ICR Treatment Study Summary Report
November 1997

Evaluation of GAC Technology Using Combination Pilot-scale GAC Post-Filter Adsorbers and Bench-scale RSSCTs for Compliance with the Information Collection Rule

Conducted during the period of November 16, 1994 through August 31, 1995

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Little Falls Water Treatment Plant
ICR Treatment Plant ID# 476

Attachments: 2 diskettes containing the Data Collection Spreadsheets

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I. Conclusions and Recommendations

Phase II pilot testing, conducted at Passaic Valley Water Commission's (PVWC's) Little Falls Water Treatment Plant (LFWTP), was initiated in November 1994 and completed at the end of August 1995. The primary objective of the Phase II pilot study was to assess the effectiveness of multiple treatment trains to meet the proposed requirements of the Enhanced Surface Water Treatment Rule (ESWTR) and Disinfectant/Disinfection By-Product (D/DBP) Rule and to provide seasonal operating data. PVWC incorporated pilot- and bench-scale Granular Activated Carbon (GAC) testing, established in the proposed Information Collection Rule (ICR) requirements prior to final promulgation of the rule, into the Phase II pilot study.

The main conclusion of the GAC treatment study is discussed based on total organic carbon (TOC) removal and total trihalomethane (TTHM) and haloacetic acid (HAA(5)) reduction to meet the proposed D/DBP Rule, Stage 1 and 2 limits.

The pilot-scale GAC adsorber was evaluated assuming single-stage operation and was shown to have a bed life, under the given operating conditions, of greater than 160 days, based on TOC removal. Breakthrough times for the pilot-scale GAC adsorber (20 min EBCT) indicated that the proposed D/DBP Stage 1 TTHM limit could be met for a bed life of greater than 160 days and the Stage 2 limit could be met up until 160 days of operations. Breakthrough times for the 10 min EBCT Rapid Small Scale Column Test (RSSCT) indicated that Stage 1 TTHMs could consistently be met at operation times up to 180 days. The Stage 2 TTHM limit was exceeded after approximately 20 to 120 days of operation depending on the season. Blending of the effluent from multiple single-stage post filter adsorbers could potentially increase the carbon bed life.

The pilot-scale GAC adsorber did not exceed the Stage 2 HAA(5) limit even after approximately 160 days of operation. Breakthrough times for 10 min RSSCTs, for Stage 2 HAA(5) occurred around 30 and 130 days during the spring and fall seasons, respectively, and did not occur for the winter and summer 1995 RSSCTs. Breakthrough above the Stage 1 HAA(5) standard were not observed in any of the RSSCTs.

TOC removal, required of the proposed D/DBP Rule, may be achieved using post filter adsorption GAC (Empty Bed Contact Time, EBCT 20 min), however, no CT credit, required under the SWTR, would be achieved upstream of the GAC adsorber. Sufficient residual disinfectant contact time would be necessary downstream of the GAC contactor. The efficiency of the adsorption process should be considered with respect to blending the effluents of multiple single-stage adsorbers, each at a different stage of TOC breakthrough, in order to maximize the efficiency of the adsorption process. The value of the RSSCT (EBCT 10 min) data may prove to be beneficial for projection of the benefits of the use of post filter adsorbers for the further reduction of TOC in finished waters. The use of GAC filter-adsorbers would preclude the use of intermediate chlorination for achieving CT credit and the efficiency of the adsorption process may be negatively impacted by the use of intermediate ozonation and the impact of backwashing. However, operation in the post filter adsorber mode may be effective in long-term removal of some taste and odor causing compounds.

In addition to conducting the pilot- and bench-scale testing needed to fulfill the ICR treatment study requirements, the Phase II pilot study identified four process train alternatives to improve finished water quality and meet future drinking water regulations. The four process trains are identified in Figure 1. Each process train will be discussed on the basis of meeting the proposed ESWTR and Stage 1 and 2 of the proposed D/DBP Rule.

Process Train one includes providing chlorine application, following sedimentation that will usually be used as the first point of chlorination and providing an ammonia system for ammonia application after the clearwells to form a combined residual in the distribution system. Enhanced coagulation will be practiced to provide removal of naturally occurring organic material prior to chlorination. Although delaying the initial point of chlorination will reduce DBPs, it also greatly reduces the available chlorine contact time for disinfection. Thus, the level of comfort provided from the high level of

disinfection with prechlorination will no longer exist (requires an intensive focus on maintaining optimized pretreatment for turbidity removal).

Process Train two includes the provision of intermediate ozone for primary disinfection and ammonia addition following the clearwells to form a combined residual in the distribution system. This process train meets the stringent DBP limits of the second stage of the proposed D/DBP Rule. The strong oxidizing and disinfection capacity of ozone will also meet the most stringent disinfection requirements of the proposed ESWTR.

Process Train three includes the use of GAC adsorption following filtration and free chlorine as the primary and final disinfectant. This process train was used to fulfill the requirements of the ICR treatment studies. The use of post filtration GAC is the only alternative which allows for the continued use of free chlorine in the distribution system while meeting the Stage 2 requirements of the proposed D/DBP Rule. However, the treatment objective also includes the provision of disinfection for 2-Log inactivation of *Cryptosporidium*. The CT values for inactivation of Cryptosporidium are much higher than those for *Giardia*. The use of free chlorine requires a large contact volume to meet the contact time needed for adequate disinfection, which is not possible at the LFWTP, due to site constraints.

