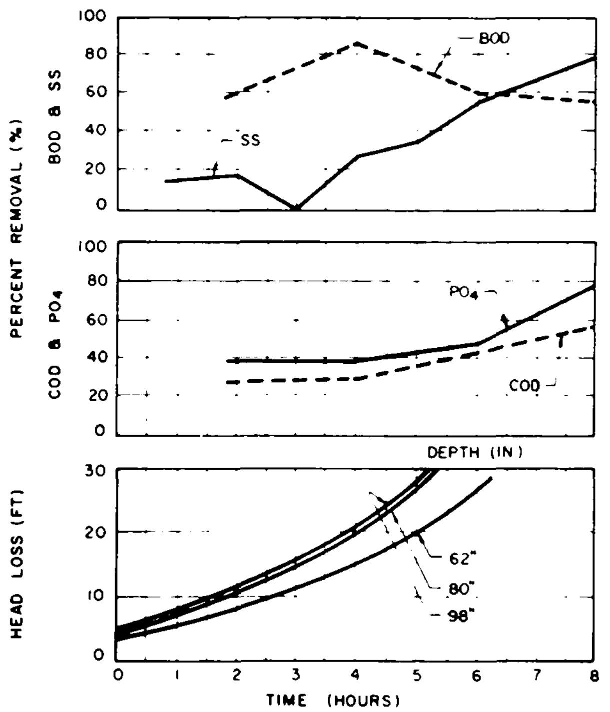
FIGURE B 29



FILTER MEDIA 60 in No 2 ANTH /24 in No 1220 SAND
DATE 11-29-71 FLUX RATE 8.0 gpm/ft² COAG ALUM 15 mg/l
POLY MAG 560C 0.5 mg/l

HIGH RATE DEEP BED FILTRATION TEST No 17-SE-I

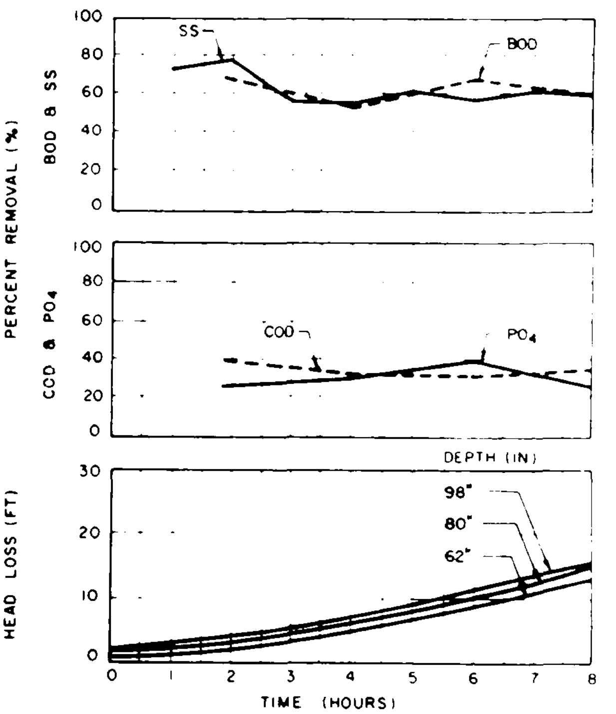
FIGURE B 31



FILTER MEDIA 60 in No. 2 ANTH /24 in No 1220 SAND
DATE 11-24-71 FLUX RATE 24.0 gpm/ft² COAG ALUM 15 mg/l
POLY MAG 560C 0.5 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.16-SE-III

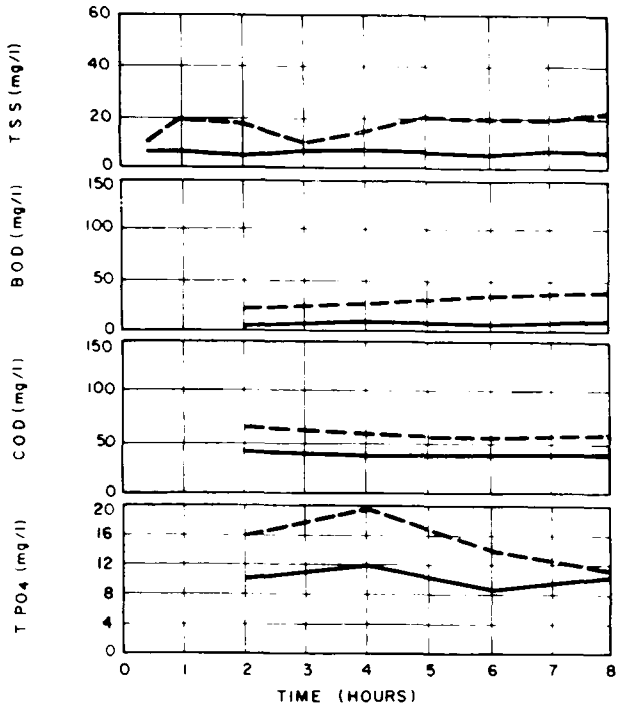
FIGURE B 30



FILTER MEDIA 60 in No 2 ANTH /24 in No 1220 SAND
DATE 11-29-71 FLUX RATE 8.0 gpm/ft² COAG ALUM 15 mg/l
POLY MAG 560C 0.5 mg/l

HIGH RATE DEEP BED FILTRATION TEST No 17-SE-I

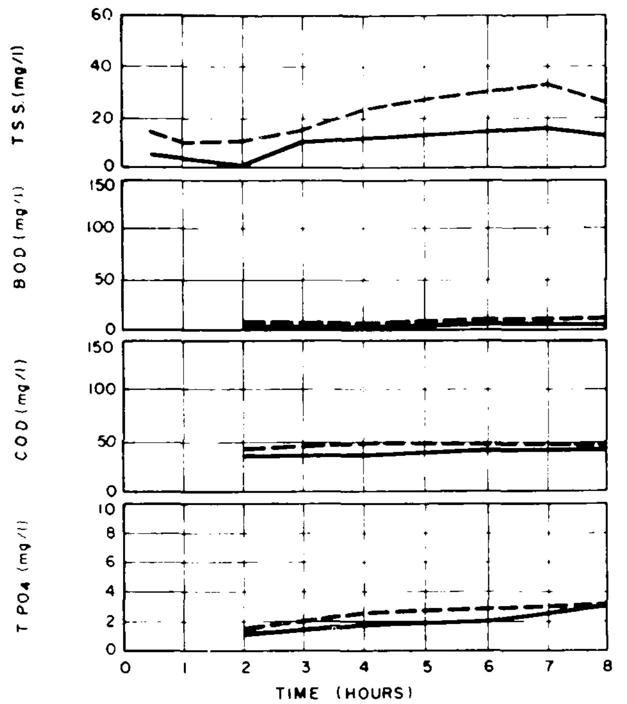
FIGURE B 32



FILTER MEDIA 60 in No 2 ANTH./24 in No 1220 SAND
DATE 11-29-71 FLUX RATE 8.0 gpm/ft² COAG ALUM 15 mg/l
POLY CAL 226 - 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No 17-SE-II

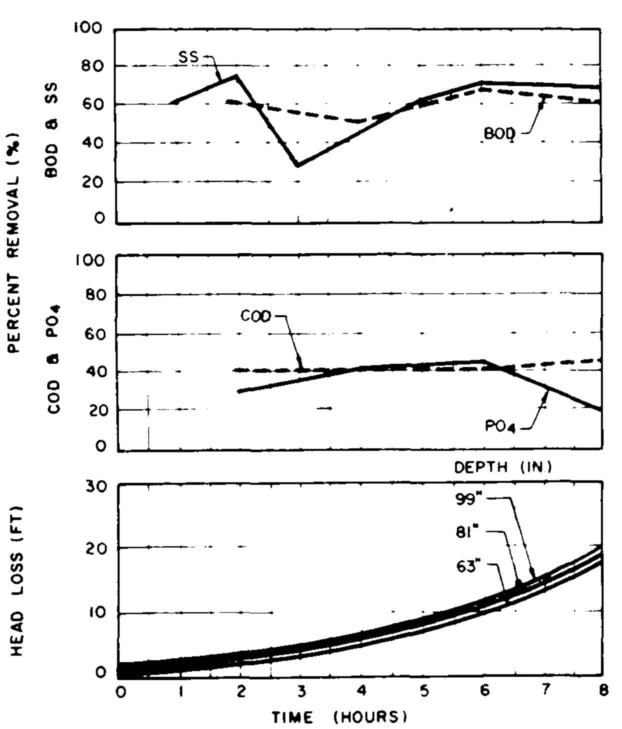
FIGURE B 33



FILTER MEDIA: 60 in No 2 ANTH./24 in No 1220 SAND
DATE 12-8-71 FLUX RATE 32.0 gpm/ft² COAG - mg/l
POLY - mg/l

HIGH RATE DEEP BED FILTRATION TEST No 18-SE-I

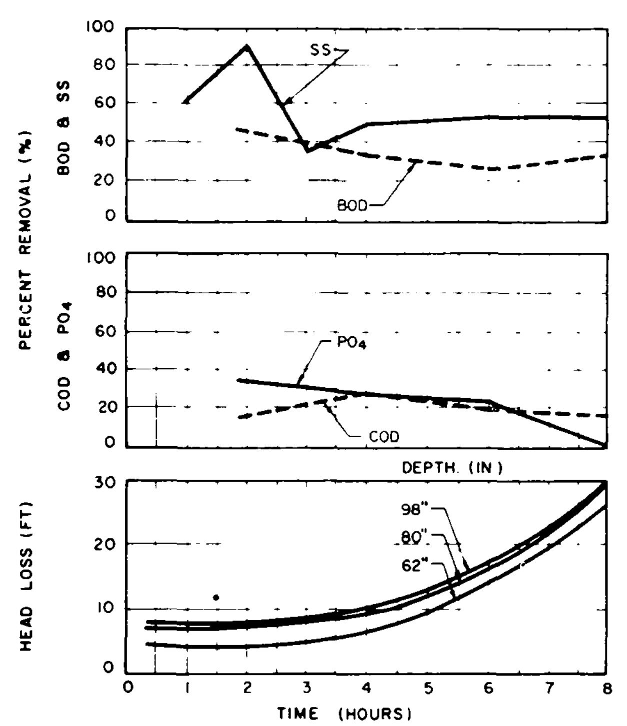
FIGURE B 35



FILTER MEDIA 60 in No 2 ANTH /24 in No 1220 SAND
DATE 11-29-71 FLUX RATE 8.0 gpm/ft² COAG ALUM 15 mg/l
POLY CAL 226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No. 17-SE-II

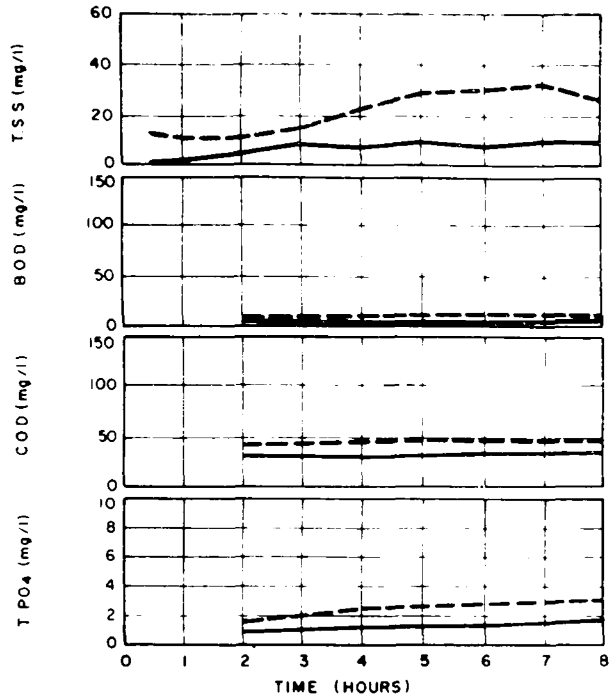
FIGURE B 34



FILTER MEDIA: 60 in No 2 ANTH /24 in No 1220 SAND
DATE 12-8-71 FLUX RATE 32.0 gpm/ft² COAG — mg/l
POLY — mg/l

HIGH RATE DEEP BED FILTRATION TEST No. 18-SE-I

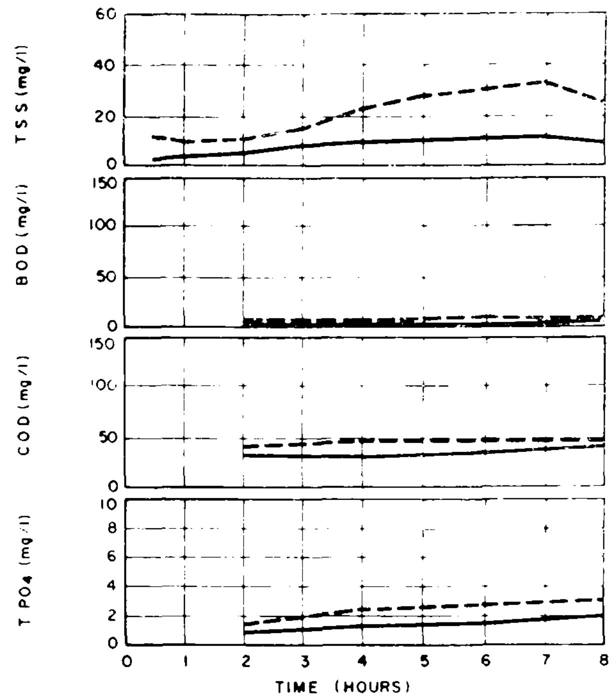
FIGURE B 36



FILTER MEDIA: 60 in No 2 ANTH./24 in No 1220 SAND
DATE 12-8-71 FLUX RATE 16.0 gpm/ft² COAG. – mg/l
POLY – mg/l

HIGH RATE DEEP BED FILTRATION TEST No 18-SE-II

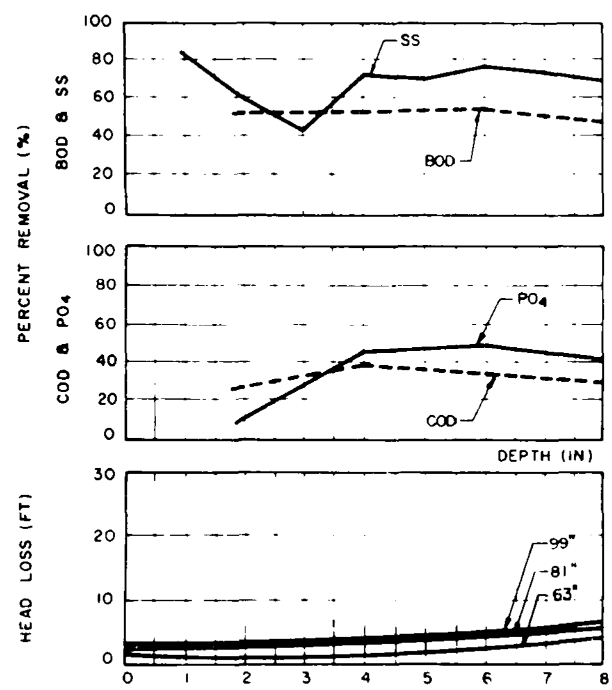
FIGURE B 37



FILTER MEDIA: 60 in No 2 ANTH./24 in No 1220 SAND
DATE 12-8-71 FLUX RATE 24.0 gpm/ft² COAG – mg/l
POLY – mg/l

HIGH RATE DEEP BED FILTRATION TEST No 18-SE-III

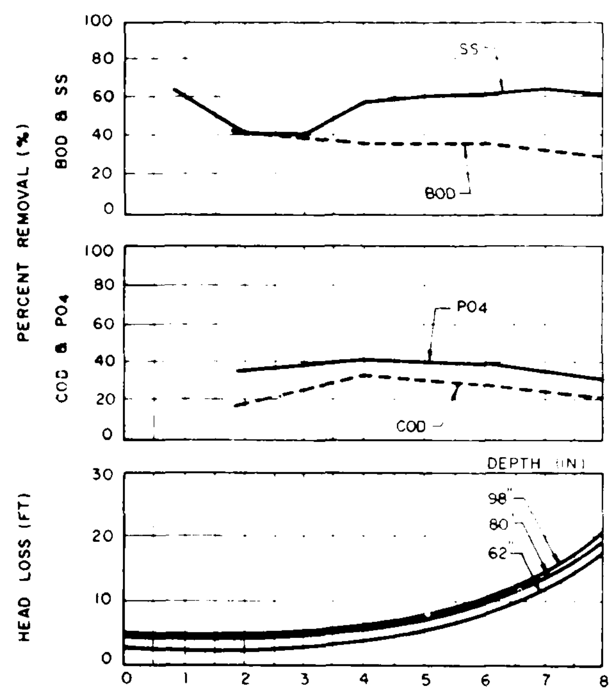
FIGURE B 39



FILTER MEDIA 60 in No. 2 ANTH /.24 in No 1220 SAND
DATE 12-8-71 FLUX RATE 16.0 gpm/ft² COAG — mg/l
POLY — mg/l

HIGH RATE DEEP BED FILTRATION TEST No.18-SE-II

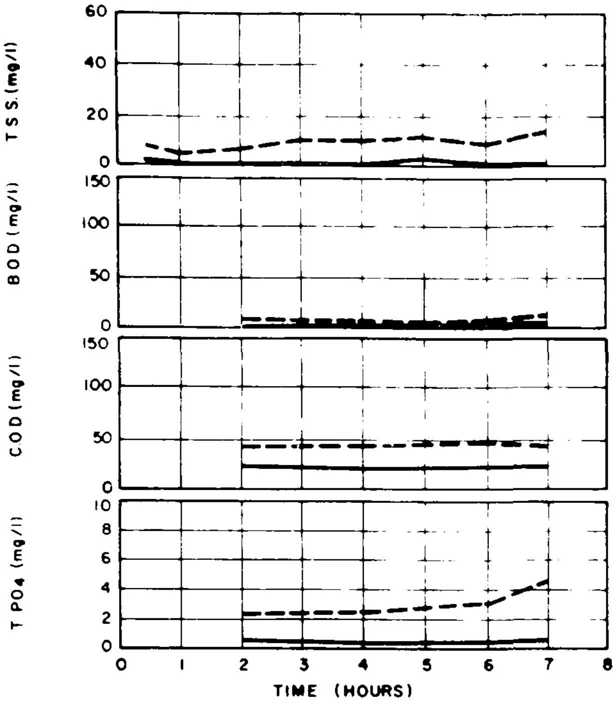
FIGURE B 38



FILTER MEDIA 60 in No 2 ANTH / 24 in No 1220 SAND
DATE 12-8-71 FLUX RATE 24.0 gpm/ft² COAG — mg/l
POLY — mg/l

HIGH RATE DEEP BED FILTRATION TEST No.18-SE-III

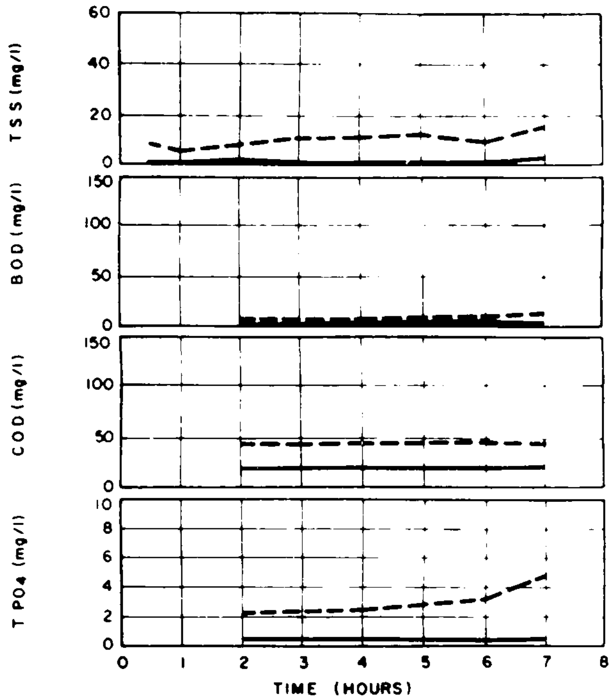
FIGURE B 40



FILTER MEDIA: 60 in No 2 ANTH./24 in No 1220 SAND
DATE 12-9-71 FLUX RATE 16.2 gpm/ft² COAG. ALUM 15 mg/l
POLY CAL 226 - 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.19-SE-I

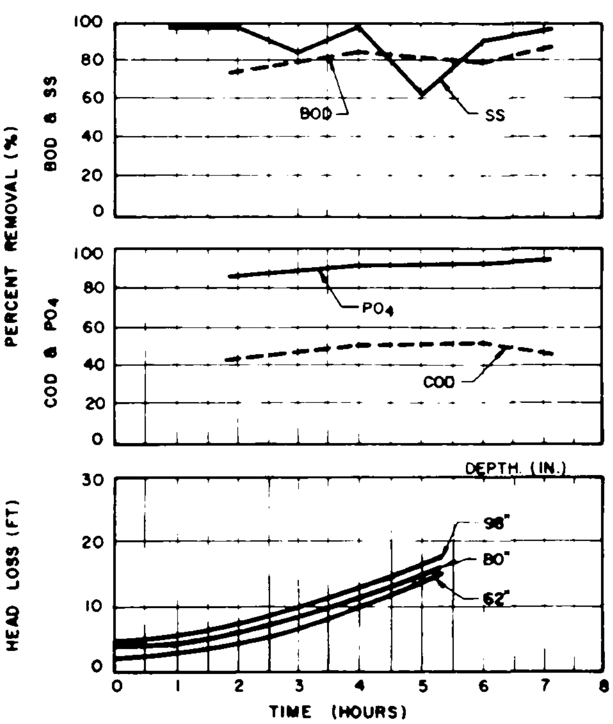
FIGURE B 41



FILTER MEDIA: 60 in No 2 ANTH./24 in No 1220 SAND
DATE 12-9-71 FLUX RATE 13.3 gpm/ft² COAG ALUM 15 mg/l
POLY CAL 226 - 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.19-SE-II

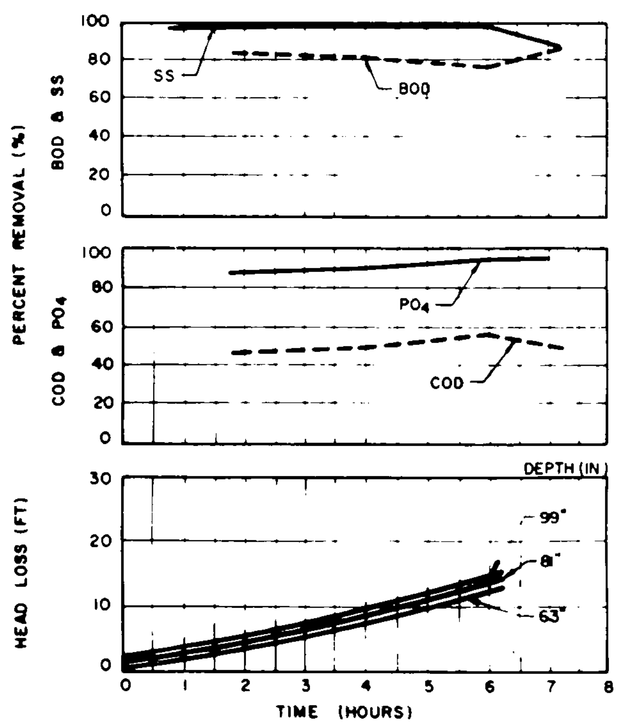
FIGURE B 43



FILTER MEDIA: 60 in No 2 ANTH./24 in No 1220 SAND
DATE 12-9-71 FLUX RATE 16.2 gpm/ft² COAG ALUM 15 mg/l
POLY CAL 226 - 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.19-SE-I

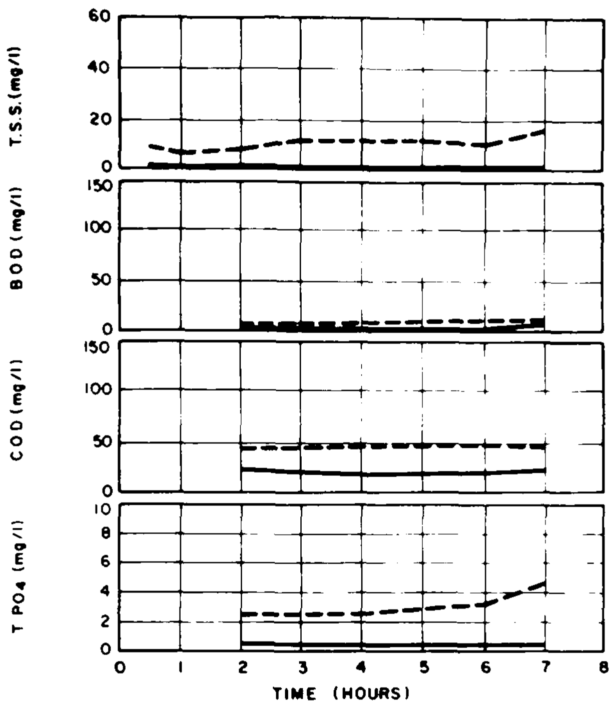
FIGURE B 42



FILTER MEDIA: 60 in No 2 ANTH /24 in No 1220 SAND
DATE 12-9-71 FLUX RATE 13.3 gpm/ft² COAG ALUM 15 mg/l
POLY CAL 226 - 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.19-SE-II

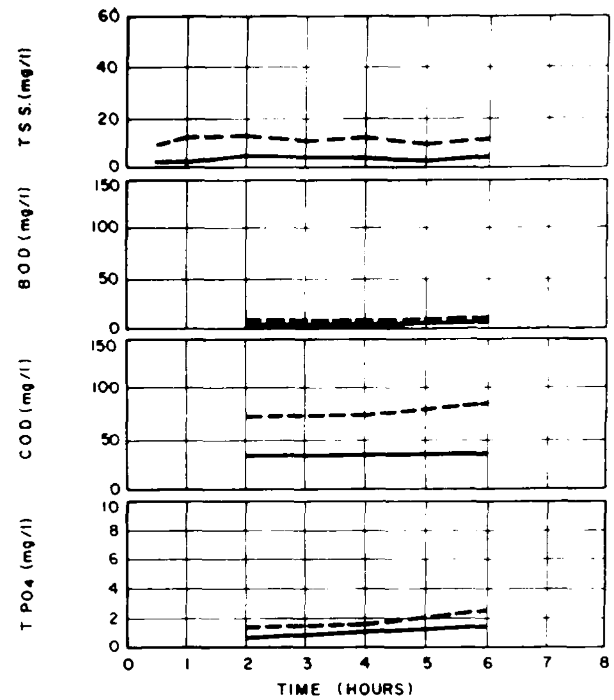
FIGURE B 44



FILTER MEDIA: 60 in No 2 ANTH./24 in No 1220 SAND
DATE 12-9-71 FLUX RATE 18.0 gpm/ft^2 COAG. ALUM. 15 mg/l
POLY CAL 226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.19-SE-III

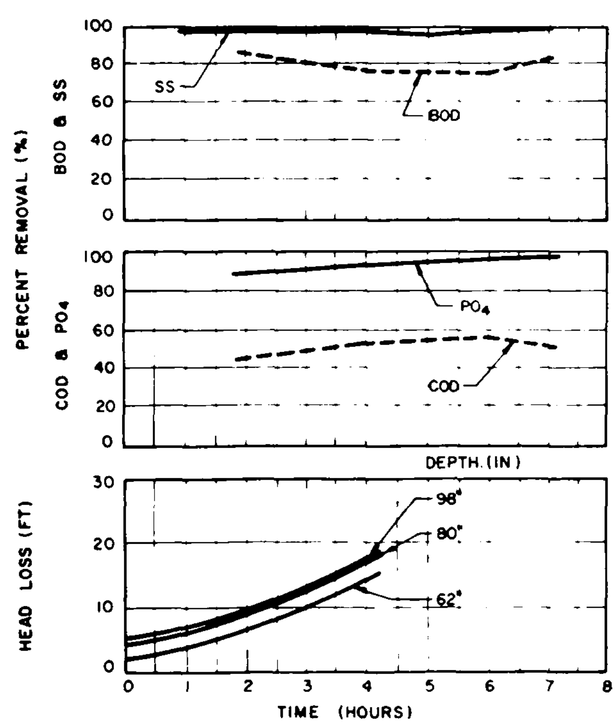
FIGURE B 45



FILTER MEDIA: 60 in No 2 ANTH./24 in No 1220 SAND
DATE 12-10-71 FLUX RATE 22.2 gpm/ft^2 COAG — mg/l
POLY — mg/l

HIGH RATE DEEP BED FILTRATION TEST No.20-SE-I

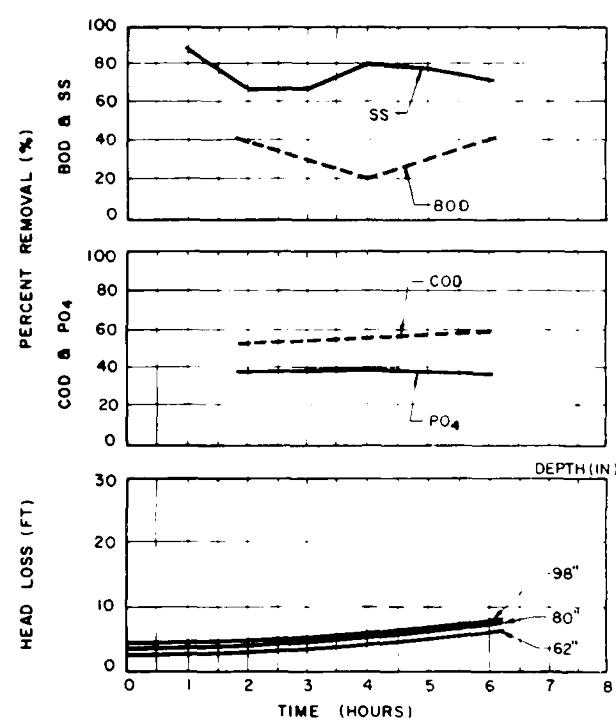
FIGURE B 47



FILTER MEDIA: 60 in No 2 ANTH /24 in No 1220 SAND
DATE 12-9-71 FLUX RATE 18.0 gpm/ft^2 COAG ALUM. 15 mg/l
POLY CAL 226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.19-SE-III

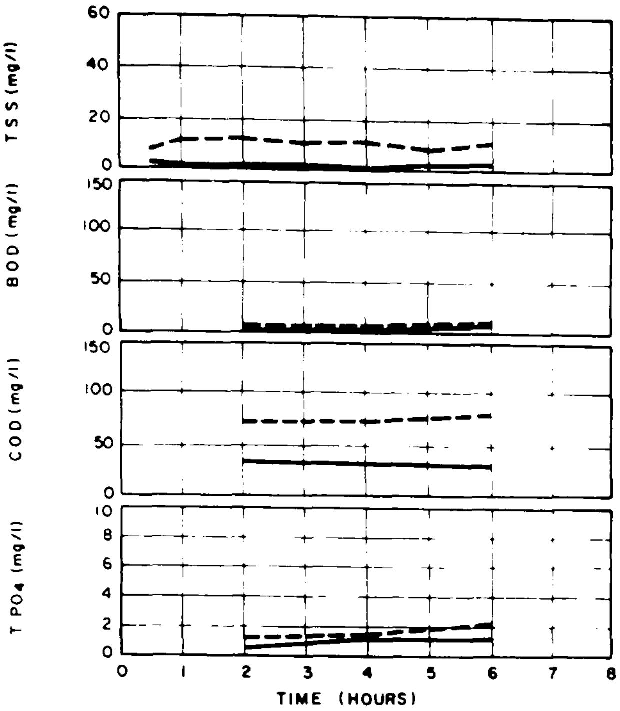
FIGURE B 46



FILTER MEDIA: 60 in No 2 ANTH /24 in No 1220 SAND
DATE 12-10-71 FLUX RATE 22.2 gpm/ft^2 COAG — mg/l
POLY — mg/l

HIGH RATE DEEP BED FILTRATION TEST No.20-SE-I

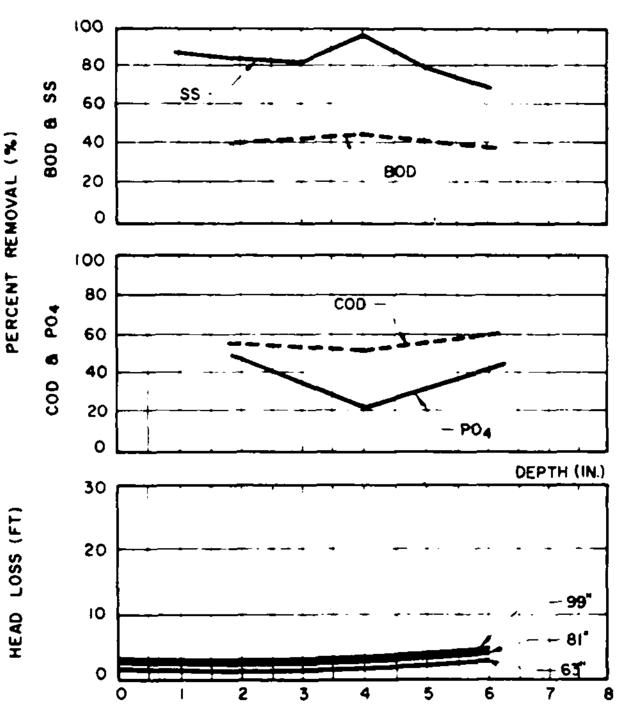
FIGURE B 48



FILTER MEDIA: 60 in No 2 ANTH./24 in No 1220 SAND
DATE 12-10-71 FLUX RATE 16.0 gpm/ft² COAG. — mg/l
POLY. — mg/l

HIGH RATE DEEP BED FILTRATION TEST No.20-SE-II

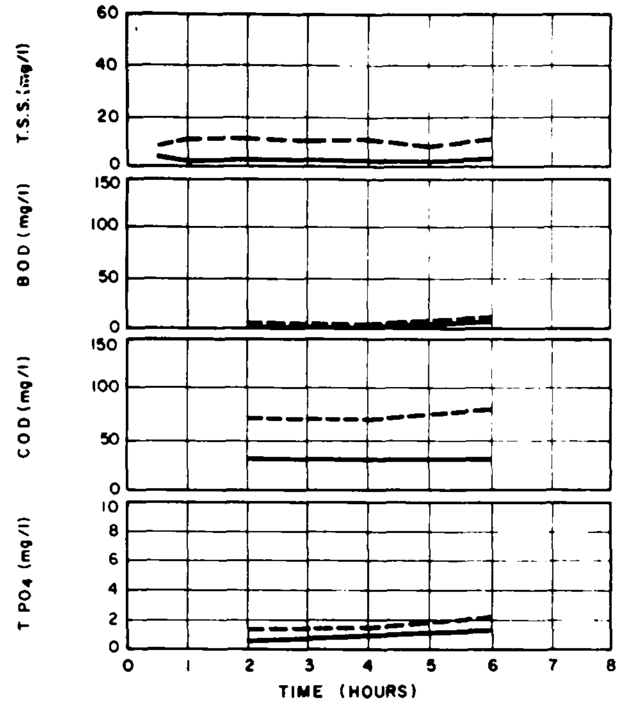
FIGURE B 49



FILTER MEDIA: 60 in No. 2 ANTH /24 in No 1220 SAND
DATE 12-10-71 FLUX RATE 16.0 gpm/ft² COAG — mg/l
POLY — mg/l

HIGH RATE DEEP BED FILTRATION TEST No.20-SE-II

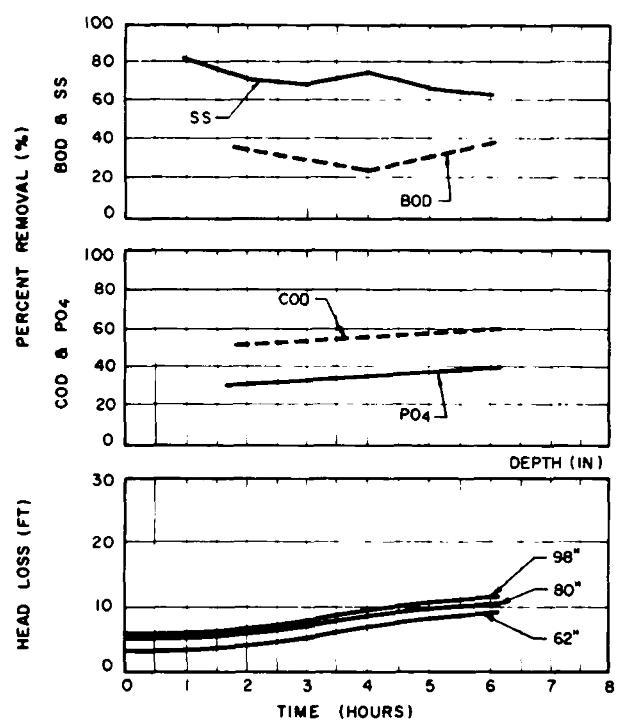
FIGURE B 50



FILTER MEDIA: 60 in No. 2 ANTH./24 in No 1220 SAND
DATE 12-10-71 FLUX RATE 27.6 gpm/ft² COAG. — mg/l
POLY. — mg/l

HIGH RATE DEEP BED FILTRATION TEST No.20-SE-III

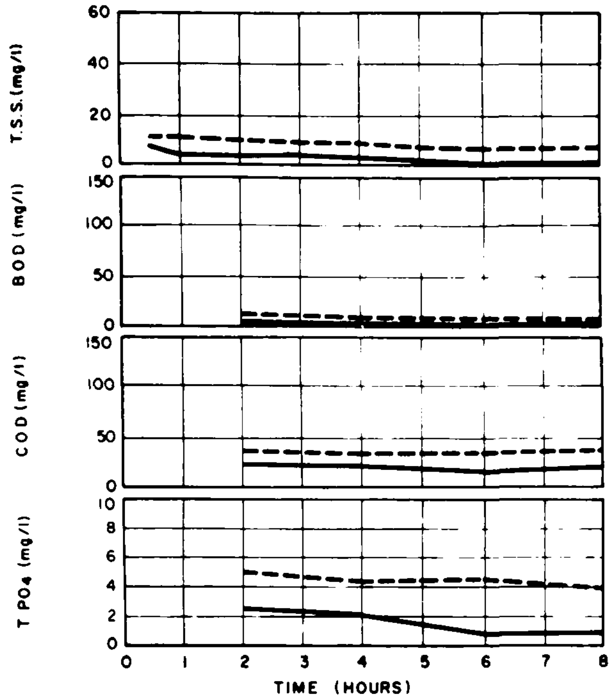
FIGURE B 51



FILTER MEDIA: 60 in No. 2 ANTH./24 in No 1220 SAND
DATE 12-10-71 FLUX RATE 27.6 gpm/ft² COAG — mg/l
POLY — mg/l

HIGH RATE DEEP BED FILTRATION TEST No.20-SE-III

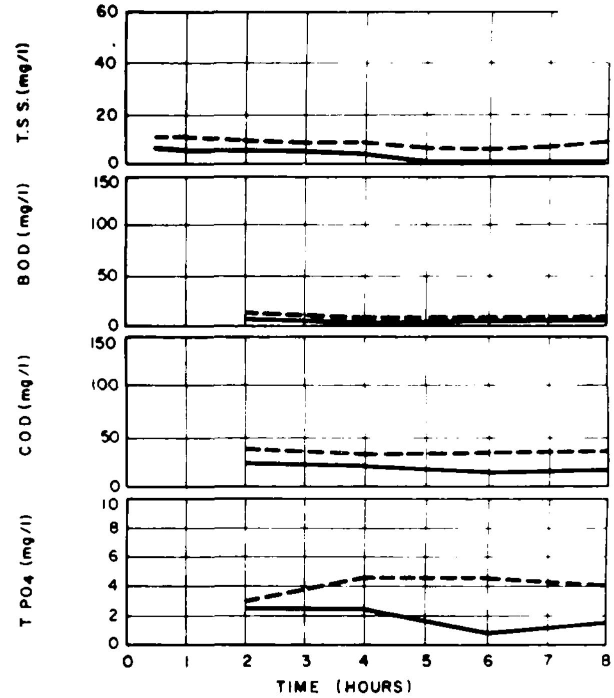
FIGURE B 52



FILTER MEDIA: 60 in No 3 ANTH./24 in No 612 SAND
DATE 12-14-71 FLUX RATE 8.0 gpm/ft^2 COAG. ALUM 15 mg/l
POLY. CAL. 226 - 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.21-SE-I