Process Train four includes the use of intermediate ozone for primary disinfection, with biological GAC adsorption following filtration to allow for the continued use of free chlorine as the secondary disinfectant to maintain a distribution system residual. The use of ozone for disinfection eliminates the large contact volume that would be needed for free chlorine, making the use of GAC a feasible option as far as site constraints. However, the cost of GAC would be far in excess of the cost of providing chloramines instead of free chlorine in the distribution system.

Based on the results of the Phase II pilot study, as described above, consultants prepared a conceptual basis of design report to assist PVWC plan for future modifications to meet

the requirements of the proposed D/DBP and ESWTR regulations. As discussed in that report, both treatment processes, Process Train Two and Process Train Three, met the Phase 2 treatment objectives. The only reason to use GAC would be if chloramines could not be used as the distribution system disinfectant. However, it is unlikely that this would occur. Therefore, future full-scale plant modifications will include a two phase process to implement Process Train two, intermediate ozone followed by chloramines as the secondary disinfectant. The first phase will most likely include moving the point of chlorination to post sedimentation and implementation of chloramination for secondary disinfection. Pilot results have indicated that this scenario would allow PVWC to meet the Stage One D/DBP requirements. The second phase of full-scale plant modifications would include changing to intermediate ozonation as the primary disinfectant, with chloramines already in place as the secondary disinfectant. The use of intermediate ozone will allow the LFWTP to meet the requirements of the ESWTR and the Stage 2 D/DBP Rule.

II. Background Information

PVWC owns and operates the LFWTP conventional filtration plant, with a rated capacity of 75 MGD and a design capacity of 100 MGD. The LFWTP is located on the border of Totowa and Little Falls in New Jersey and supplies drinking water to a retail population of 285,000 and a wholesale population of approximately 500,000. The treatment plant is a conventional filtration plant which includes prechlorination, alum coagulation, flocculation, sedimentation and dual-media filtration with final pH adjustment and chlorine disinfection. Figure 2, provides a schematic of the existing LFWTP. The plant's primary source water the Passaic River, is a surface water that is heavily impacted by industrial and municipal wastewater.

The basic LFWTP schematic is shown in Figure 2. Figures 3a-3c show the treatment plant and distribution system schematic used to develop the ICR initial sampling plan. Basic engineering data for each unit process is provided in Table 1, Full-scale Treatment Design Data. The data for Table 1 was derived from the ICR Water Utility Database

System report A.2, Design Plant Parameters and report A.3, Design Plant Chemical Parameters.

PVWC recognized that drinking water standards would grow in number and stringency as a result of the 1986 Safe Drinking Water Act Amendments and committed to construct a permanent on-site pilot-plant facility for continued use in identifying treatment needs as regulatory requirements developed. In order to prepare for the upcoming regulations such as the ESWTR and D/DBP Rule, a 10 gpm pilot facility was constructed, with the flexibility to evaluate advanced alternative treatment processes such as ozonation and GAC adsorption. In addition to responding to regulatory requirements, PVWC also recognized that the on-site pilot plant offered the benefits of optimizing facility operations in response to seasonal needs and provided a unique opportunity for operator training.

The pilot plant project was initiated in 1989 with design of the pilot plant prior to the development of the proposed D/DBP and ESWTR regulations. However, the flexibility in the facility design proved to be successful in generating data necessary to evaluate processes for meeting these regulations. Pilot testing was initiated shortly after the completion of construction in the Summer of 1992 and continued with two sequential phases of testing that were completed in August 1995. Currently, Phase III pilot evaluations are underway to provide continued regulatory support, full-scale coagulation optimization support and to supplement the seasonal ozone treatment database developed as part of the Phase II testing program.

After completion of the Phase I pilot testing, the draft D/DBP Rule was proposed, establishing target MCLs for finished water DBPs and TOC removal. The ESWTR was also proposed establishing the potential for more stringent disinfection requirements. Pilot evaluations conducted during Phase I identified multiple treatment process trains that warranted further evaluation in response to these proposed regulations. The primary objective of continued process evaluations under the Phase II pilot study, as discussed

previously in the Conclusions and Recommendations section, was to assess the effectiveness of these multiple trains to meet the proposed requirements and to provide seasonal operating data. Another objective of the Phase II pilot study was to develop a conceptual design report for full-scale plant upgrades based on the process trains that were capable of achieving the proposed regulations.

The objective of the Phase III pilot study, currently underway, is divided into three tasks designed to evaluate treatment options which can be used at the LFWTP for regulatory compliance and treatment optimization. Data generated from each task will supplement the existing Passaic River water treatment database generated in pilot studies I & II. The first task of the Phase III study is to provide regulatory support by evaluating the effect on DBP precursor removal and DBP production and the ability to achieve CT credit for different application points of disinfectant (chlorine) in the treatment train, under enhanced coagulation conditions. Task two will evaluate different coagulants for use at the full-scale plant in our on-going pretreatment optimization effort. Finally task three will continue evaluating the use of intermediate ozone as the primary disinfectant for treatment of Passaic River water.

PVWC made a commitment to conduct bench- and pilot-scale testing as established in the proposed ICR requirements prior to final promulgation of this rule and incorporated this testing into its ongoing pilot studies, specifically the Phase II pilot study. PVWC was one of the first utilities to conduct these ICR treatment studies under the direction of Dr. R. Scott Summers and contributed to the approach and final language of the GAC testing requirements included in the final ICR.

Summaries of full-scale plant source and finished water quality for the time period during which the bench- and pilot-scale GAC tests were conducted, are included in Tables 2 and 3, respectively. The average yearly source water temperature, pH, turbidity, alkalinity, total hardness, TOC, UV-254 and bromide concentrations over the period of testing is given in Table 2. Average finished water temperature, pH, turbidity, TOC and

distribution system TTHM4 is given in Table 3. Standard deviation, maximum and minimum yearly values for each analyte are included on each table.