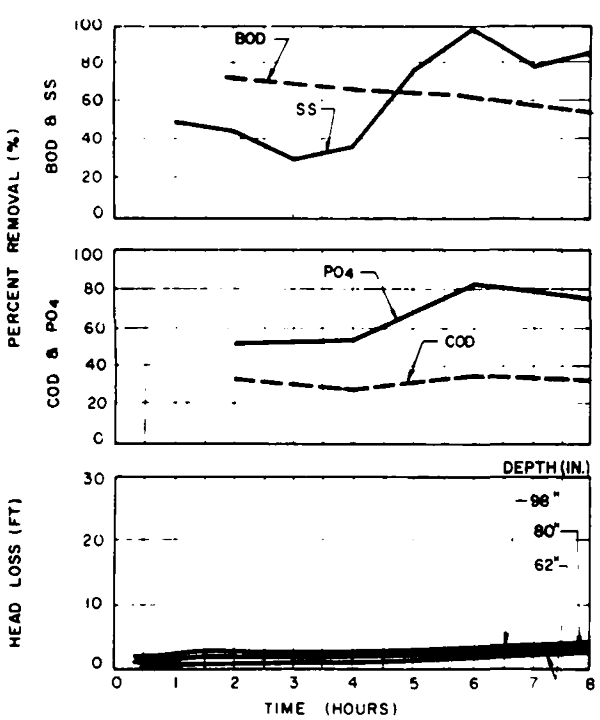
FIGURE B 53



FILTER MEDIA: 60 in No 3 ANTH./24 in No 612 SAND
DATE 12-14-71 FLUX RATE 16.0 gpm/ft^2 COAG. ALUM 15 mg/l
POLY. CAL. 226 - 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No 21-SE-II

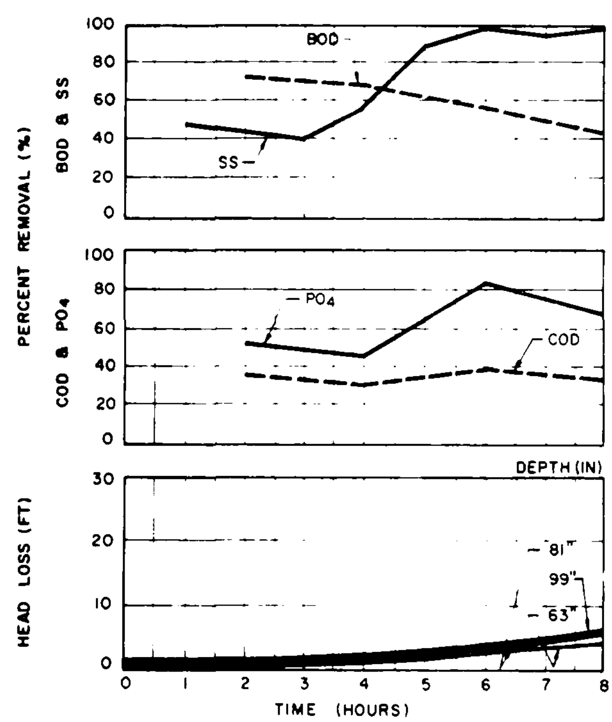
FIGURE B 55



FILTER MEDIA 60 in No 3 ANTH / 24 in No 612 SAND
DATE 12-14-71 FLUX RATE 8.0 gpm/ft^2 COAG ALUM 15 mg/l
POLY CAL 226 - 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.21-SE-I

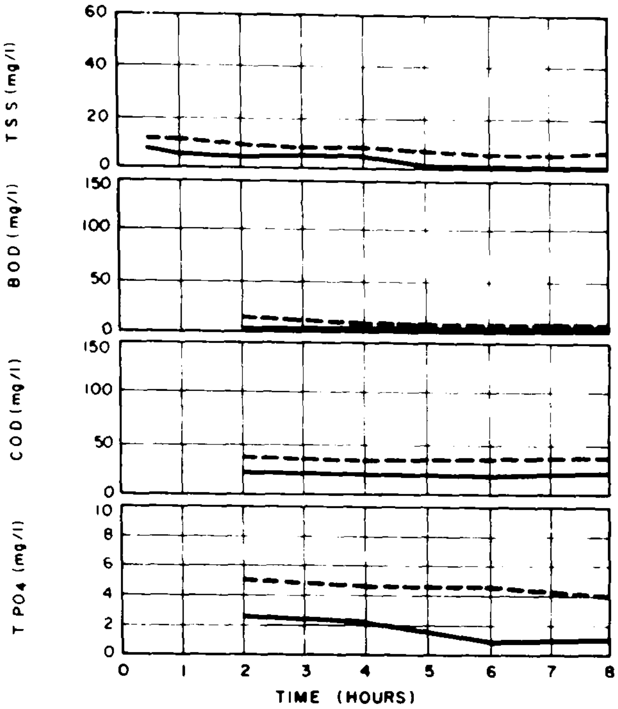
FIGURE B 54



FILTER MEDIA: 60 in No. 3 ANTH / 24 in No 612 SAND
DATE 12-14-71 FLUX RATE 16.0 gpm/ft^2 COAG ALUM. 15 mg/l
POLY CAL. 226 - 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.21-SE-II

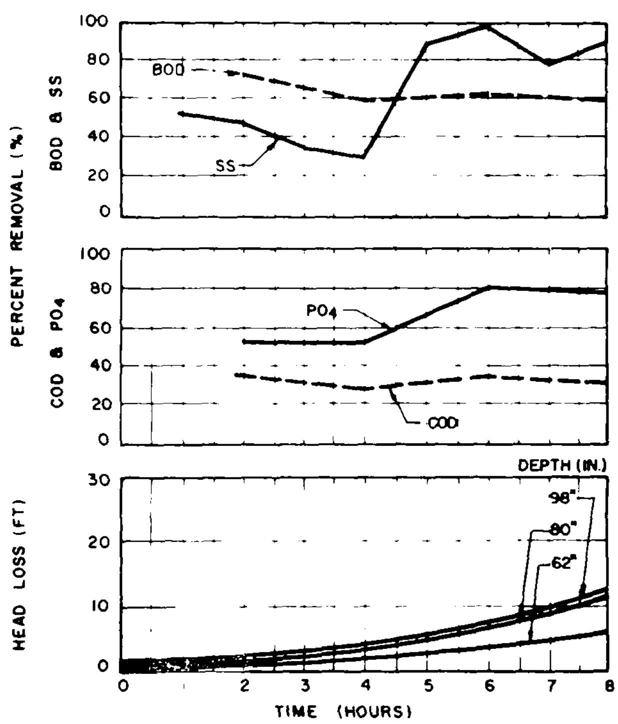
FIGURE B 56



FILTER MEDIA: 60 in No 3 ANTH./24 in No 612 SAND
DATE 12-14-71 FLUX RATE 24.0 gpm/ft² COAG. ALUM. 15 mg/l
POLY CAL.226 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No 21-SE-III

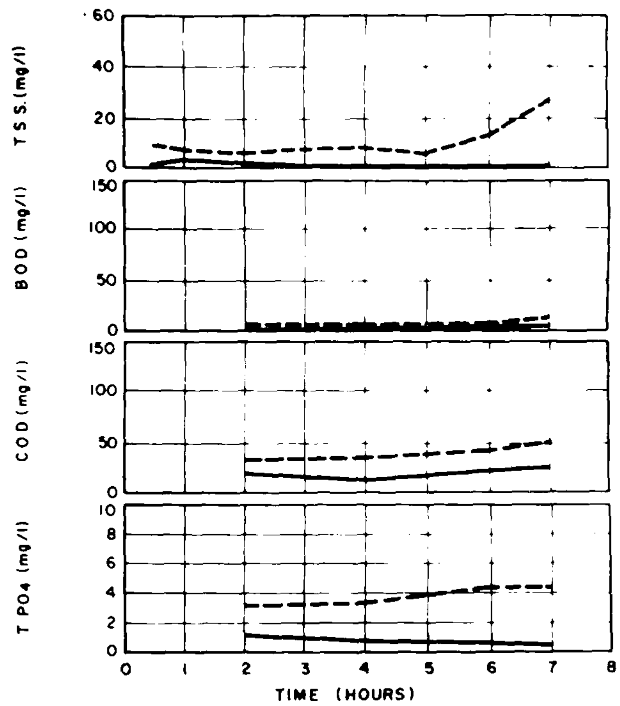
FIGURE B 57



FILTER MEDIA: 60 in No. 3 ANTH /24 in No. 612 SAND
DATE 12-14-71 FLUX RATE 24.0 gpm/ft² COAG ALUM. 15 mg/l
POLY CAL. 226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.21-SE-III

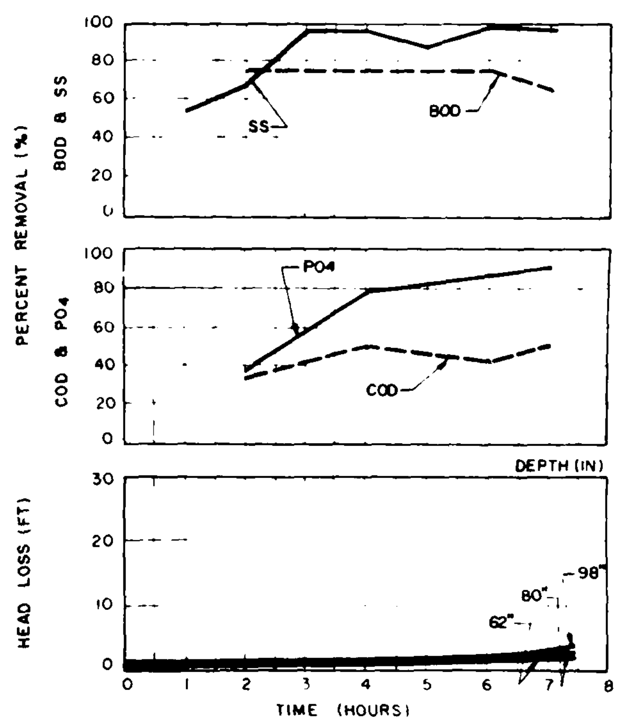
FIGURE B 58



FILTER MEDIA: 60 in No 3 ANTH./24 in No 612 SAND
DATE 12-17-71 FLUX RATE 7.5 gpm/ft² COAG. ALUM 15 mg/l
POLY CAL.226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.22-SE-I

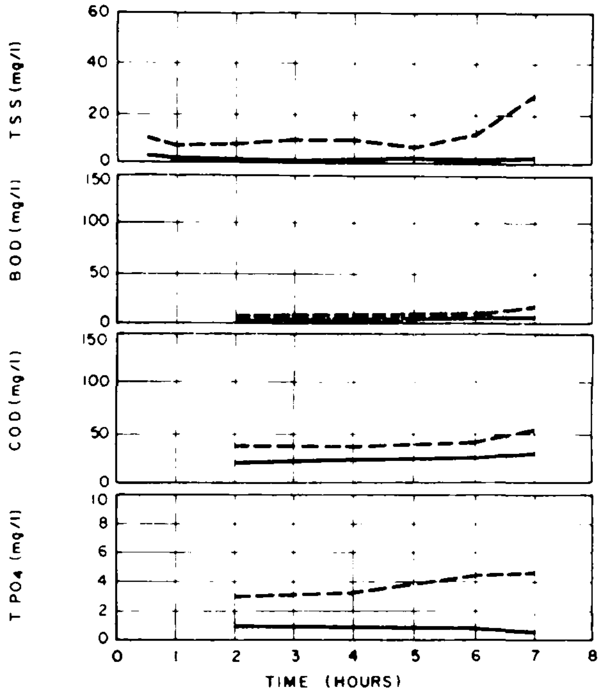
FIGURE B 59



FILTER MEDIA 60 in No. 3 ANTH / 24 in No 612 SAND
DATE 12-17-71 FLUX RATE 7.5 gpm/ft² COAG ALUM 15 mg/l
POLY CAL.226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.22-SE-I

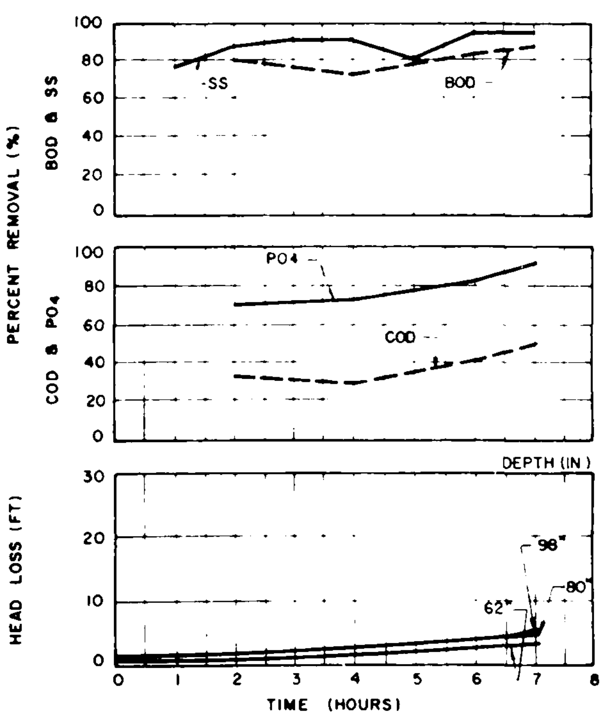
FIGURE B 60



FILTER MEDIA: 60 in No 3 ANTH / 24 in No 612 SAND
DATE 12-17-71 FLUX RATE 16.6 gpm/ft² COAG ALUM 15 mg/l
POLY CAL 226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No 22-SE-II

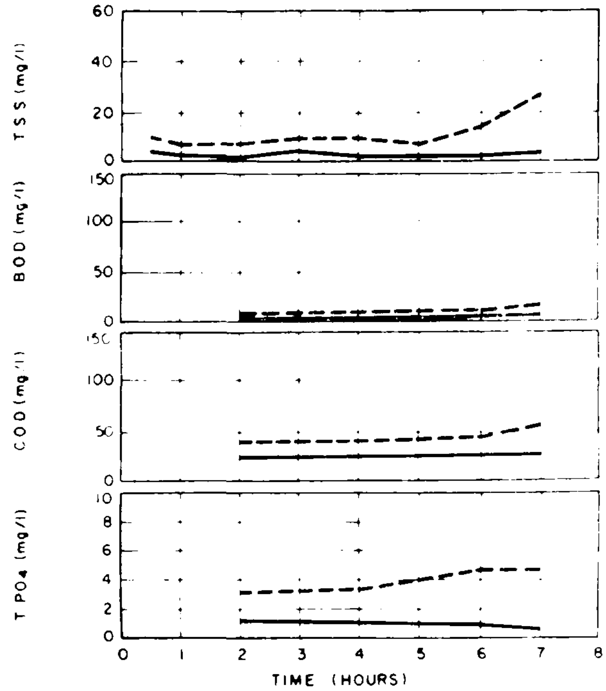
FIGURE B 61



FILTER MEDIA 60 in No. 3 ANTH / 24 in No 612 SAND
DATE 12-17-71 FLUX RATE 16.6 gpm/ft² COAG ALUM 15 mg/l
POLY CAL. 226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.22-SE-II

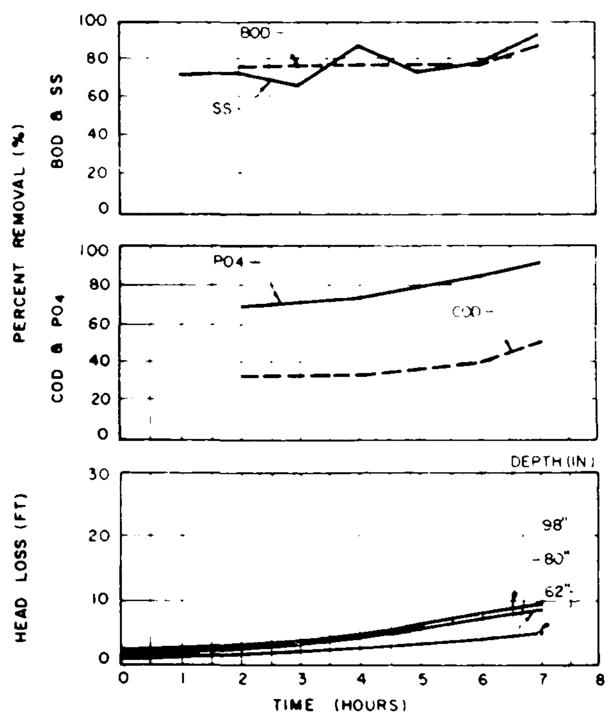
FIGURE B 62



FILTER MEDIA: 60 in No 3 ANTH / 24 in No 612 SAND
DATE 12-17-71 FLUX RATE 22.4 gpm/ft² COAG ALUM 15 mg/l
POLY CAL 226 - 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No 22-SE-III

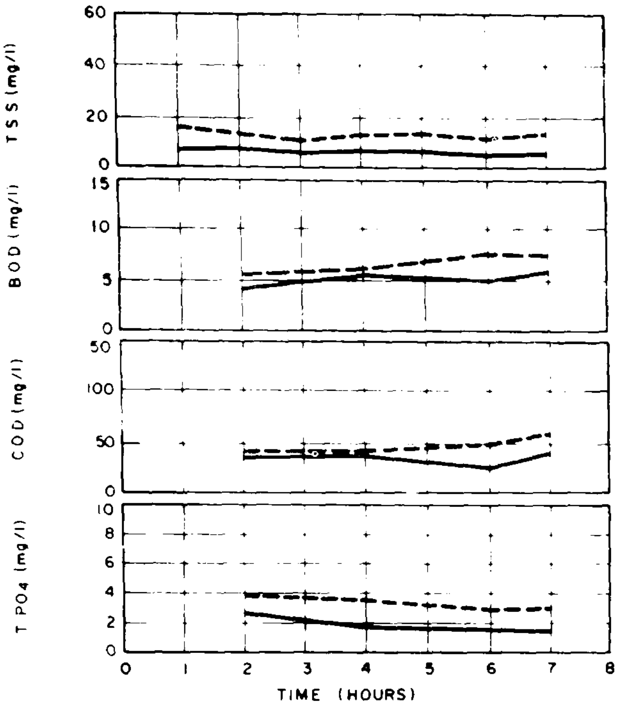
FIGURE B 63



FILTER MEDIA 60 in No. 3 ANTH / 24 in No 612 SAND
DATE 12-17-71 FLUX RATE 22.4 gpm/ft² COAG ALUM 15 mg/l
POLY CAL. 226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.22-SE-III

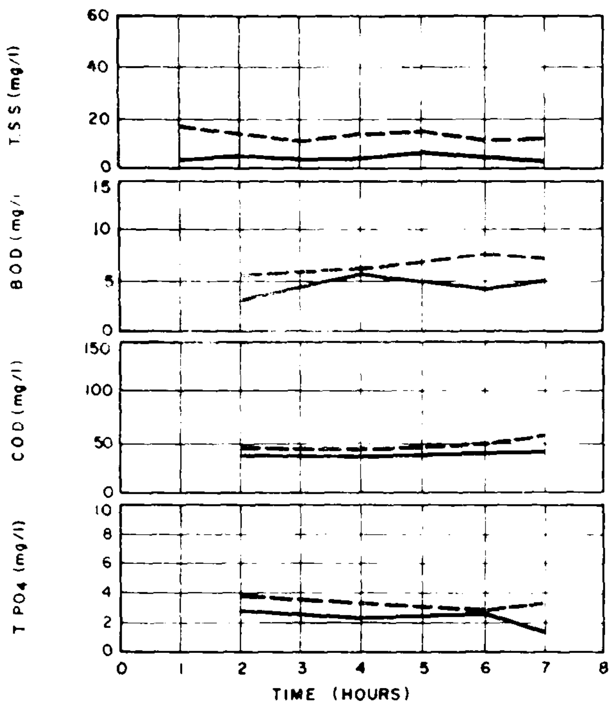
FIGURE B 64



FILTER MEDIA: 60 in No 3 ANTH./24 in No 612 SAND
DATE 12-21-71 FLUX RATE 24.0 gpm/ft² COAG — mg/l
POLY — mg/l

HIGH RATE DEEP BED FILTRATION TEST No 23-SE-I

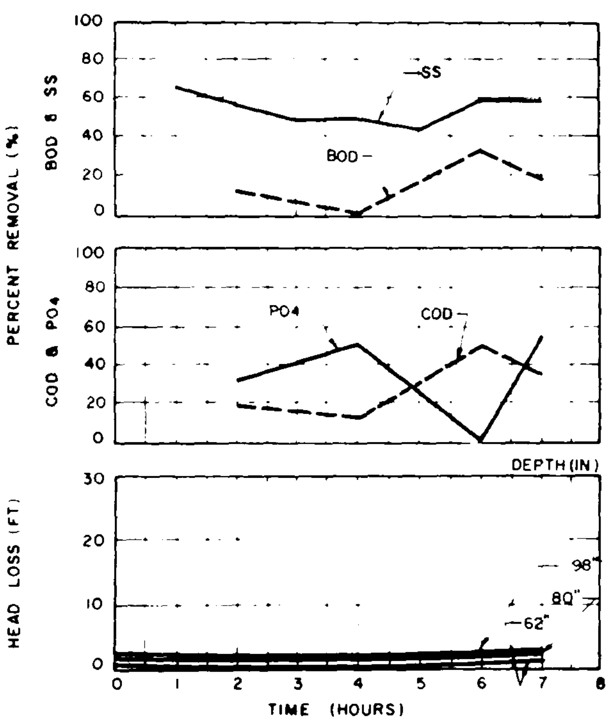
FIGURE B 65



FILTER MEDIA: 60 in No 3 ANTH./24 in No 612 SAND
DATE 12-21-71 FLUX RATE 16.0 gpm/ft² COAG — mg/l
POLY — mg/l

HIGH RATE DEEP BED FILTRATION TEST No.23-SE-II

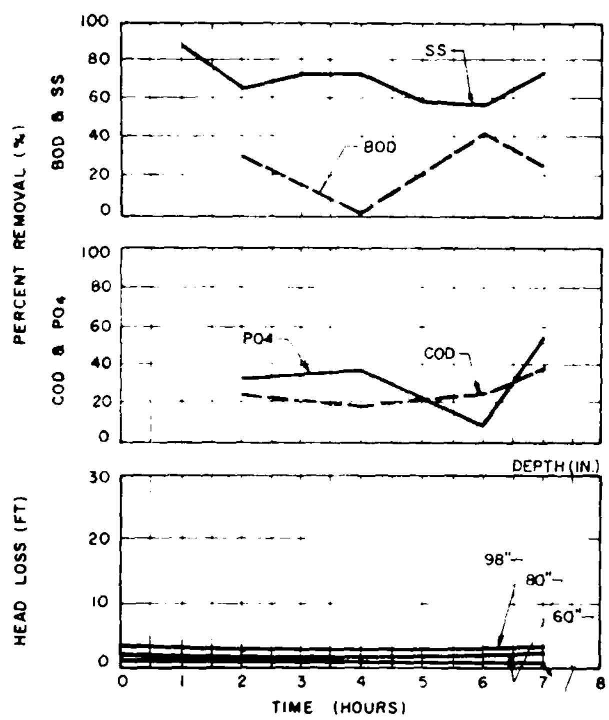
FIGURE B 67



FILTER MEDIA 60 in No. 3 ANTH /24 in No 612 SAND
DATE 12-21-71 FLUX RATE 24 gpm/ft² COAG — mg/l
POLY — mg/l

HIGH RATE DEEP BED FILTRATION TEST No.23-SE-I

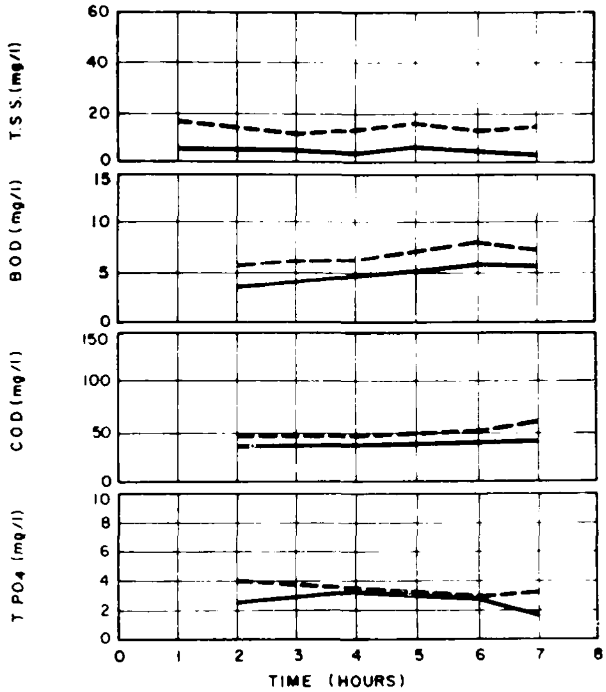
FIGURE B 66



FILTER MEDIA 60 in No 3 ANTH /24 in No 612 SAND
DATE 12-21-71 FLUX RATE 16.0 gpm/ft² COAG — mg/l
POLY — mg/l

HIGH RATE DEEP BED FILTRATION TEST No.23-SE-II

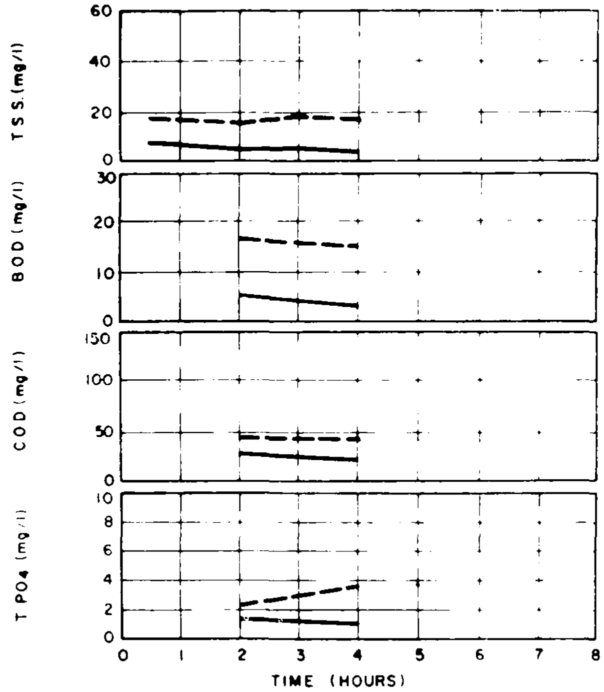
FIGURE B 68



FILTER MEDIA: 60 in No 3 ANTH./24 in No 612 SAND
DATE 12-21-71 FLUX RATE 8.0 gpm/ft^2 COAG — mg/l POLY — mg/l

HIGH RATE DEEP BED FILTRATION TEST No 23-SE-III

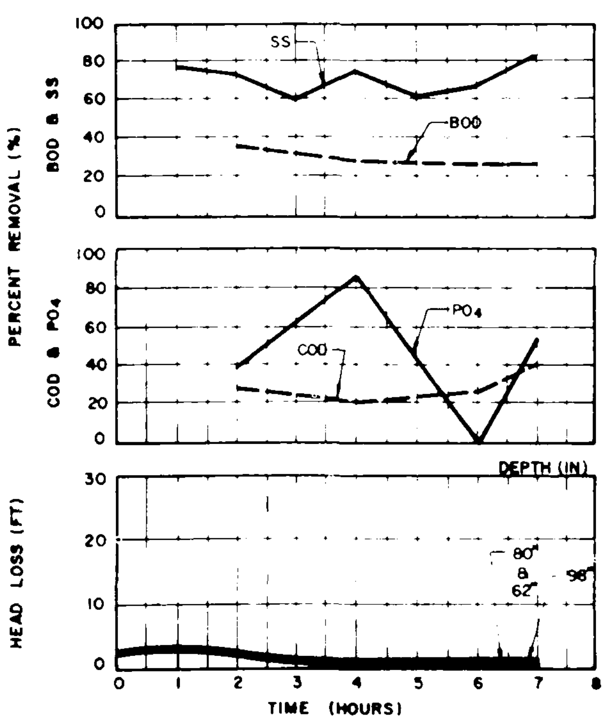
FIGURE B 69



FILTER MEDIA: 60 in No 2 ANTH./24 in No 1220 SAND
DATE 1-7-72 FLUX RATE 16.4 gpm/ft^2 COAG ALUM. 15 mg/l POLY CAL. 226 - 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No 25-SE-I

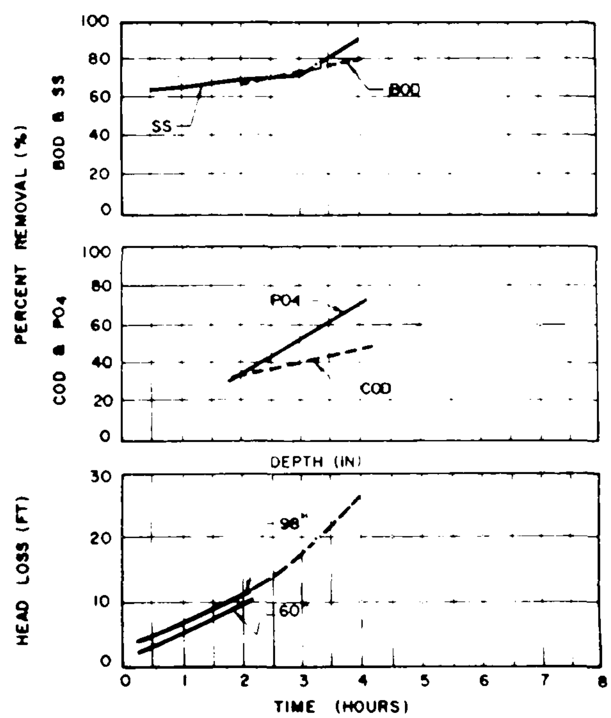
FIGURE B 71



FILTER MEDIA 60 in No. 3 ANTH./24 in No 612 SAND
DATE 12-21-71 FLUX RATE 8.0 gpm/ft^2 COAG — mg/l POLY — mg/l

HIGH RATE DEEP BED FILTRATION TEST No.23-SE-II

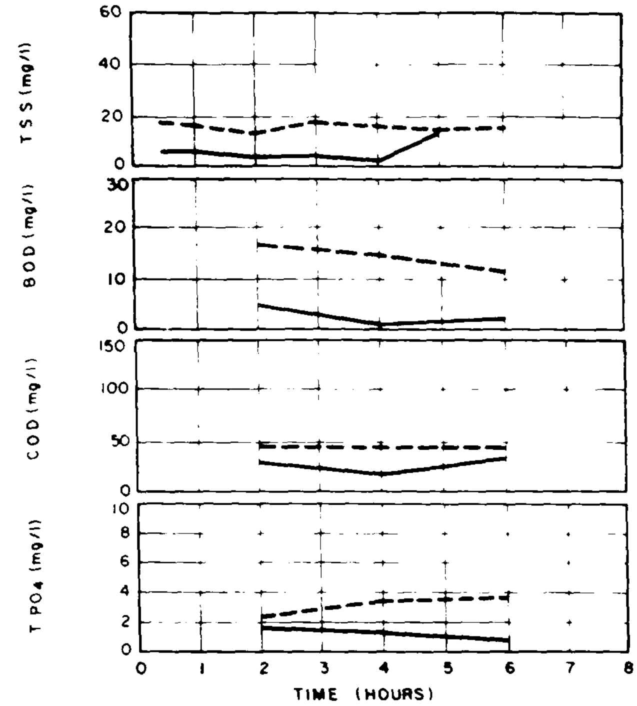
FIGURE B 70



FILTER MEDIA 60 in No. 2 ANTH / 24 in No. 1220 SAND
DATE 1-7-72 FLUX RATE 16.4 gpm/ft^2 COAG ALUM 15 mg/l POLY CAL. 226 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.25-SE-I

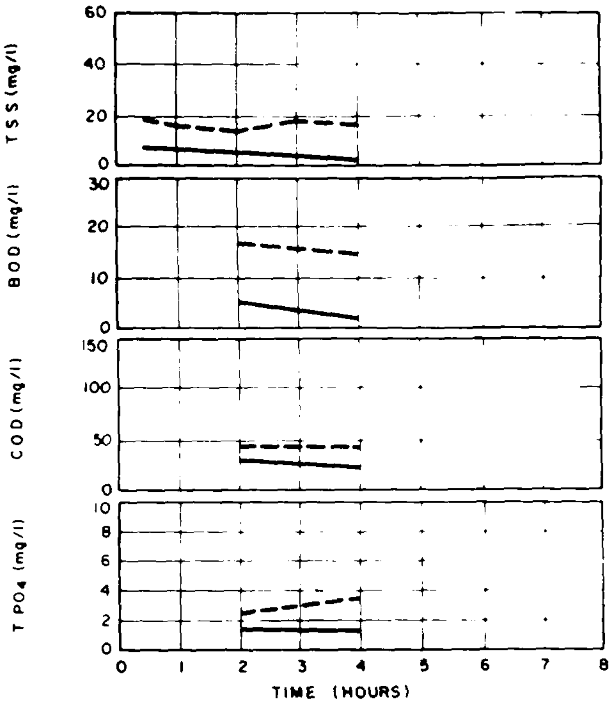
FIGURE B 72



FILTER MEDIA: 60 in No 2 ANTH./24 in No 1220 SAND
DATE 1-7-72 FLUX RATE 15.5 gpm/ft^2 COAG ALUM. 15 mg/l
POLY CAL.226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No 25-SE-II

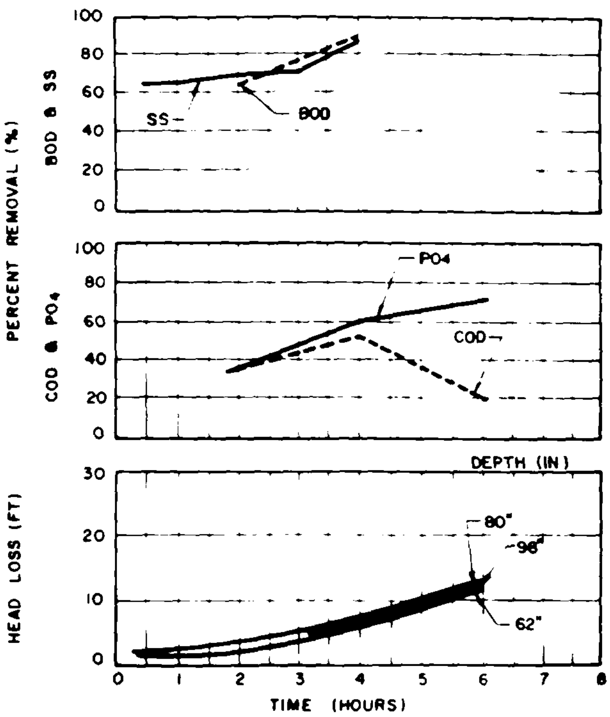
FIGURE B 73



FILTER MEDIA: 60 in No 2 ANTH./24 in No 1220 SAND
DATE 1-7-72 FLUX RATE 23.0 gpm/ft^2 COAG ALUM 15 mg/l
POLY CAL.226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No 25-SE-III

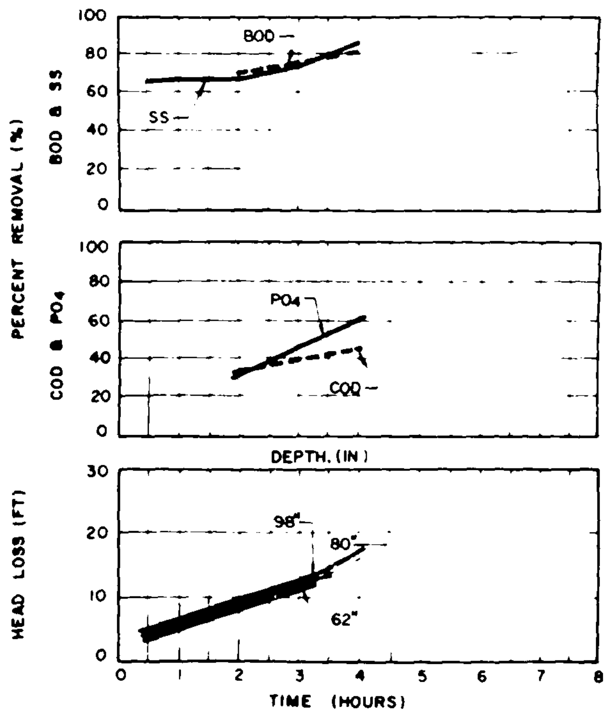
FIGURE B 75



FILTER MEDIA: 60 in No 2 ANTH /24 in No 1220 SAND
DATE 1-7-72 FLUX RATE 15.5 gpm/ft^2 COAG ALUM 15 mg/l
POLY CAL.226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.25-SE-II

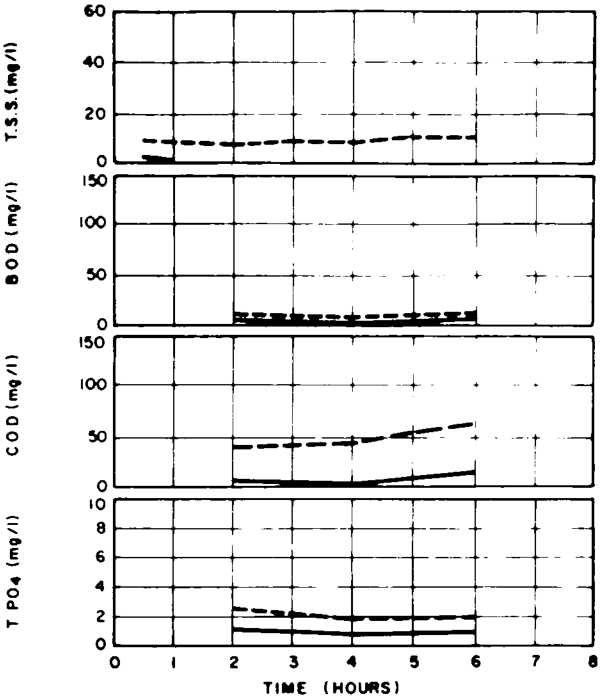
FIGURE B 74



FILTER MEDIA 60 in No 2 ANTH /24 in No 1220 SAND
DATE 1-7-72 FLUX RATE 23.0 gpm/ft^2 COAG ALUM 15 mg/l
POLY CAL 226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.25-SE-III

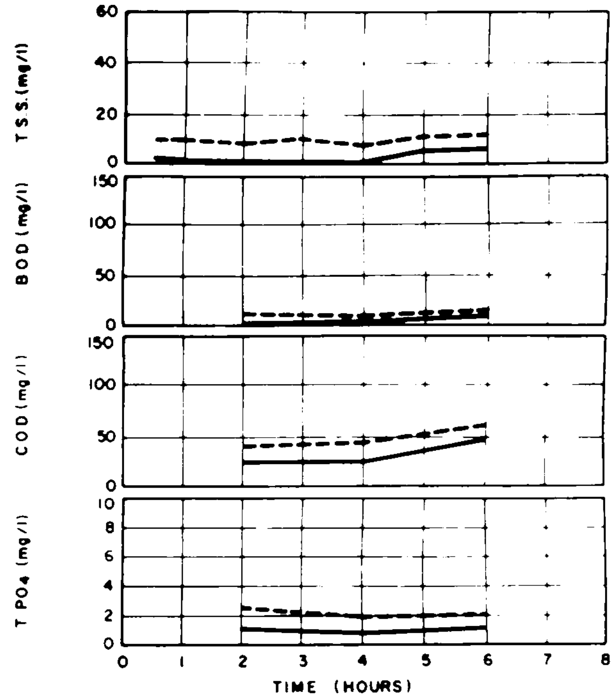
FIGURE B 76



FILTER MEDIA: 60 in No 2 ANTH./24 in No 1220 SAND
DATE 1-12-72 FLUX RATE 14.5 gpm/ft² COAG. ALUM 1.0 mg/l
POLY CAL 226 - 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.26-SE-I