III. Materials and Methods

PVWC chose to run a combination of pilot- and bench-scale GAC systems to meet the ICR Treatment Study Requirement. Tables 4 and 5, respectively, represent the experimental design for both the pilot- and bench-scale GAC studies. The experimental design for both systems were as specified in the guidance manual. The Post Filter-Adsorber train, (rapid mix, coagulation, flocculation, sedimentation, dual-media filtration followed by post filtration GAC adsorption), and the RSSCTs were operated in accordance with the guidelines established in the 1994, Draft USEPA Guidance Manual for Treatment Studies. PVWC's study was used to develop the final ICR GAC Treatment Study Guidance Manual.

The pilot-scale GAC evaluation was conducted during the Phase II Pilot Study, at PVWC's pilot facility. The 10 gpm pilot plant flow splits equally to two 5 gpm identical pretreatment trains consisting of 100 rpm rapid mix followed by three-stage flocculation, each stage at a mixing speed of 17 rpm, and sedimentation through plate settlers. Mixing conditions were established during Phase I pilot testing as optimum for achieving settled water turbidity levels similar to the full-scale plant.

The pilot PFA train shown on the pilot plant schematic, Figures 4 and 5, was used to achieve both the ICR GAC treatment requirements and the Phase II pilot study objectives. The PFA train was operated on a continuous basis, beginning November 16, 1994, to maintain a constant feed to the GAC adsorber. Alum was the sole treatment chemical applied in the pretreatment process for the PFA train. The alum dose for this train was chosen based on the results of routine jar tests where the optimum alum dose was based on the removal of turbidity. The primary water quality goals targeted during Phase II pilot testing were a settled water turbidity less than 2 NTU, filtered water turbidity less than 0.2 NTU, and enhanced coagulation (for all but the Post Filter

Adsorber (PFA)Train used to fulfill ICR treatment study requirements) to provide TOC removal requirements of the draft D/DBP Rule. The GAC adsorber tests were run in parallel to the other Phase II pilot trains for final assessment of water quality objectives and for cost comparisons in the conceptual design report.

As indicated the operational variables were held constant during each experiment (i.e., flocculation conditions, type of coagulant, filtration rates etc.). In order to consistently achieve the operational water quality goals (i.e., settled water turbidity, TOC removal, filtered water turbidity, etc.), the only parameter that was varied during testing on the PFA train was the coagulant dose. Therefore, by holding the operational parameters constant and having an objective set of water quality goals, the impact of seasonal variation on the efficiency of each process could be evaluated.

Fresh GAC was placed in the GAC adsorber at the time the PFA was put in operation. Phase II Pilot Study filter media characteristics are shown in Table 6. Table 7 shows the pilot-scale pretreatment design data. The date of each test and the basic operational conditions for the PFA train is included in Table 8. The PFA train was initiated on November 16, 1994 and run through August 30, 1995. This column was operated continuously at an empty bed contact time (EBCT) of 20 minutes to evaluate the carbon usage rate for removal of TOC. When needed, due to air accumulation in the GAC contactor, the flow was gently reversed to release the entrapped air. No media was lost during this process. Process water used for this process was passed through a GAC cartridge to remove any residual chlorine present.

Seasonal GAC evaluations were also conducted using the RSSCT in order to comply with the requirements of the ICR. Additional RSSCTs were conducted to fulfill the objectives of AWWARF project RFP-816 “Removal of DBP Precursors by Activated Carbon Adsorption”. Water for the RSSCTs was produced on a seasonal basis from a second, identical, anthracite/sand filter (ASF), ASF2, operated in parallel to the ASF. ASF1 was used to feed the pilot-scale GAC adsorber. Both ASF1 and ASF2 are shown on the

PVWC Phase II Pilot Schematic in Figure 5. ASF2 water samples were shipped in 55 gallon containers to the University of Cincinnati. The RSSCTs were conducted in the Environmental Engineering Laboratory at the University of Cincinnati by Gabriele Solarik under the direction of Dr. R. Scott Summers. The RSSCTs conducted included:

- 20 minute verification RSSCT conducted in November 1994.
- 10 minute RSSCTs conducted during the Fall (1994), Winter (1998), Spring (1995) and Summer (1995) seasons.

A proportional diffusivity design was used for the RSSCTs. Operating conditions for all RSSCTs were identical. See Table 9 for RSSCT pretreatment design data. The RSSCTs were constructed of 8 mm glass chromatography columns. All fittings and tubing were of Teflon or stainless steel construction. Figure 6 shows the RSSCT schematic. The GAC was ground to the required size using a mortar and pestle and washed with laboratory clean water in order to remove fines. Once the GAC was clean, a vacuum was applied to remove air trapped within the pores. Stainless steel screens and glass beads were used as support for the GAC bed. A diaphragm metering pump head (Cole-Parmer model H-07090-62) and modular drive system (Cole-Parmer model H-07553-80) were used as the feed pump. A 19-L capacity glass carboy was used to feed the column. Influent feed at room temperature was prefiltered (1 um) through a polypropylene cartridge and added to the feed carboy as needed. The influent water was pumped into a stainless steel cylinder, which served to dampen the pulsing effect of the diaphragm pump.

Fifteen influent and effluent samples were taken for the pilot-scale system and twelve effluent and three influent samples were taken for all four RSSCTs. In addition, a 20 min EBCT verification RSSCT was run in November 1994, to determine the capability of the RSSCT to generate representative process performance data for this source water.

The ICR Manual for Bench- and Pilot- Scale Treatment Studies was revised between the time the first two and the last two RSSCTs were run. Originally, in the draft guidance

manual no duplicates were required, as a result duplicates were only analyzed for the last two RSSCTs and once at the end of the pilot-scale test.

For both the pilot- and bench-scale tests, the Simulated Distribution System (SDS) samples were set-up according to Uniform Formation Conditions (UFC):

- Incubation temperature of 20°C.
- pH of 8.0
- Incubation period of 24 hours
- Final free chlorine residual at the end of the incubation period of 1.0 mg/L ± 0.4 mg/L.

Analysis of the general water quality samples (temperature, UV-254, Total and Calcium Hardness, and Ammonia) were conducted at the PVWC laboratory. Turbidity, pH, alkalinity, and chlorine residuals were conducted on-site at the pilot plant. Analyses for bromide, TOC and all of the Disinfection By-Products (DBPs) were conducted at Montgomery Laboratories. Specific laboratory information is given in Table 10. The methods and Minimum Detection Limits (MDL) are listed in Table 11. All analyses were conducted using ICR approved methods. QA/QC data summary tables are included in Appendix D.

IV. Results and Discussion

The Phase II pilot study testing was initiated in November 1994 and completed at the end of August 1995. The pilot plant process schematic for Phase II testing is shown in Figure 4. The objectives of the Phase II pilot study were to evaluate alternate treatment processes to meet upcoming D/DBP and ESWTR regulations and to obtain seasonal operating data. The pilot PFA train was evaluated during the Phase II pilot study during each of six experimental evaluations of alternate treatment processes and was also evaluated in a more in-depth, parallel study to meet the requirements of the ICR and the objectives of the AWWARF project “Removal of DBP Precursors by GAC Adsorption” (RFP-816).

Although only the results of the PFA pilot train to meet ICR treatment study requirements are needed for this report the results from the PFA train to meet the other Phase II objectives will be included where applicable to emphasize seasonal variability observed as evidenced by changes in raw, settled and anthracite/sand filtered (ASF) water. For the purposes of this discussion the results of the pilot-scale testing to fulfill ICR requirements will be referred to as 'pilot-scale' and the results of the additional pilot testing will be referred to as the 'phase II pilot' results. Tables 12 and 13 summarize influent water quality for the treatment study. Pilot- and bench-scale GAC influent organic and inorganic water quality are given in Table 12 and 13, respectively.

As described in the experimental design, for the Phase II Pilot Study, the PFA train consisted of normal coagulation (coagulant addition for turbidity removal) followed by anthracite/sand filtration (ASF) and GAC adsorption. Post Filter Adsorber Train SDS samples for ICR testing were set-up under UFC. For all non-ICR testing, Phase II pilot tests the PFA train SDS samples were set-up under UFC with the exception of increased incubation time of 3 days. The pilot-scale GAC adsorber was operated at an EBCT of 20 minutes throughout the Phase II pilot study.

Additional bench-scale tests were also conducted using the RSSCT to meet the ICR requirements and to observe additional impacts on the seasonal changes in water quality on the adsorption characteristics of the GAC. Each RSSCT was operated at an EBCT of 10 minutes with water collected from the pilot-scale ASF2.

The D/DBP levels for the proposed Stage 1 and Stage 2 standards were used as a basis for review of the test results, targeting these levels for each sample rather than an average of results. This is a conservative approach to provide a level of confidence that samples in all areas of the system will reliably meet the proposed standards and to evaluate seasonal variability.

The effluent TOC concentrations in the raw water and through the sedimentation, ASF, and GAC adsorption (20 minute EBCT) processes for the Phase II pilot study experiments are shown in Figure 7. The TOC data collected for the ASF and GAC effluent during the ICR/AWWARF testing are shown in Figure 8.

The TOC removal through sedimentation attenuated the raw water TOC, and resulted in similar TOC concentrations through the ASF. The TOC concentrations in the GAC adsorber effluent, shown in Figures 7 and 8, indicated a non-adsorbable TOC fraction of approximately 0.5 mg/L. TOC breakthrough from a GAC adsorber began to occur at an operation time of approximately 80 days (as shown on Figure 8), or in March (as shown on Figure 7). The TOC concentration measured plateaued between 90 and 130 days of operation to a level of about 1.0 mg/L and then increased to a value of approximately 1.5 to 2.0 mg/L; the plateau and subsequent decrease in TOC concentrations (see Figure 7) most likely correspond to a change in the raw water quality (adsorption characteristics) during the spring months.

The TOC breakthrough curves for the November, February, May and August 10-minute EBCT RSSCTs are shown in Figure 9. TOC breakthrough is defined as the time when the TOC concentration increased from a stable value. Throughout this discussion, the time period of the results are referred to by season as follows: November-fall; February - winter; May - spring; and August - summer. The time to TOC breakthrough and the shape of the breakthrough pattern from each of the RSSCTs indicate a definite seasonal change in the adsorption characteristics of the TOC, where an increase in the adsorbability of the TOC (delay in time of breakthrough), is seen in the winter and summer test results. The time to breakthrough occurred at approximately 30, 70, 10 and 70 days for fall, winter, spring, and summer RSSCTs, respectively. It appears that the TOC compounds during the spring were the least adsorbable. The initial concentrations shown on Figure 9, for the RSSCTs are the TOC concentrations measured for the batch water sample collected at the effluent of the pilot-scale ASF. These values were within the range (Figure 8) of that experienced by the pilot-scale GAC contactor.