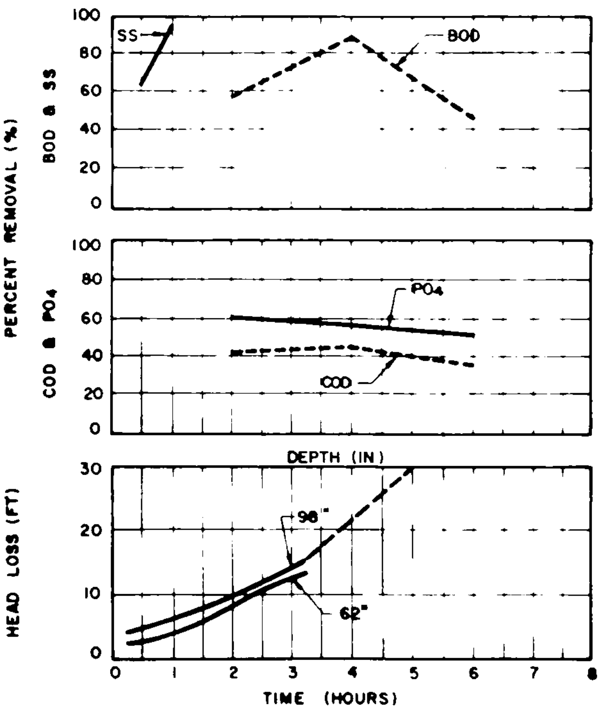
FIGURE B 77



FILTER MEDIA: 60 in No 2 ANTH./24 in No 1220 SAND
DATE 1-12-72 FLUX RATE 13.5 gpm/ft² COAG. ALUM 15.0 mg/l
POLY CAL 226 - 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.26-SE-II

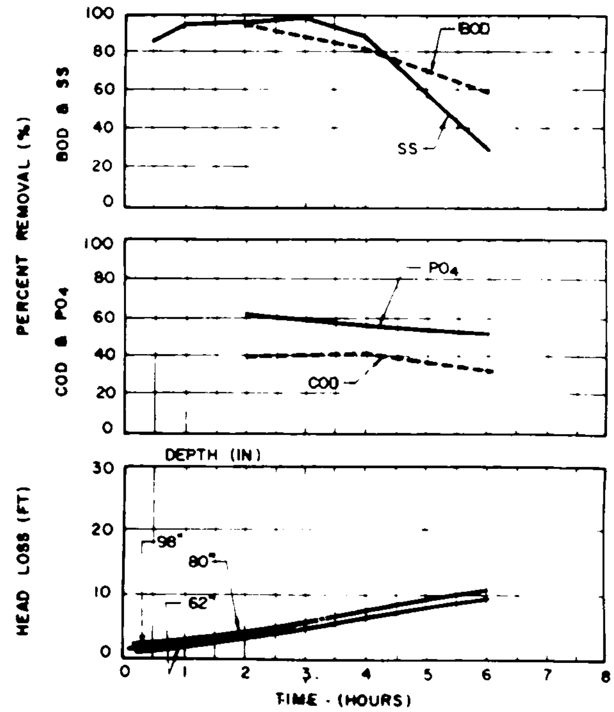
FIGURE B 79



FILTER MEDIA: 60 in No 2 ANTH./24 in No 1220 SAND
DATE 1-12-72 FLUX RATE 14.5 gpm/ft² COAG ALUM 1.0 mg/l
POLY CAL 226 - 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.26-SE-I

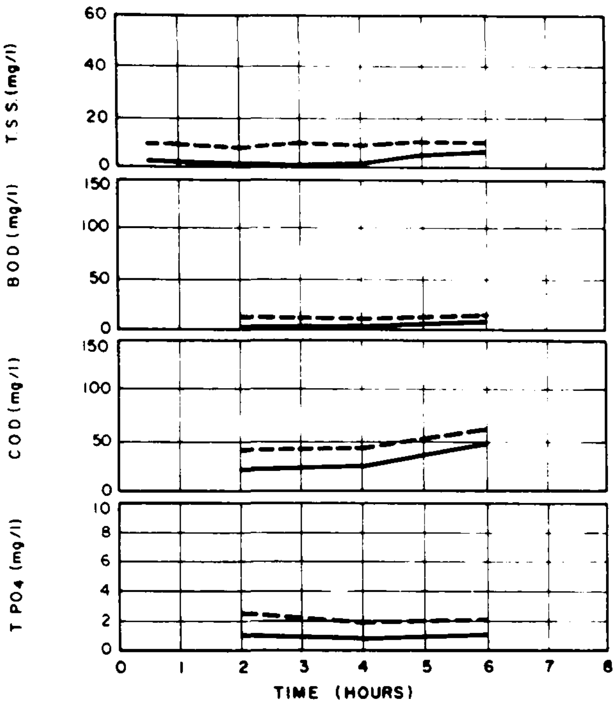
FIGURE B 78



FILTER MEDIA: 60 in No 2 ANTH./24 in No 1220 SAND
DATE 1-12-72 FLUX RATE 13.5 gpm/ft² COAG ALUM 15.0 mg/l
POLY CAL 226 - 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.26-SE-II

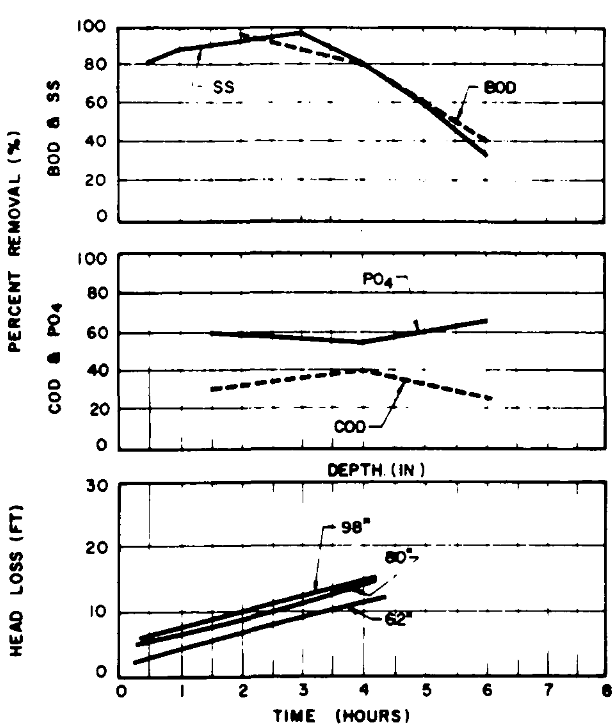
FIGURE B 80



FILTER MEDIA: 60 in No. 2 ANTH./24 in No 1220 SAND
DATE 1-12-72 FLUX RATE 20.0 gpm/ft² COAG. ALUM 15.0 mg/l
POLY. CAL.226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.26-SE-III

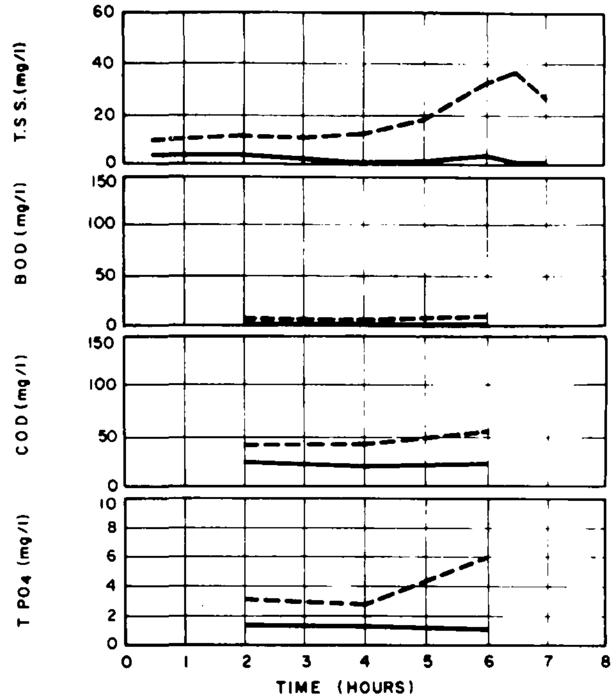
FIGURE B 81



FILTER MEDIA: 60 in No. 2 ANTH./24 in No. 1220 SAND
DATE 1-12-72 FLUX RATE 20.0 gpm/ft² COAG ALUM 15.0 mg/l
POLY CAL. 226 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.26-SE-III

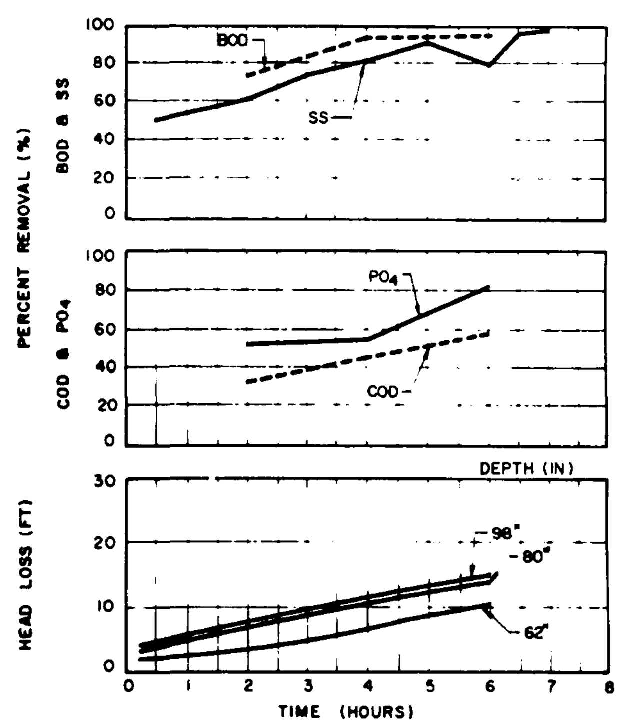
FIGURE B 82



FILTER MEDIA: 60 in No. 2 ANTH./24 in No 1220 SAND
DATE 1-14-72 FLUX RATE 20.0 gpm/ft² COAG. ALUM. 15.0 mg/l
POLY. CAL.226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.27-SE-I

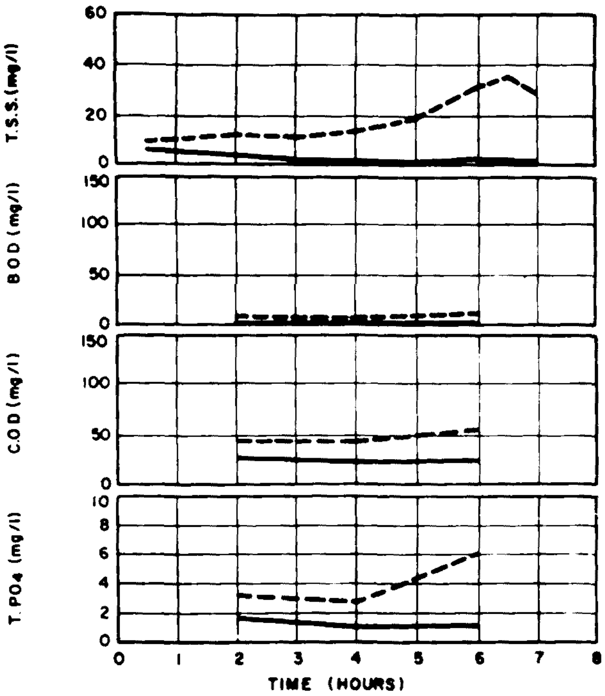
FIGURE B 83



FILTER MEDIA: 60 in No. 2 ANTH./24 in No 1220 SAND
DATE 1-14-72 FLUX RATE 20.0 gpm/ft² COAG ALUM 15.0 mg/l
POLY CAL. 226 0.5 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.27-SE-I

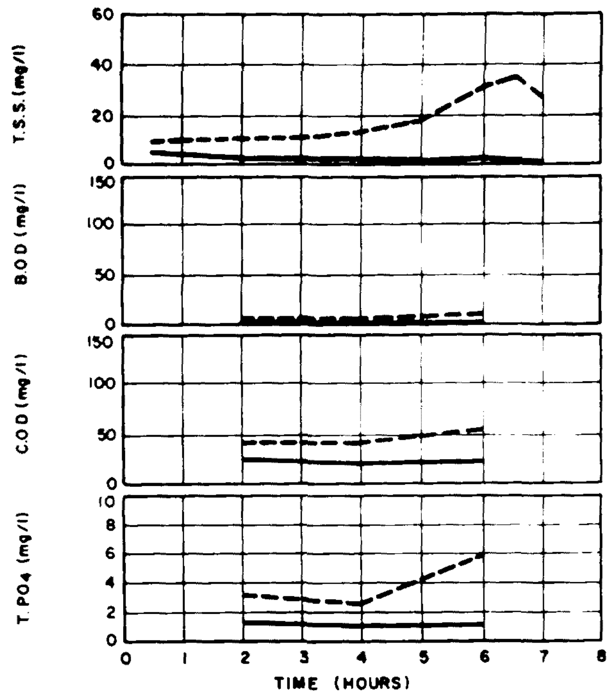
FIGURE B 84



FILTER MEDIA: 60 in No. 2 ANTH./24 in No. 1220 SAND
DATE 1-14-72 FLUX RATE 13.4 gpm/ft^2 COAG. ALUM 15.0 mg/l
POLY. CAL. 226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.27-SE-II

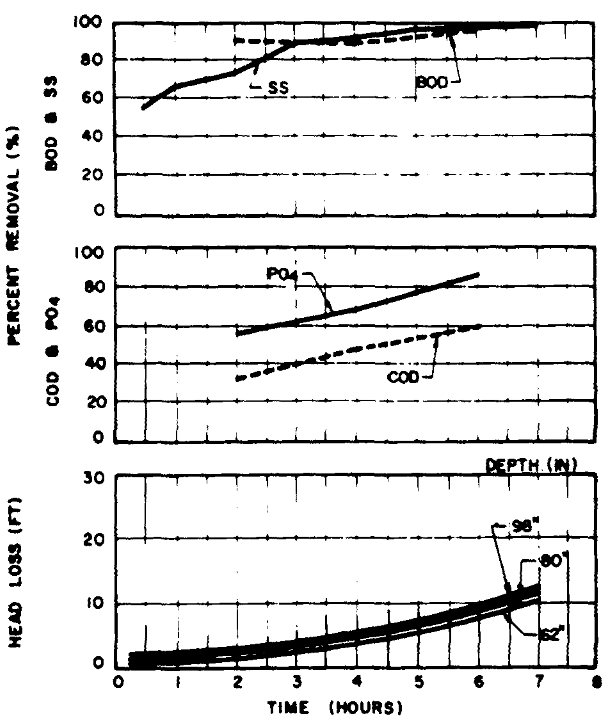
FIGURE B 85



FILTER MEDIA: 60 in No. 2 ANTH./24 in No 1220 SAND
DATE 1-14-72 FLUX RATE 18.6 gpm/ft^2 COAG. ALUM. 15.0 mg/l
POLY. CAL. 226-0.5 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.27-SE-III

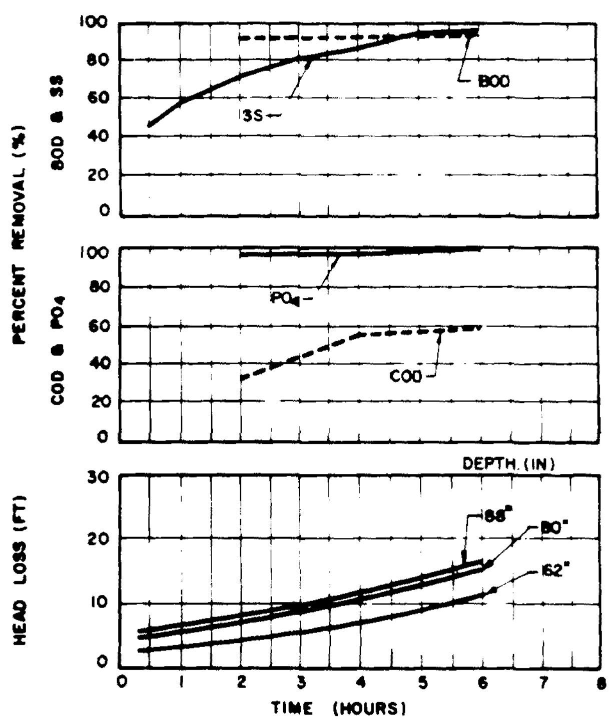
FIGURE B 87



FILTER MEDIA: 60 in No. 2 ANTH./24 in No. 1220 SAND
DATE 1-14-72 FLUX RATE 13.4 gpm/ft^2 COAG. ALUM 15.0 mg/l
POLY CAL. 226 0.5 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.27-SE-II

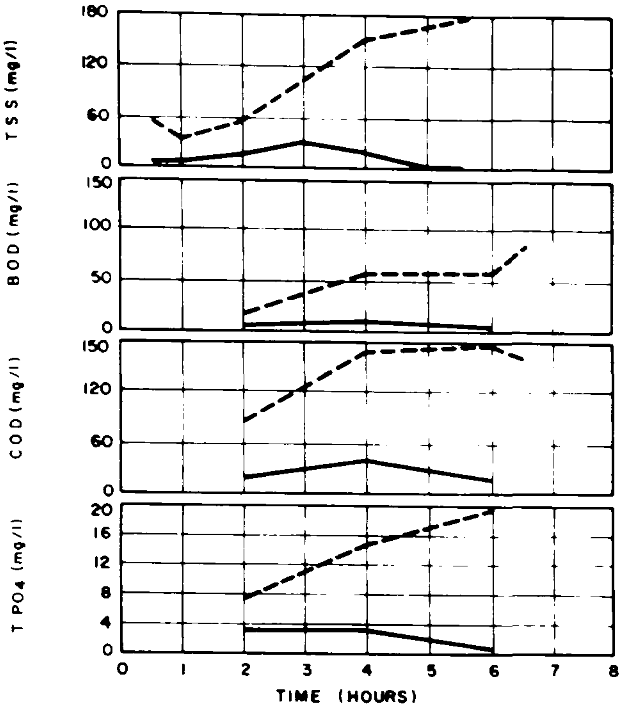
FIGURE B 86



FILTER MEDIA: 60 in No. 2 ANTH./24 in No. 1220 SAND
DATE 1-14-72 FLUX RATE 18.6 gpm/ft^2 COAG. ALUM 15.0 mg/l
POLY CAL. 226-0.5 mg/l

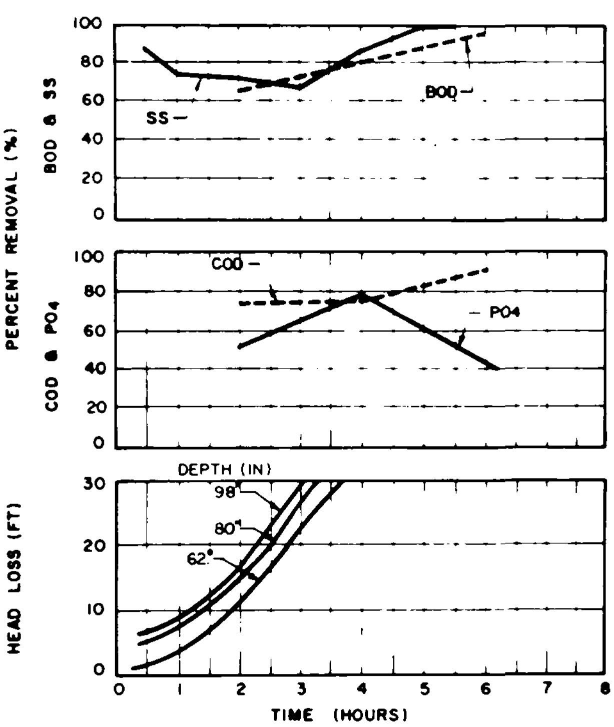
HIGH RATE DEEP BED FILTRATION TEST No.27-SE-III

FIGURE B 88



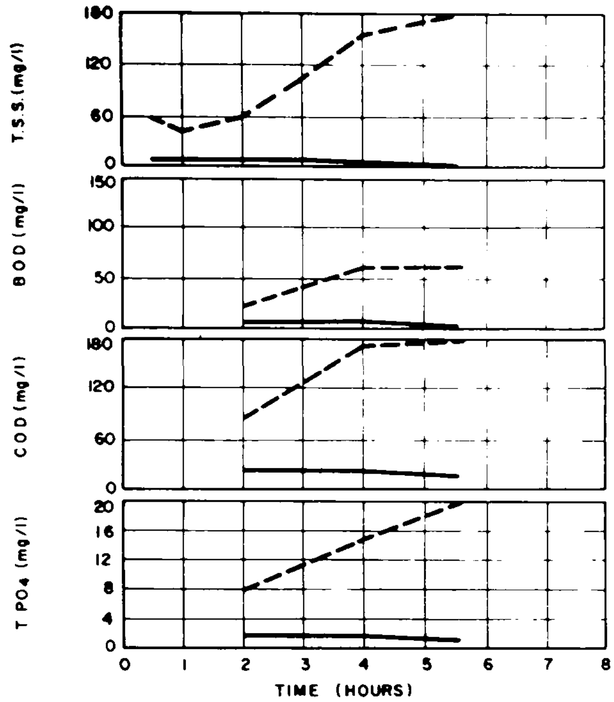
FILTER MEDIA: 60 in No 2 ANTH./24 in No 1220 SAND
DATE 1-19-72 FLUX RATE 24.0 gpm/ft² COAG. ALUM 15.0 mg/l
POLY CAL.226-0.5 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.28-SE-I
FIGURE B 89