The results of the RSSCTs provide insight on the use of GAC in the filter adsorber mode. Data collected from the AWWARF study for PVWC indicated that an approximate 15% reduction in TOC adsorption capacity may be experienced due to backwashing of the filter adsorbers, and that blending of the GAC effluents may increase the efficiency of the adsorption process. Computer modeling of the data collected would be required to further evaluate the efficiency of the use of filter adsorbers.

The percent TOC removals calculated from the raw water through the ASF and GAC adsorber during the Phase II pilot study are shown in Figure 10. As indicated, the ASF was unable to achieve the required percent TOC removals specified in the D/DBP Rule for the entire testing period, whereas the percent TOC removal requirements were consistently exceeded through the GAC adsorber. The percent TOC removal (raw to GAC adsorbed) for the RSSCTs could not be calculated since no data on the raw water TOC were collected at the time the batch water samples were collected. However, in review of typical TOC concentrations during these time periods required percent TOC removals would be as follows:

Season	Raw Water Alkalinity (mg/L as CaCO3)	Raw Water TOC (mg/L)	Required TOC Removal
Fall	**60**	**5**	**35%**
Winter	**55 - 60**	**3.5**	**30 - 40%**
Spring	**60**	**5.5**	**35%**
Summer	**60**	**6**	**35%**

Based on these values, the controlling effluent TOC concentration from the RSSCTs and corresponding times to exhaustion or usage rate would be:

Season	Target Effluent TOC (mg/L)	Usage Rate (Days)
Fall	**3.2**	**>150**
Winter	**2.1**	**>180**
Spring	**3.6**	**>100**
Summer	**3.9**	**>180**

Based on the Phase II pilot study results, the removal of TOC can be achieved through several different types of treatment processes in accordance with the specified removal requirements in the proposed D/DBP Rule, as discussed in the Conclusions and Recommendations section of this report. A summary of the observations made for the removal of TOC during the Phase II pilot study is summarized in the following text.

- The raw Passaic River water is amenable to enhanced coagulation; however, the specific percent removal requirements were shown to vary based on the raw water TOC and alkalinity measurements, which varies seasonally.
- Required TOC removal may be achieved with normal coagulation, followed by both ASF and GAC adsorption (EBCT of 20 minutes); however, no CT credit, required under the SWTR, would be achieved upstream of the GAC adsorber. Sufficient residual disinfectant contact time would be necessary downstream of the GAC contactor.
- The GAC PFA Train data was evaluated assuming single-stage operation and was shown to have a bed life, under the given operating conditions, of greater than 160 days, based on TOC. The efficiency of the adsorption process should be considered with respect to blending the effluents of multiple single-stage adsorbers, each at a different stage of TOC breakthrough, in order to maximize the efficiency of the adsorption process.

The UV-254 measurements for the raw, settled and ASF and GAC adsorbed waters under normal coagulation conditions are shown for the Phase II pilot study experiments in Figure 11. The UV-254 measurements for the ASF and GAC adsorbed data collected for the ICR/AWWARF pilot-scale study are shown in Figure 12.

The measurements at the effluent of the ASF were less than that of the settled and were typically around 0.05/cm. The measured UV-254 through May on the GAC adsorber was less than 0.03/cm. The UV-254 appears to be relatively constant with only a small increase over time, at about 80 days of operation, for the GAC adsorber even though the UV-254 of the raw water indicated a steady increase.

The UV-254 measurements collected during the RSSCT evaluations are shown in Figure 13. A significant increase in the adsorbability of the UV-254 absorbing compounds for the winter and summer RSSCTs (C_0 = 0.042/cm, respectively) as compared to the fall and spring RSSCTs (C_0 = 0.075/cm, for both) is indicated by the later time to breakthrough of 70 days for winter and summer as compared to 30 days for fall and immediate breakthrough in the spring and the decrease in the slope of the breakthrough pattern. Breakthrough was defined as the time when the UV-254 concentration increased from a stable state. These results again indicate seasonal variability in the quality of the Passaic River water.

In summary, the time to breakthrough was observed at about 80 days for the 20 minute EBCT pilot GAC adsorber and ranged from immediate breakthrough in the spring up to 70 days in the winter and summer for the 10 minute EBCT RSSCTs.

The Phase II pilot, raw, settled, and GAC, chlorinated Total Trihalomethane-Simulated Distribution System (TTHM-SDS) production during the testing period of the PFA Train are shown in Figure 14. The settled water TTHM-SDS concentrations indicate a relatively constant value between January and March with values of less than 60 ug/L. This was followed by a sharp increase in concentration, corresponding to a change in the raw water quality, to levels close to 180 ug/L between the months of April through July. This same behavior is exhibited for the GAC breakthrough of the TTHMs. The GAC adsorber was able to maintain finished water concentrations below Stage 1 up through the month of July (approximately at 240 operation days with an effluent TOC less than 2.5 mg/L), whereas Stage 2 limits were exceeded during the month of April (effluent TOC concentration of approximately 1.5 mg/L) after an operation time of approximately 160 operation days.

The results of the pilot-scale, chlorinated, TTHM-SDS samples are shown in Figure 15, for the ASF and GAC adsorbed waters. Breakthrough was defined as the time when the

TTHM concentration increases from a stable value. The ASF indicated a decrease in TTHMs from December 1994 to January 1995, followed by relatively constant concentrations in the January to March time period (50 to 120 operation days), and ending with a steady increase to a maximum concentration of about 110 ug/L in April 1995 (about 160 operation days). Using the pilot-scale SDS test for the ASF, Stage 1 limit was exceeded during the months of December 1994 and July 1995 and all measurements were above the D/DBP Stage 2 limit.