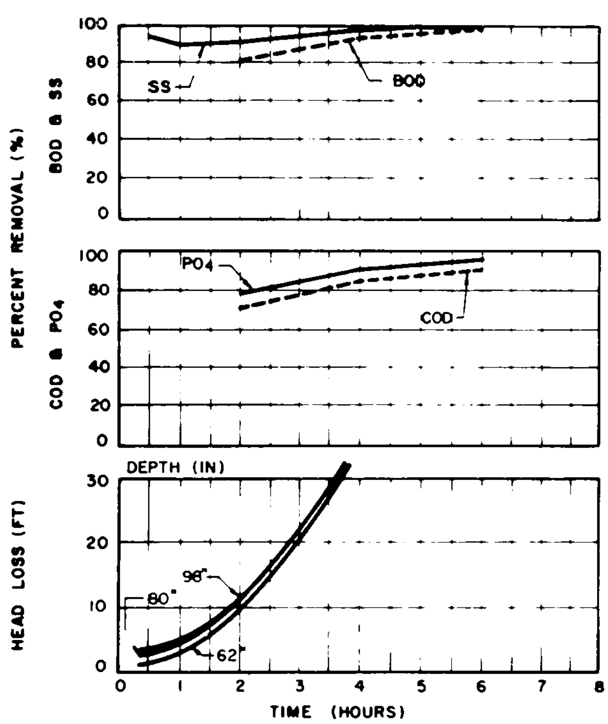
FILTER MEDIA: 60 in No. 2 ANTH./24 in No. 1220 SAND
DATE 1-19-72 FLUX RATE 24.0 gpm/ft² COAG ALUM 15.0 mg/l
POLY CAL 226 0.5 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.28-SE-I
FIGURE B 90



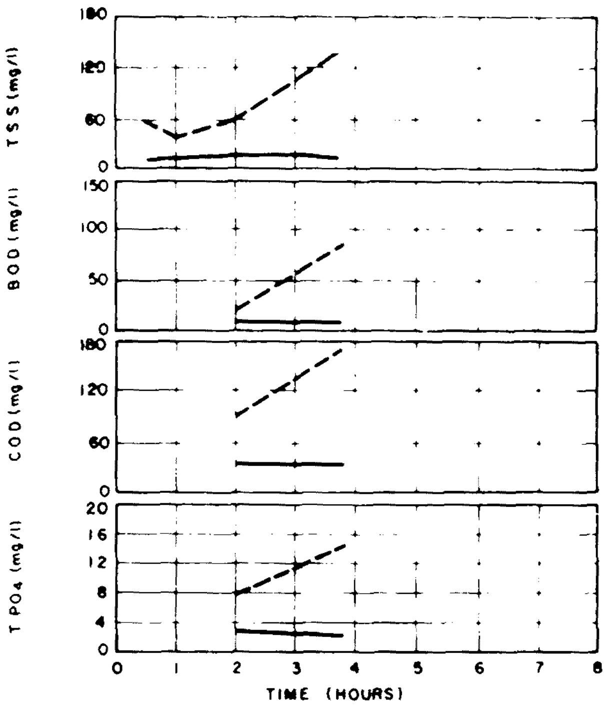
FILTER MEDIA: 60 in No. 2 ANTH./24 in No 1220 SAND
DATE 1-19-72 FLUX RATE 16.0 gpm/ft² COAG. ALUM 15.0 mg/l
POLY CAL.226-0.5 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.28-SE-II
FIGURE B 91



FILTER MEDIA: 60 in No. 2 ANTH./24 in No. 1220 SAND
DATE 1-19-72 FLUX RATE 16.0 gpm/ft² COAG ALUM 15.0 mg/l
POLY CAL. 226 0.5 mg/l

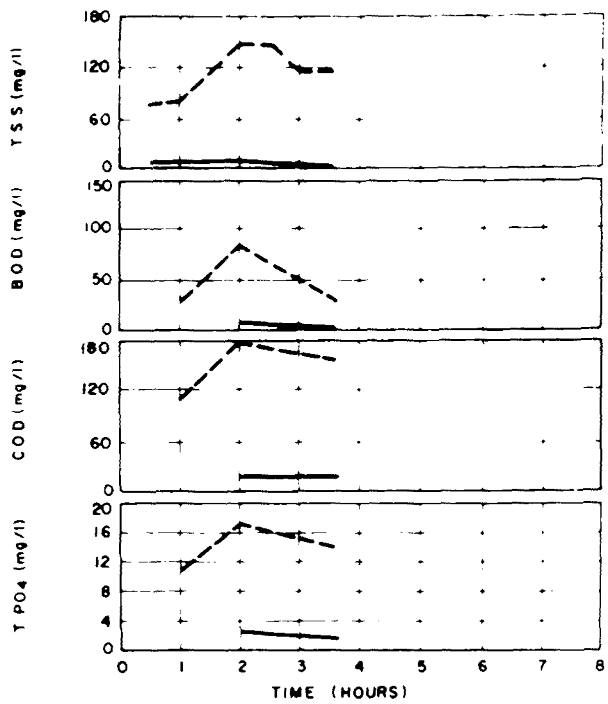
HIGH RATE DEEP BED FILTRATION TEST No.28-SE-II
FIGURE B 92



FILTER MEDIA: 60 in No 2 ANTH./24 in No 1220 SAND
DATE 1-19-72 FLUX RATE 32.0 gpm/ft² COAG ALUM 15.0 mg/l
POLY CAL 226-05 mg/l

HIGH RATE DEEP BED FILTRATION TEST No. 28-SE-III

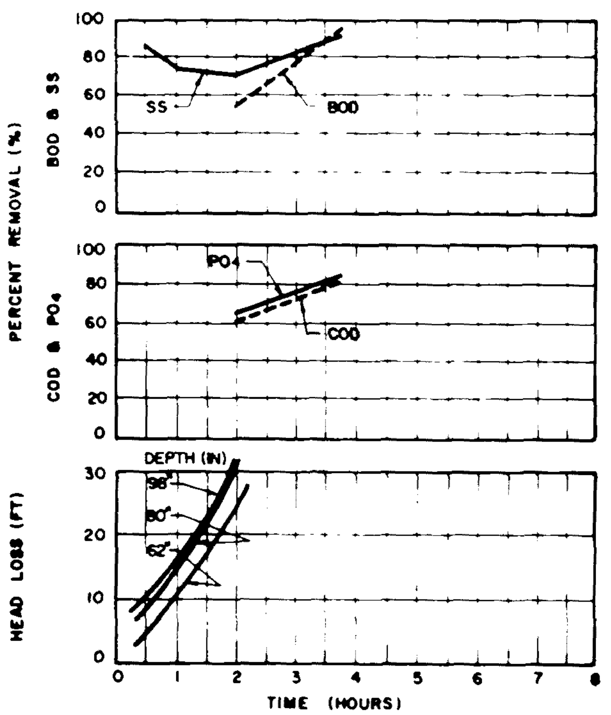
FIGURE B 93



FILTER MEDIA: 60 in No 2 ANTH./24 in No 1220 SAND
DATE 1-20-72 FLUX RATE 24.0 gpm/ft² COAG ALUM 15.0 mg/l
POLY CAL 226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No 29-SE-I

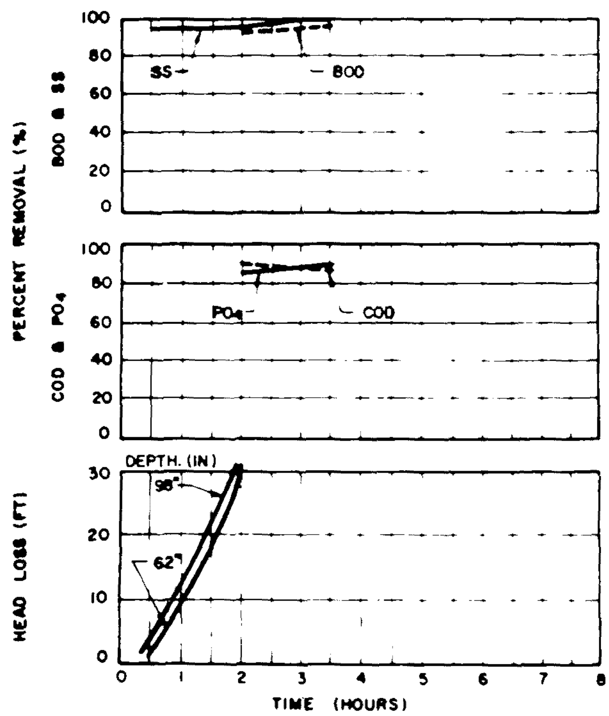
FIGURE B 95



FILTER MEDIA: 60 in No 2 ANTH /24 in No 1220 SAND
DATE 1-19-72 FLUX RATE 32.0 gpm/ft² COAG ALUM 15.0 mg/l
POLY CAL 226 0.5 mg/l

HIGH RATE DEEP BED FILTRATION TEST No. 28-SE-III

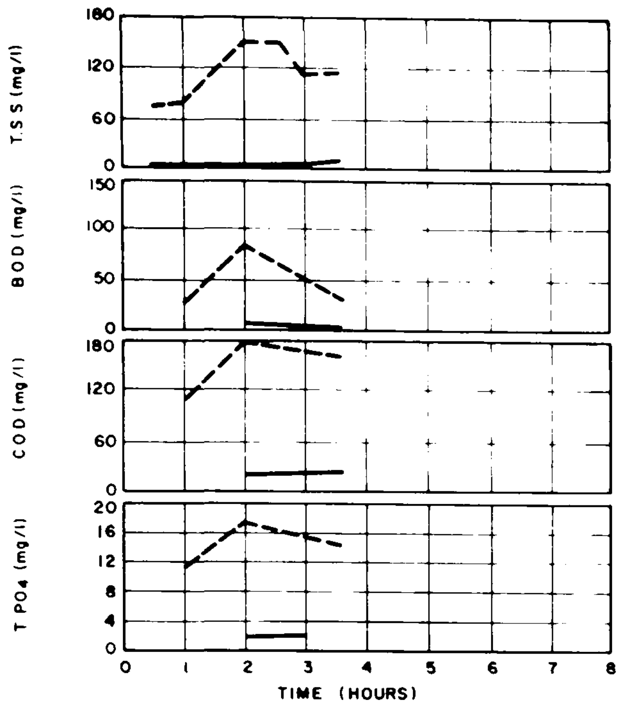
FIGURE B 94



FILTER MEDIA: 60 in No 2 ANTH /24 in No 1220 SAND
DATE 1-20-72 FLUX RATE 24.0 gpm/ft² COAG ALUM 15.0 mg/l
POLY CAL 226 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No. 29-SE-I

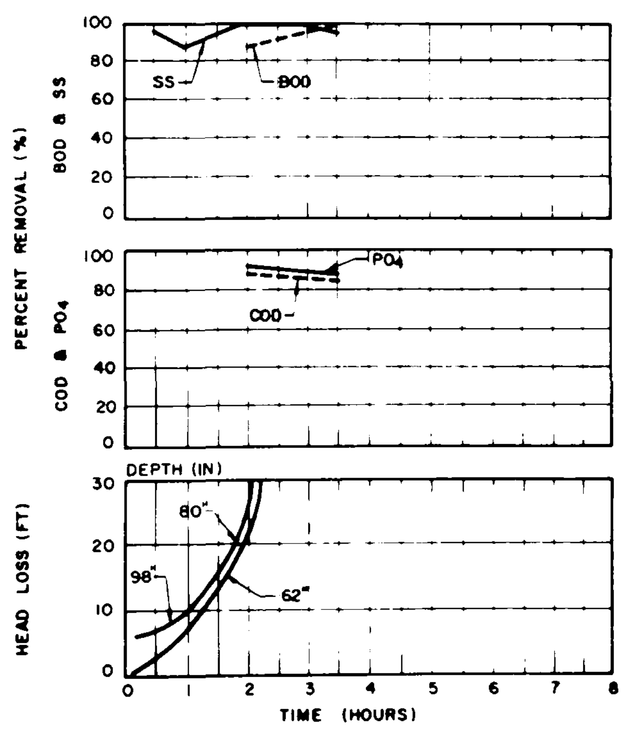
FIGURE B 96



FILTER MEDIA: 60 in No 2 ANTH./24 in No 1220 SAND
DATE 1-20-72 FLUX RATE 16.0 gpm/ft^2 COAG. ALUM 15.0 mg/l POLY CAL. 226 - 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No. 29-SE-II

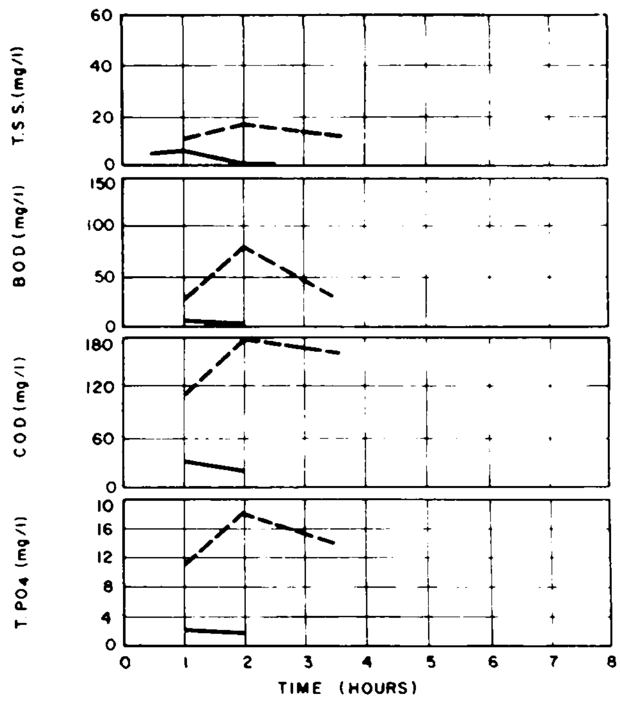
FIGURE B 97



FILTER MEDIA: 60 in No 2 ANTH /24 in No 1220 SAND
DATE 1-20-72 FLUX RATE 16.0 gpm/ft^2 COAG ALUM 15.0 mg/l POLY CAL. 226 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No. 29-SE-II

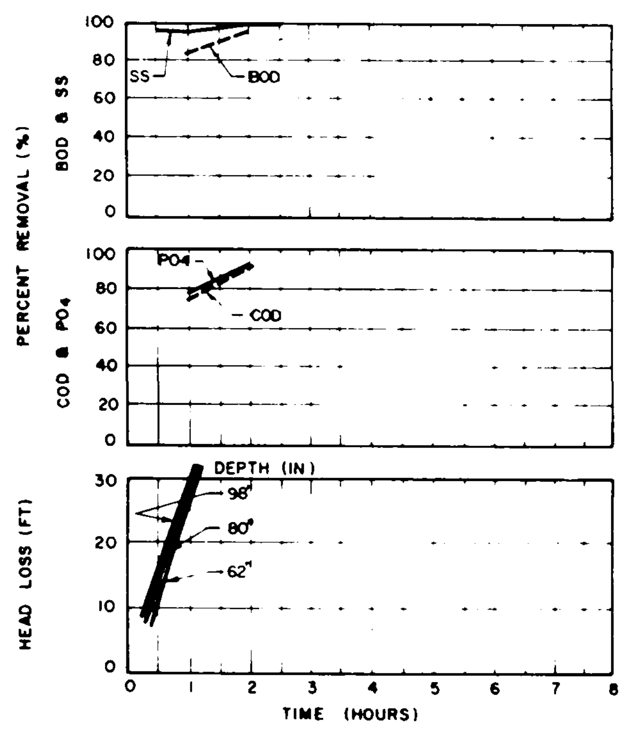
FIGURE B 98



FILTER MEDIA: 60 in No 2 ANTH./24 in No 1220 SAND
DATE 1-20-72 FLUX RATE 32.0 gpm/ft^2 COAG. ALUM 15.0 mg/l POLY CAL. 226 - 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No 29-SE-III

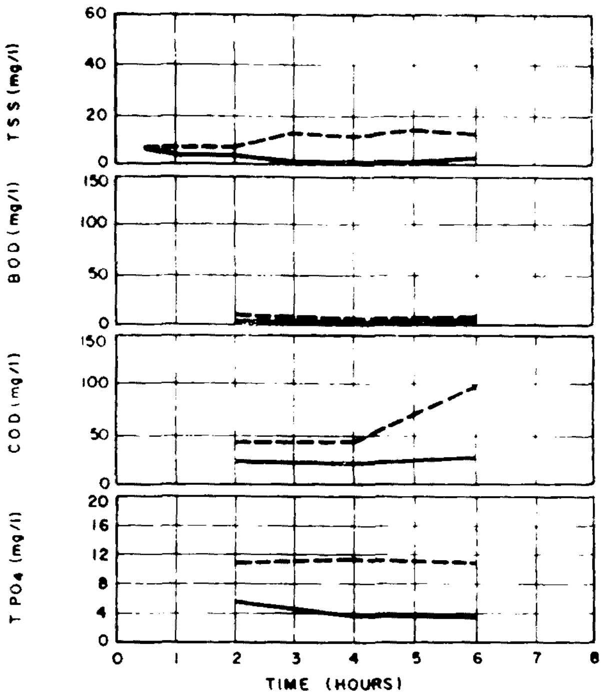
FIGURE B 99



FILTER MEDIA 60 in No 2 ANTH /24 in No 1220 SAND
DATE 1-20-72 FLUX RATE 32.0 gpm/ft^2 COAG ALUM 15.0 mg/l POLY CAL. 226 - 1.0 mg/l