The TTHM breakthrough curves for the RSSCT one-day chlorinated SDS samples are shown in Figure 16. As shown by the data on the figure, the time of operation to reach TTHM exceedances of the proposed Stage 1 and Stage 2 limits of the D/DBP Rule were:

Season	Usage Rate (Days) Stage 1 TTHM	Usage Rate (Days) Stage 2 TTHM
Fall	**>150**	**60**
Winter	**>180**	**120**
Spring	**80**	**20**
Summer	**>180**	**110**

Summary of TTHM results.

- Pilot-scale, TTHM-SDS concentrations at the effluent of the ASF contactor on the PFA Train indicated that the Stage 1 limit could only be met between January and May and that the Stage 2 limit was consistently exceeded.
- Breakthrough times for the pilot-scale, TTHM-SDS pilot PFA indicated that the Stage 1 limit could be met for a bed life of greater than 160 days and the Stage 2 limit could be met up until 160 days of operation. Blending of the effluent from multiple single-stage PFA could potentially increase the carbon bed life.
- Breakthrough times for 10 minute EBCT RSSCTs indicated that Stage 1 could consistently be met at operation times up to 80 days. The Stage 2 limit was exceeded after approximately 20 to 120 days of operation depending on the season. Blending of the effluent of multiple contactors could potentially increase the carbon bed-life in the PFAs operation mode.

The Phase II pilot, raw, settled and GAC adsorbed Total Haloacetic acid, (5)-Simulated Distribution System (THAA(5)-SDS) concentrations are presented in Figure 17, for the PFA. These Phase II pilot SDS results again indicated a change in raw water quality around the month of April (approximately 160 days of operation). The Stage 1 and Stage 2 limitations were consistently achieved for the GAC adsorber through the month of July, although the concentrations during the months of April and June were measured as 32 and 30 ug/L, respectively. The time of operation to meet both Stage 1 and 2 limits was equal to about 240 days.

The pilot-scale, THAA(5)-SDS measurements indicated similar behavior where the time of operation was observed to be greater than 160 days to meet both Stage 1 and Stage 2 D/DBP limits as shown in Figure 18. The shorter incubation period did indicate slightly lower concentrations.

The data for the pilot-scale, THAA(5)-SDS RSSCTs (10 minute EBCT) are presented in Figure 19. As shown by the data on the figure, the time of operation resulting in exceedances of the Stage 1 and Stage 2 requirements of the proposed D/DBP Rule were:

Season	Usage Rate (Days) Stage 1 THAA(5)	Usage Rate (Days) Stage 2 THAA(5)
Fall	**>160**	**130**
Winter	**>180**	**>180**
Spring	**>100**	**30**
Summer	**>180**	**>180**

Summary

- Pilot-scale, THAA(5)-SDS concentrations at the effluent of the ASF on the PFA Train indicated that the Stage 1 limit could only be met between December and June and that the Stage 2 limit was consistently exceeded except during the month of February.
- The pilot-scale and Phase II pilot, THAA(5)-SDS did not exceed the Stage 2 limit even after approximately 160 to 240 days of operation, respectively. Slightly higher

concentrations were observed for the 3-day incubation period as compared to the 1-day incubation period.

- Breakthrough times for 10 min RSSCTs for Stage 2 occurred around 30 and 130 days during Spring 1995 and Fall 1994, respectively, and did not occur for the Winter and Summer 1995 RSSCT. Breakthrough above the Stage 1 standard were not observed in any of the RSSCTs.

V. QA/QC Summary

QA/QC summaries for bromide, TOC, TTHM-SDS and HAA6-SDS sample analysis are given in Tables 14-20. Abbreviations used in the tables are as follows:

- LSC1: Laboratory Control Sample 1
- LSC2: Laboratory Control Sample 2
- MBLK: Method Blank
- MS: Matrix Spike
- MSD: Matrix Spike Duplicate

Calibration summaries for TOC, bromide, trihalomethane and haloacetic acid analysis were obtained from the methods as supplied by Montgomery Laboratories.

TOC Analysis Calibration Summary:

- A linearity calibration was performed every six months or on an as needed basis based on instrument performance. This consisted of a blank and five standards (0.5, 0.7, 4.0, 10.0 and 20.0 mg/L KHP). The lowest concentration is at the MRL. The highest concentration is the upper limit of the usable linear range. The minimum correlation coefficient is 0.995; the slope must be 1.0 ± 0.1
- Every day the instrument was run a blank, instrument calibration verification and a MRL check were run to verify calibration. A linearity check is run to verify linearity at the upper limit of the calibration range.

Bromide Analysis Calibration Summary:

An external calibration was performed using six calibration standards between 0.02 and 03 ppm. This calibration was run as needed based on the control sample results.

Trihalomethane Analysis Calibration Summary:

The external standard procedure was used for this analyte for both methods (501.2 and 502.2). A calibration mix containing all of the single component target analytes was prepared along with a surrogate spiking solution. The standards were prepared and purged using the same procedure that is used to process the actual samples, and the ratios of the peak areas to the amounts injected are used to calculate calibration factors for each analyte at each standard concentration.

A working calibration curve was calculated for each analyte, using a first order fit forced through the origin. If the percent relative standard deviation (%RSD) of the response factors was less than 10 % over the working range, and the R-squared value for the curve was ≥ 0.995, linearity through the origin was assumed, and the average response factor was used in place of the calibration curve. If the % RSD for any analyte was greater than 10 % , or the R-squared value was <0.995, the calibration curve as a second order fit was used.