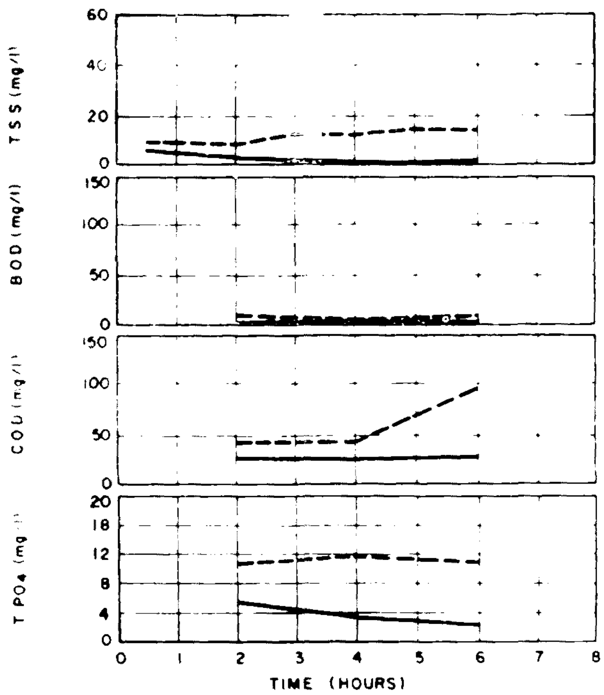
HIGH RATE DEEP BED FILTRATION TEST No. 29-SE-III

FIGURE B 100



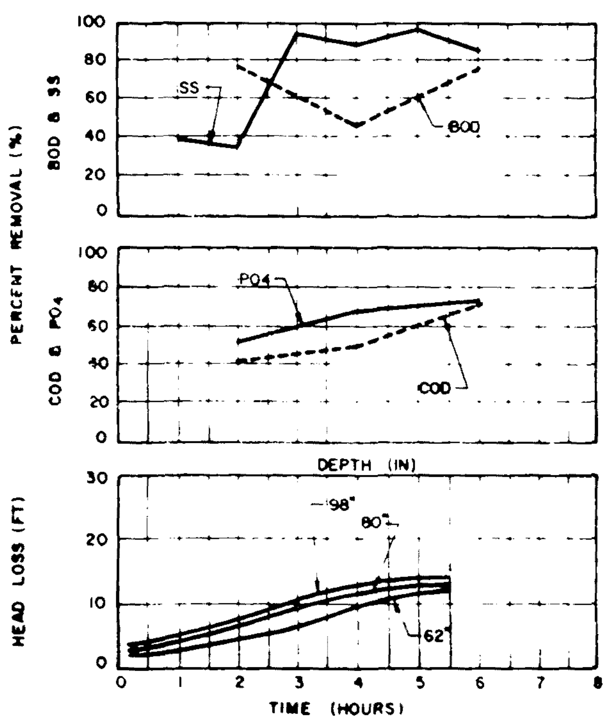
FILTER MEDIA: 60 in No 2 ANTH./24 in No 1220 SAND
DATE 1-3-72 FLUX RATE 16.3 gpm/ft^2 COAG ALUM 15.0 mg/l
POLY CAL.226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No 30-SE-I
FIGURE B 101



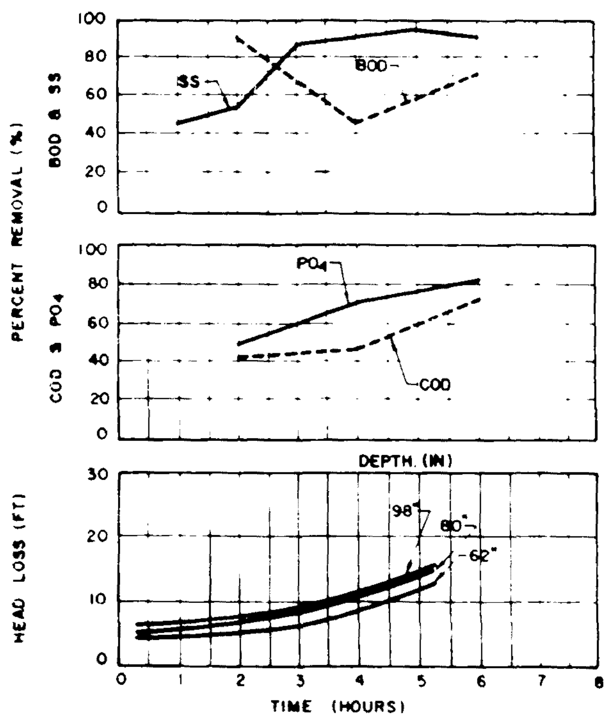
FILTER MEDIA: 48 in No 2 ANTH./24 in No 1220 SAND
DATE 1-3-72 FLUX RATE 17.3 gpm/ft^2 COAG ALUM 15.0 mg/l
POLY CAL.226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No 30-SE-II
FIGURE B 103



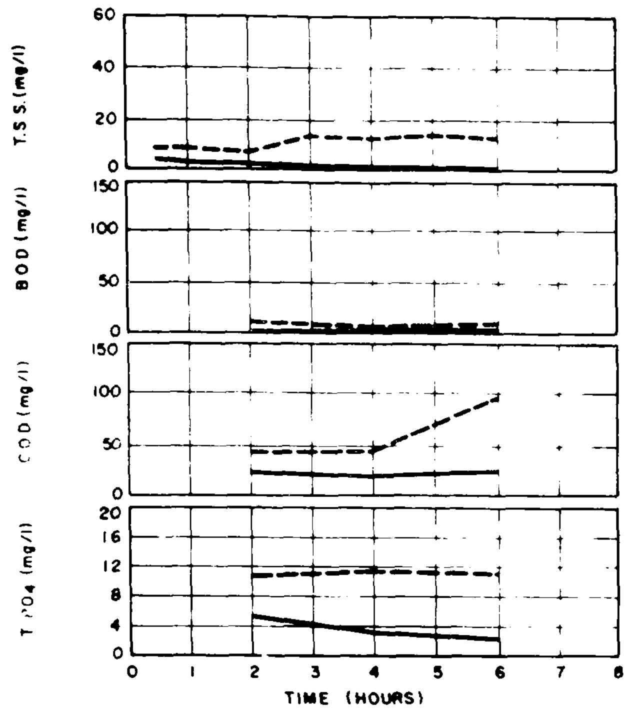
FILTER MEDIA· 60 in No 2 ANTH /24 in No 1220 SAND
DATE 1-3-72 FLUX RATE 16.3 gpm/ft^2 COAG ALUM 15.0 mg/l
POLY CAL.226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.30-SE-I
FIGURE B 102



FILTER MEDIA 48 in No 2 ANTH /24 in No 1220 SAND
DATE 1-31-72 FLUX RATE 17.3 gpm/ft^2 COAG ALUM 15.0 mg/l
POLY CAL.226-1.0 mg/l

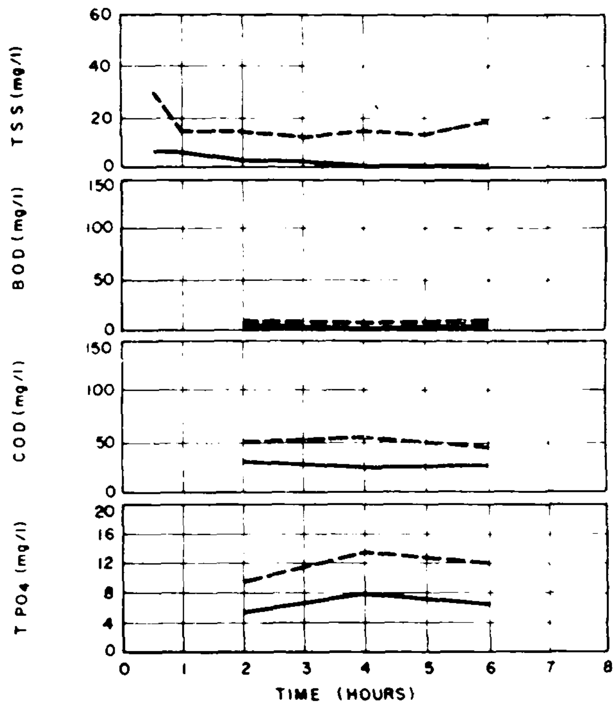
HIGH RATE DEEP BED FILTRATION TEST No.30-SE-II
FIGURE B 104



FILTER MEDIA: 72 in No 2 ANTH./24 in No 1220 SAND
DATE 1-31-72 FLUX RATE 14.0 gpm/ft² COAG. ALUM. 15.0 mg/l
POLY. CAL. 226- 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No. 30-SE-II

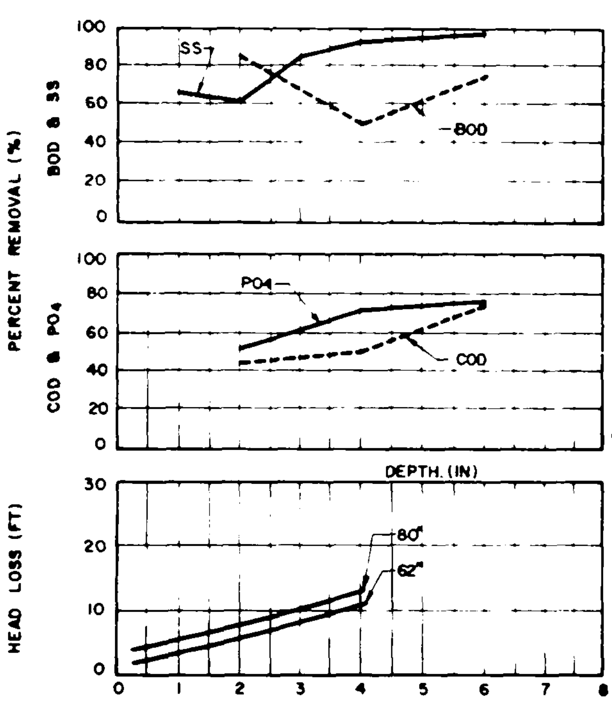
FIGURE B 105



FILTER MEDIA: 60 in No 2 ANTH./24 in No 1220 SAND
DATE 2-1-72 FLUX RATE 7.5 gpm/ft² COAG ALUM. 15.0 mg/l
POLY CAL. 226 - 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No 31-SE-I

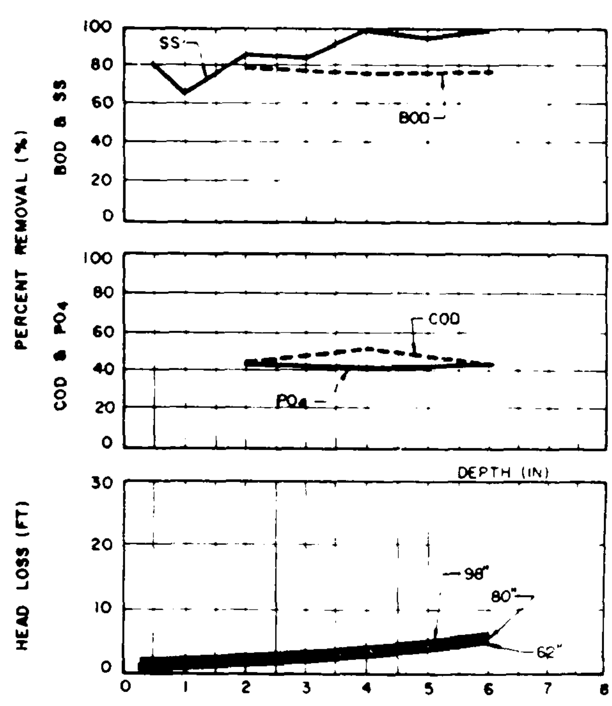
FIGURE B 107



FILTER MEDIA: 72 in No 2 ANTH./24 in No 1220 SAND
DATE 1-31-72 FLUX RATE 14.0 gpm/ft² COAG ALUM 15.0 mg/l
POLY CAL. 226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.30-SE-II

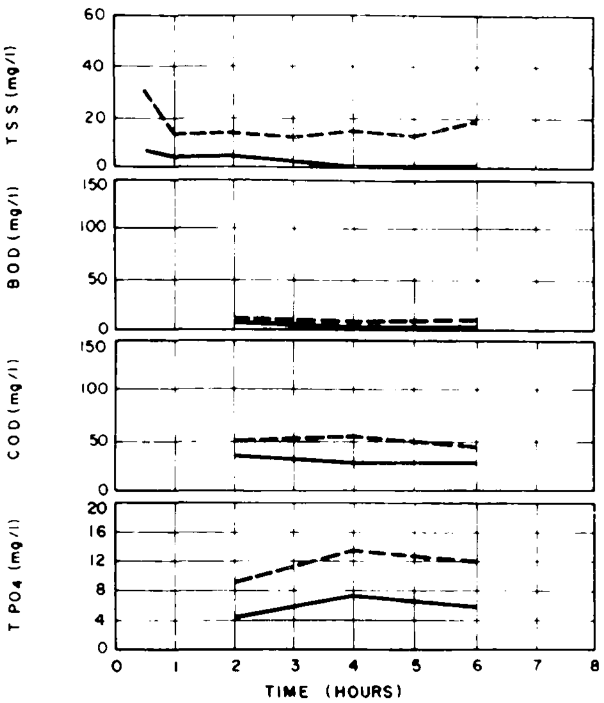
FIGURE B 106



FILTER MEDIA: 60 in No 2 ANTH./24 in No 1220 SAND
DATE 2-1-72 FLUX RATE 7.5 gpm/ft² COAG ALUM 15.0 mg/l
POLY CAL. 226 - 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.31-SE-I

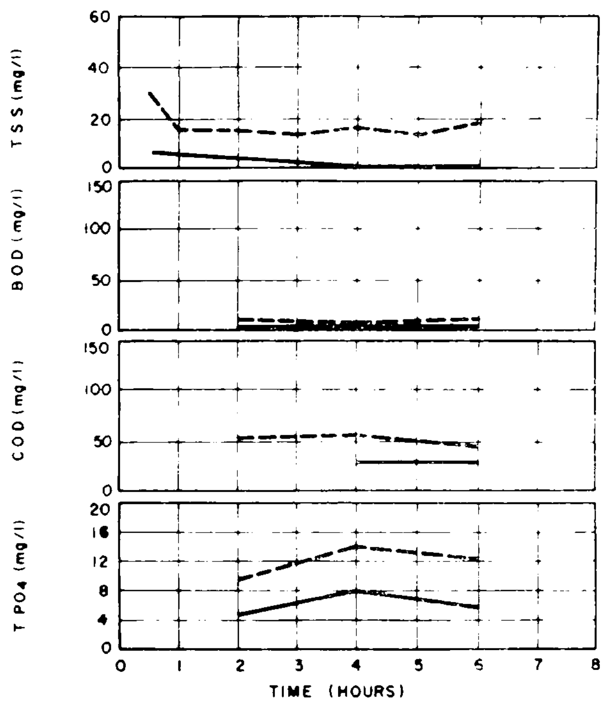
FIGURE B108



FILTER MEDIA: 48 in No 2 ANTH./24 in No 1220 SAND
DATE 2-1-72 FLUX RATE 7.3 gpm/ft² COAG. ALUM 15.0 mg/l
POLY CAL. 226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.31-SE-II

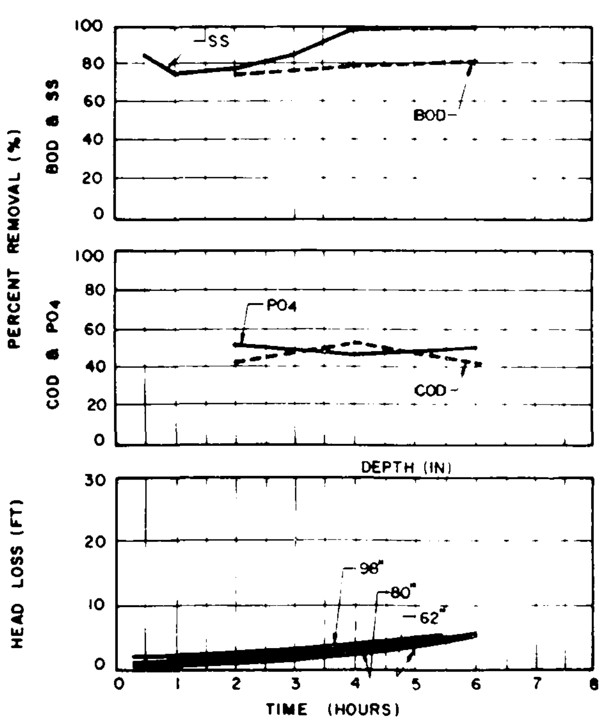
FIGURE B 109



FILTER MEDIA: 72 in No 2 ANTH./24 in No 1220 SAND
DATE 2-1-72 FLUX RATE 7.0 gpm/ft² COAG ALUM 15.0 mg/l
POLY CAL. 226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No 31-SE-III

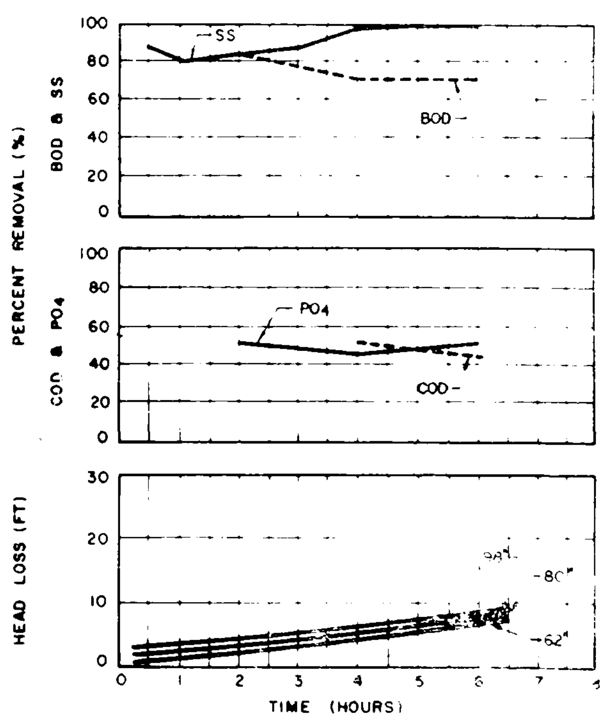
FIGURE B 111



FILTER MEDIA: 48 in No 2 ANTH /24 in No 1220 SAND
DATE 2-1-72 FLUX RATE 7.3 gpm/ft² COAG ALUM 15.0 mg/l
POLY CAL. 226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.31-SE-II

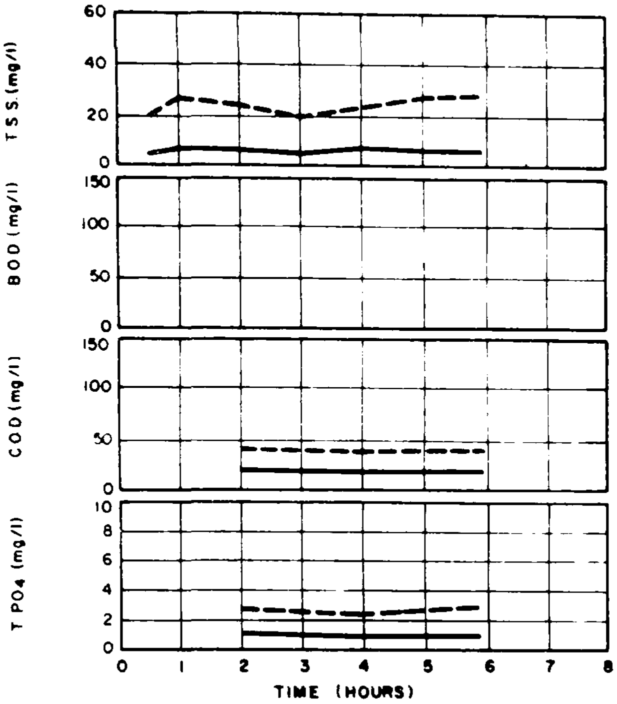
FIGURE B 110



FILTER MEDIA: 72 in No 2 ANTH /24 in No 1220 SAND
DATE 2-1-72 FLUX RATE 7.0 gpm/ft² COAG ALUM 15.0 mg/l
POLY CAL. 226-1.0 mg/l