Haloacetic acid Analysis Calibration Summary:

The external standard calibration procedure was used for this method. A calibration mix containing all target analytes was prepared and diluted to a minimum of five calibration concentration levels. The lowest calibrations standard was at a concentration equal to the minimum reporting level. The standards were extracted and injected using the same procedure that is used to process the actual samples, and the ratios of the peak areas to the amounts injected are used to calculate calibration factors for each analyte at each standard concentration.

A working calibration curve was calculated for each analyte, using a first order fit constrained through the origin. If the % RSD of the calibration factor was less than 20%, the calibration curve as a second order fit was used. Single point calibration

was also acceptable, providing that the absolute difference between the area counts of the target analyte in the sample and in the standard was not greater than 20%.

APPENDIX A

Table 1 - Full-scale Treatment Design Data

Sample Location	Unit Process	Chemical Name	Process Description
PAC Addition	Other Treatment Process	Powdered Activated Carbon	
WW Return	Washwater Return		Washwater Treated: No Coagulation/Sedimentation: Yes Filtration: No Disinfectant Addition: No Plain Sedimentation: No 24 Hr average Water flow returned (MGD): 3.0
Chemical Addition	Coagulant Addition Disinfectant Addition	Aluminum sulfate (Alum) Chlorine gas (Cl^2)	
FLOCC BASIN 1-4	Flocculation		Type of Mixer: Mechanical Liquid Volume (gal): 3,378,858 Short Circuiting Factor: 0.1 Baffling Type: Unbaffled Stage Sequence Number: 1 Stage Mean Velocity Gradient (sec^{-1}):30 Stage Liquid Volume (gal): 3,378,858
SED BASIN 1-4	Sedimentation		Surface Area (ft^2): 146,036 Liquid Volume (gal): 7,492,190 Baffling Type: Unbaffled Short Circuiting Factor: 0.1
OPF ADD	Other Treatment Process	Organic Polymer-Filter Aid	
1966+86 FILTERS	Filtration		Surface Area (ft^2): 18,872 Liquid Volume (gal): 1,131,462 Total Media Depth (in): 42 Media Type: Dual - Anthracite/sand Minimum Water Depth to Top of Media (ft): 4.8 Depth From Top of Media to Top of Backwash Trough (ft): 2.5
CLEARWELL 1-5	Clearwell		Surface Area (ft^2): 34,242 Liquid Volume (gal): 4,524,182 Minimum Liquid Volume (gal): 3,755,791 Baffling Type: Unbaffled Short Circuiting Factor: 0.1
Sodium Hypochlo	Disinfectant Addition	Sodium hypochlorite	
NaOH ADDITION	Other Treatment Process	Sodium hydroxide	
NJDWS	Additional Water Source		

Design Data from the July - ICR WIDBS report A.2 Design Plant Parameters and A.3 Design Plant Chemical Parameters

Table 2 - Full-scale Plant Source Water Quality During Nov 94-Aug 95

Water Quality Parameter	Average Yearly Concentration	Standard Deviation	Maximum Yearly Value	Minimum Yearly Value
Temperature, ^{o}C	59	14.25	79	38
pH	7.33	0.4	8.1	6.9
Turbidity, NTU	10.3	6.57	21	3.5
Alkalinity, mg/L CaCO3	63	20.75	96	26
Total Hardness, mg/L CaCO3	101	30.64	167	58
TOC, mg/L	4.34	1.25	8.39	2.78
UV-254, cm^{-1}	0.21	0.07	0.31	0.11
Bromide, ug/L	0.1	0	0.1	0.1

Table 3 - Full-scale Plant Finished Water Quality During Nov 94-Aug 95

Water Quality Parameter	Average Yearly Concentration	Standard Deviation	Maximum Yearly Value	Minimum Yearly Value
Temperature (^{0}C)	59	13.68	84	38
pH	7.99	0.27	8.9	7
Turbidity (ntu)	0.16	0.06	0.4	0.03
TOC, mg/L	2.61	0.8	4.08	1.61
Distribution System TTHM, ug/L	80.7	37.15	123	53.5

Table 4 - Pilot-scale* GAC Study Experimental Design

Season	Pretreatment	EBCT, min
Fall	Conventional filtration	20
Winter	Conventional filtration	20
Spring	Conventional filtration	20
Summer	Conventional filtration	20

*Pilot-scale GAC PFA Adsorber was run continously from Nov 94-Aug 95.

Table 5 - Bench-scale (RSSCT) GAC Study Experimental Design

Season	Pretreatment	EBCT, min
Fall	Conventional filtration	10
Winter	Conventional filtration	10
Spring	Conventional filtration	10
Summer	Conventional filtration	10