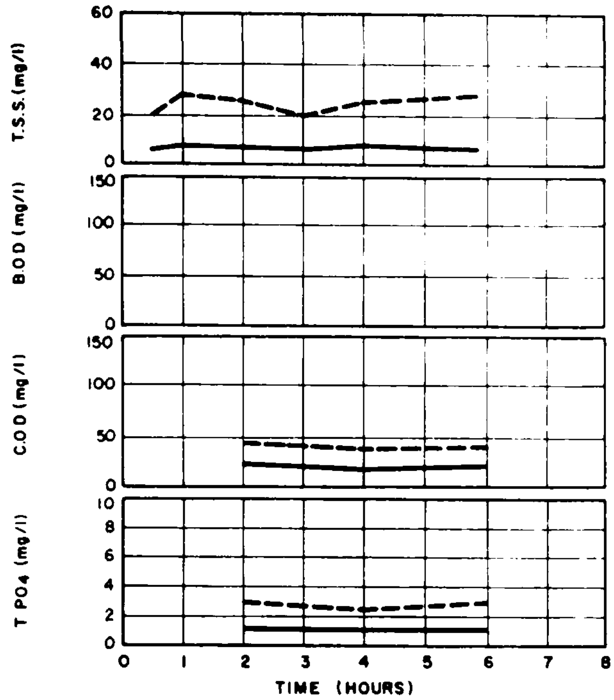
HIGH RATE DEEP BED FILTRATION TEST No.31-SE-III

FIGURE B 112



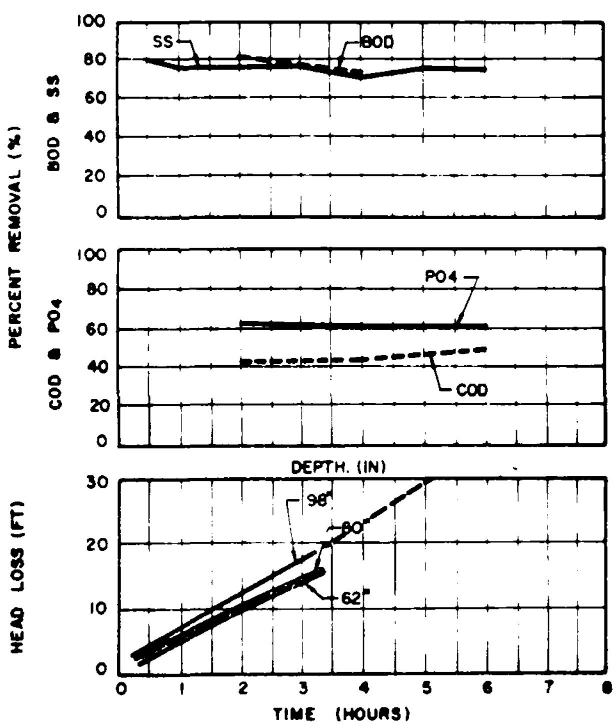
FILTER MEDIA: 60 in No. 2 ANTH./24 in No 1220 SAND
DATE 1-25-72 FLUX RATE 24.0 gpm/ft² COAG. ALUM. 15.0 mg/l
POLY. CAL 226- 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.34-SE-I
FIGURE B 113



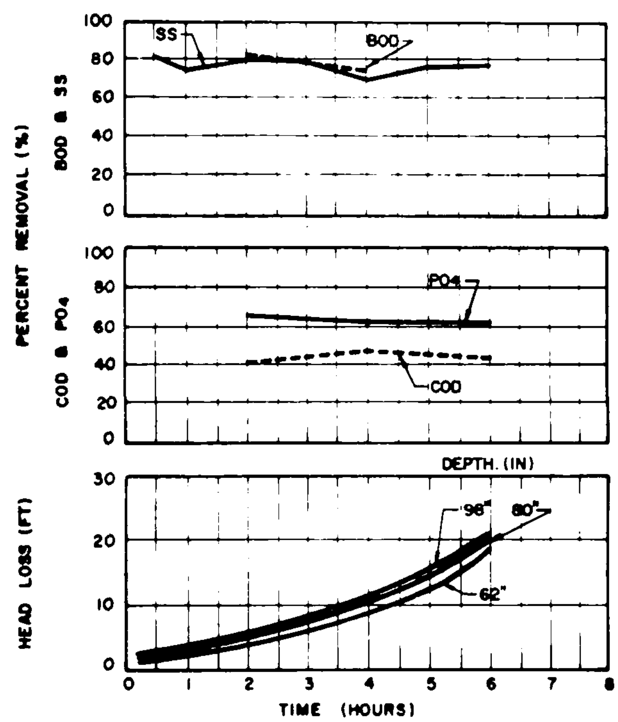
FILTER MEDIA: 60 in No. 2 ANTH./24 in No 1220 SAND
DATE 1-25-72 FLUX RATE 16.0 gpm/ft² COAG. ALUM. 15.0 mg/l
POLY. CAL 226- 1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.34-SE-II
FIGURE B 115



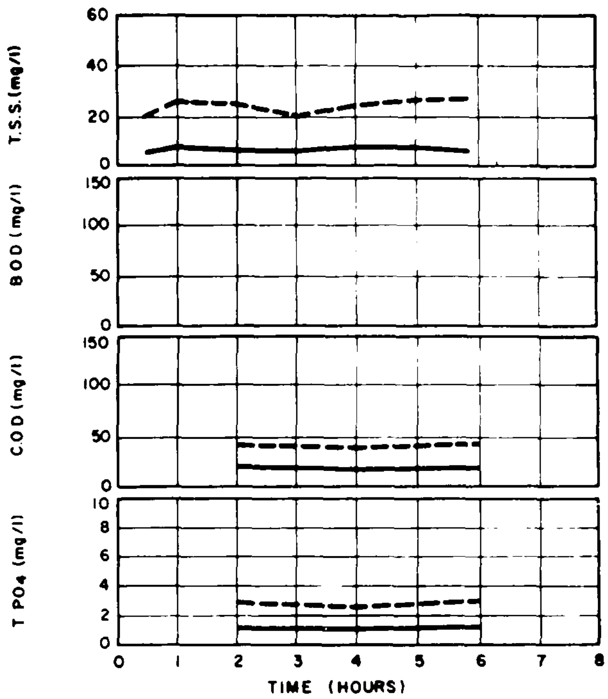
FILTER MEDIA: 60 in No. 2 ANTH./24 in No. 1220 SAND
DATE 1-25-72 FLUX RATE 24.0 gpm/ft² COAG. ALUM. 15.0 mg/l
POLY CAL 226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No.34-SE-I
FIGURE B 114



FILTER MEDIA: 60 in No. 2 ANTH./24 in No. 1220 SAND
DATE 1-25-72 FLUX RATE 16.0 gpm/ft² COAG. ALUM 15.0 mg/l
POLY CALG 226-1.0 mg/l

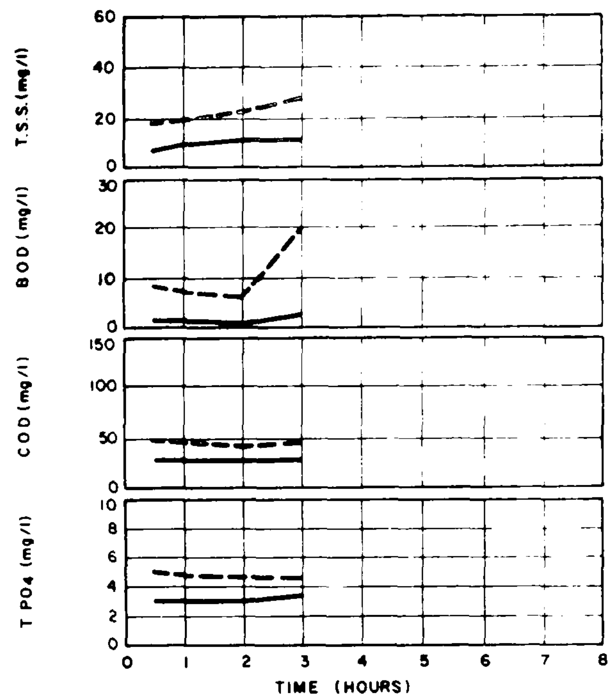
HIGH RATE DEEP BED FILTRATION TEST No.34-SE-II
FIGURE B 116



FILTER MEDIA: 60 in No. 2 ANTH./24 in No 1220 SAND
DATE 1-25-72 FLUX RATE 32.0 gpm/ft² COAG. ALUM. 15.0 mg/l
POLY. CAL. 226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No. 34-SE-III

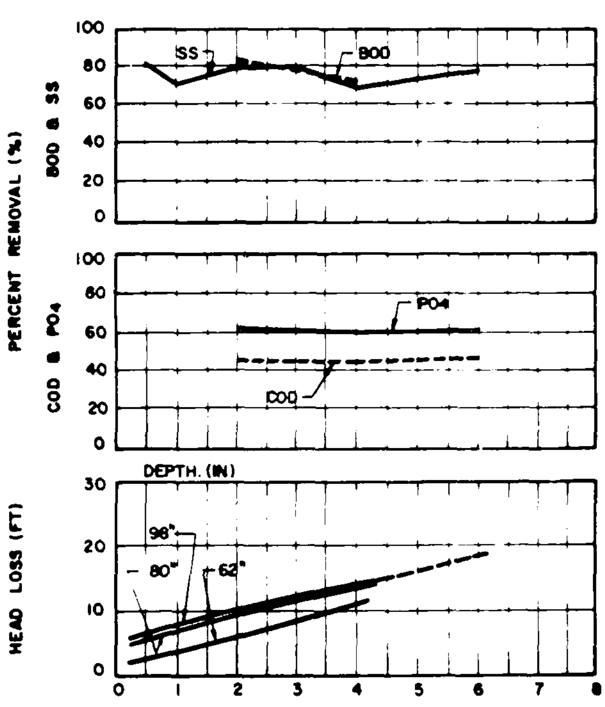
FIGURE B 117



FILTER MEDIA: 60 in No. 2 ANTH./24 in No 1220 SAND
DATE 1-27-72 FLUX RATE 23.6 gpm/ft² COAG. — mg/l
POLY. CAL. 226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No. 35-SE-I

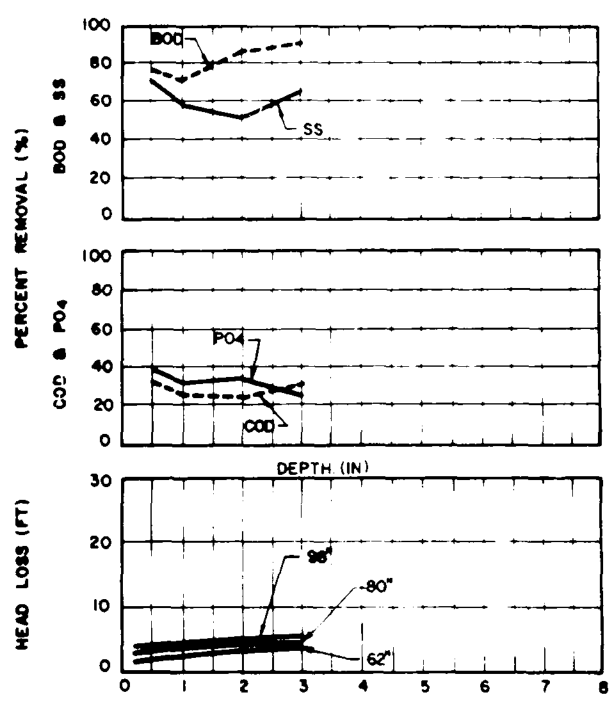
FIGURE B 119



FILTER MEDIA: 60 in No. 2 ANTH./24 in No. 1220 SAND
DATE 1-25-72 FLUX RATE 32.0 gpm/ft² COAG. ALUM 15.0 mg/l
POLY CAL. 226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No. 34-SE-III

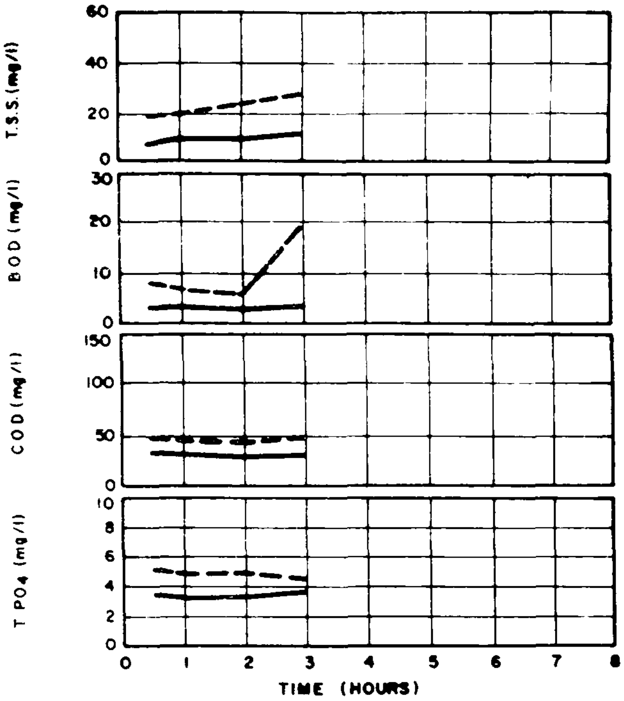
FIGURE B 118



FILTER MEDIA: 60 in No. 2 ANTH./24 in No. 1220 SAND
DATE 1-27-72 FLUX RATE 23.6 gpm/ft² COAG. — mg/l
POLY CAL. 226-1.0 mg/l

HIGH RATE DEEP BED FILTRATION TEST No. 35-SE-I

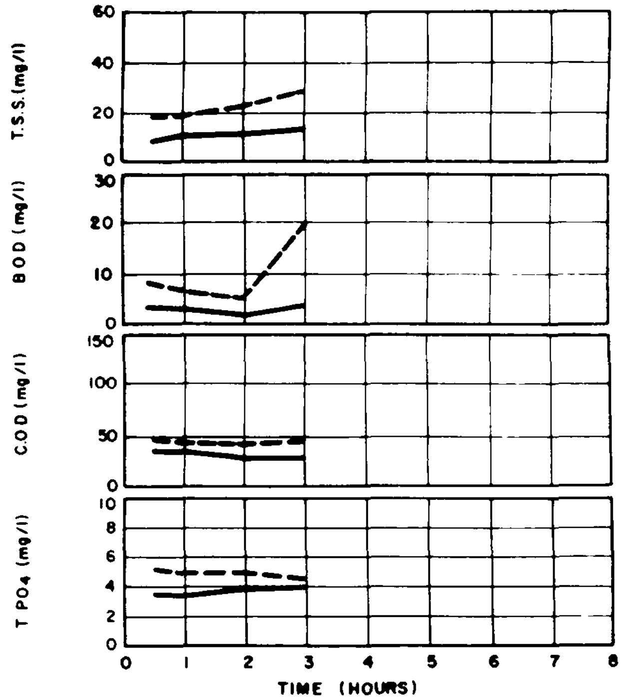
FIGURE B 120



FILTER MEDIA: 60 in No. 2 ANTH./24 in No. 1220 SAND
DATE 1-27-72 FLUX RATE 23.6 gpm/ft² COAG. ____ mg/l POLY. CAL 226-0.5 mg/l

HIGH RATE DEEP BED FILTRATION TEST No. 35-SE-II

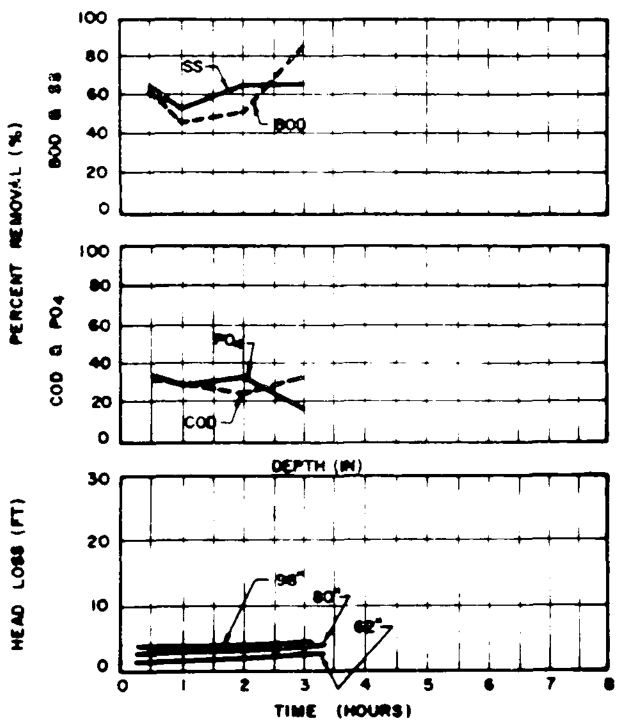
FIGURE B 121



FILTER MEDIA: 60 in No. 2 ANTH./24 in No. 1220 SAND
DATE 1-27-72 FLUX RATE 23.6 gpm/ft² COAG. - mg/l POLY. - mg/l

HIGH RATE DEEP BED FILTRATION TEST No. 35-SE-III

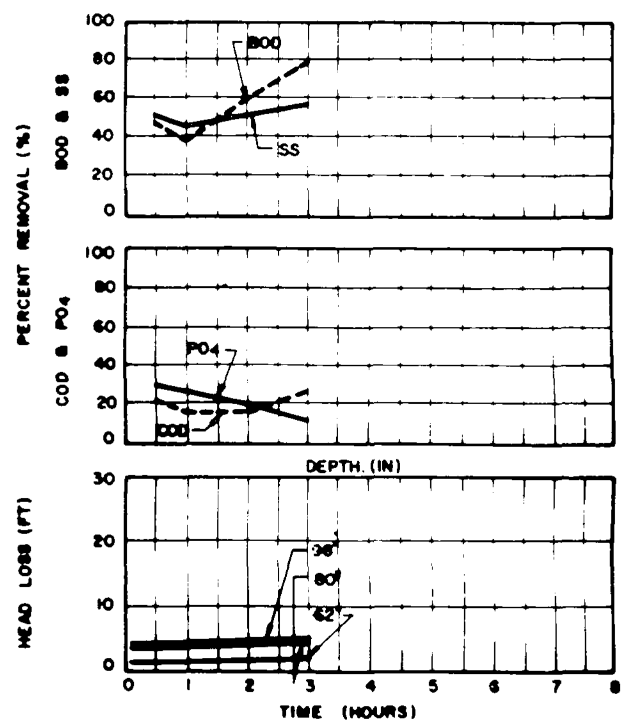
FIGURE B 123



FILTER MEDIA 60 in No. 2 ANTH./24 in No. 1220 SAND
DATE 1-27-72 FLUX RATE 23.60 gpm/ft² COAG. ____ mg/l POLY CAL 226-0.5 mg/l

HIGH RATE DEEP BED FILTRATION TEST No. 35-SE-II

FIGURE B 122



FILTER MEDIA: 60 in No. 2 ANTH./24 in No. 1220 SAND
DATE 1-27-72 FLUX RATE 23.6 gpm/ft² COAG. ____ mg/l POLY ____ mg/l

HIGH RATE DEEP BED FILTRATION TEST No. 35-SE-III

FIGURE B 124

SELECTED WATER RESOURCES ABSTRACTS

INPUT TRANSACTION FORM

1. Report No.

2.

W

4. Title

ULTRA HIGH RATE FILTRATION OF ACTIVATED SLUDGE PLANT EFFLUENT

5. Report Date

6.

8. Performing Organization Report No.

7. Author(s)

Nebolsine, R., Pouschine, I., Fan, C.Y.

10. Project No.

17030 HMM

9. Organization

Hydrotechnic Corporation
New York, New York

11. Contract/Grant No.

17030 HMM

13. Type of Report and Period Covered

12. Sponsoring Organization

15. Supplementary Notes

Environmental Protection Agency report number, EPA-R2-73-222, April 1973.

16. Abstract

Pilot plant studies were conducted at the Southerly Wastewater Treatment Plant in Cleveland to evaluate the capabilities of the deep bed, dual media, ultra high rate filtration process for treating an activated sludge plant secondary effluent.

The various operating variables that were tested and evaluated, included different media sizes, sizes, various depth, bed, filtration rates from 8 to 32 gpm/sq ft, different types of polymer, and different combinations of coagulants and polymers.

The principal parameter for evaluating process efficiency was suspended solids. High removals were obtained with respect to suspended solids and to pollutants associated with suspended solids. The removal of these pollutants reduced biochemical oxygen demand, chemical oxygen demand and total phosphate values.

Capital costs for a filtration process of this type as estimated to range from $1,200,000 for a 25 MGD plant to $5,400,000 for a 200 MGD plant. Total treatment costs, including capital and operating charges, are estimated to be 4.32-2.97¢/1000 gallons for the 25 and 200 MGD plants respectively.

17a. Descriptors

*Separation techniques, *Tertiary treatment, *Filtration, *Activated sludge, coagulation

17b. Identifiers

*Cleveland (Ohio), *Alum, *Polymer, *Dual-media, *Ultra-high rate, Variable studies

17c. COWRR Field & Group 05 D

18. Availability

19. Security Class. (Report)

20. Security Class. (Page)

21. No. of Pages

22. Price

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WASHINGTON, D. C. 20240

Abstractor: Chi-Yuan Fan | Institution: Hydrotechnic Corporation

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