Table 6

PVWC Phase II Pilot Plant Filter Media Characteristics

	Conventional Treatment Train	Biologically Active Carbon (BAC) Train		Biological Filter Adsorber	Post-Filter Adsorber Train	
	ASF	ASF	BAC	GSF	ASF	GAC
Filter Design	Dual-Media	Dual-Media	Mono-Media	Dual-Media	Dual-Media	Mono-Media
Bed Diameter (in)	6	6	4	6	6	4
Surface Area (sq. ft)	0.20	0.20	0.09	0.20	0.20	0.09
Bed Volume (gal)	2.4	2.4	4.3	2.4	2.4	5.7
Flowrate (gpm)	0.6	0.6	0.29	0.6	0.6	0.29
Filtration Rate (gpm/sf)	3	3	3.3	3	3	3.3
Contact Time (min)	4.2	4.2	15	4.2	4.2	20
Media Characteristics						
Media 1:						
Type	Anthracite	Anthracite	GAC	GAC	Anthracite	GAC
Depth (in)	20	20	80	20	20	105
ES (mm)	0.9 to 1.0	0.9 to 1.0	0.55 to 0.75	0.8 to 1.0	0.9 to 1.0	0.55 to 0.75
UC	1.4	1.4	1.9	2.1	1.4	1.9
Brand/Source	Unifilt	Unifilt	Calgon F400	Calgon F300	Unifilt	Calgon F400
Media 2:						
Type	Sand	Sand	None	Sand	Sand	None
Depth (in)	10	10	-	10	10	-
ES (mm)	0.45 to 0.55	0.45 to 0.55	-	0.45 to 0.55	0.45 to 0.55	-
UC	1.5	1.5	-	1.5	1.5	-
Brand/Source	Unifilt	Unifilt	-	Unifilt	Unifilt	-
Total L/d (Media 1 + 2)	1043	1043	3126	1072	1043	4103

Notes:

ES and UC provided by manufacturer

ASF - Anthracite Sand Filter

GSF - Granular Activated Carbon and Sand Filter

GAC - Granular Activated Carbon (post-filter adsorber)

BAC - Biologically Active (Granular Activated) Carbon

L/d - Length (depth) of media/diameter of the media

Table 7 - Pilot- Scale Pretreatment Design Data

Unit Process	Process Description
Rapid Mix (Pilot-scale)	Type of Mixer: Mechanical Baffling Type: Unbaffled - Mixed tank Liquid Volume (gal): 3.75 Mean Velocity Gradient (sec^{-1}): 22 Coagulant Addition: Alum Coagulant Dose (mg/L): 30-70 mg/L
Flocculation (Pilot-scale)	Type of Mixer: Mechanical Liquid Volume (gal): 150 Short Circuiting Factor: 0.5 Baffling Type: Average Stage Sequence Number: 1 Stage Mean Velocity Gradient (sec^{-1}): 3.7 Stage Liquid Volume (gal): 50 Stage Sequence Number: 2 Stage Mean Velocity Gradient (sec^{-1}): 3.7 Stage Liquid Volume (gal): 50 Stage Sequence Number: 3 Stage Mean Velocity Gradient (sec^{-1}): 3.7 Stage Liquid Volume (gal): 50
Sedimentation (Pilot-scale)	Surface Area (ft^2): 90.7 Liquid Volume (gal): 17.3 Baffling Type: Average - Plate Settlers Short Circuiting Factor: 0.5
Filtration (Pilot-scale)	Surface Area (ft^2): 0.20 Liquid Volume (gal): 2.4 Total Media Depth (in): 30 Media Type: Dual - Anthracite/sand Minimum Water Depth to Top of Media (in):

Table 8

Phase II Pilot Study Experimental Conditions

Treatment Train	Date Tests Conducted	Pre-Oxidation	Coagulation	Flocculation	Sedimentation	Post-Sedimentation Ozonation	Filter Design	
							Filter 1	Filter 2 (In series with Filter 1)
Conventional Treatment Train (operated under enhanced coagulation conditions)	Dec 94, Feb 95, Mar 95, May 95, June 95, July 95	None	Alum with intermittant pH adjustment	3-stage 17 rpm per stage	Plate Settler	Intermediate Chlorination	Anthracite/sand Filter 3 gpm/sf	None
Biologically Activated Carbon Train	Jan 95, Feb 95, Mar 95, April 95, June 95, and July 95	None	Alum	3-stage 17 rpm per stage	Plate Settler	Intermediate Ozonation	Anthracite/sand Filter 3 gpm/sf	Biologically Activated Carbon (1) 3.3 gpm/sf
Biological Filter Adsorber (BFA) Train	Jan 95, Feb 95, Mar 95, April 95, June 95, and July 95	None	Alum	3-stage 17 rpm per stage	Plate Settler	Intermediate Ozonation	GAC/sand Filter (1) 3 gpm/sf	
Post-Filter Adsorber (PFA) Train	Jan 95, Feb 95, Mar 95, April 95, June 95, and July 95	None	Alum	3-stage 17 rpm per stage	Plate Settler	None	Anthracite/sand Filter 3 gpm/sf	Granular Activated Carbon (2) 3.3 gpm/sf

Notes:

(1) GAC adsorption exhausted

(2) Fresh GAC used to pack column

Table 9 - Bench-scale Pretreatment Design Data

Unit Process	Process Description
Rapid Mix (Pilot-scale)	Type of Mixer: Mechanical Baffling Type: Unbaffled - Mixed tank Liquid Volume (gal): 3.75 Mean Velocity Gradient (sec^{-1}): 22 Coagulant Addition: Alum Coagulant Dose (mg/L): 30-70 mg/L
Flocculation (Pilot-scale)	Type of Mixer: Mechanical Liquid Volume (gal): 150 Short Circuiting Factor: 0.5 Baffling Type: Average Stage Sequence Number: 1 Stage Mean Velocity Gradient (sec^{-1}): 3.7 Stage Liquid Volume (gal): 50 Stage Sequence Number: 2 Stage Mean Velocity Gradient (sec^{-1}): 3.7 Stage Liquid Volume (gal): 50 Stage Sequence Number: 3 Stage Mean Velocity Gradient (sec^{-1}): 3.7 Stage Liquid Volume (gal): 50
Sedimentation (Pilot-scale)	Surface Area (ft^2): 90.7 Liquid Volume (gal): 17.3 Baffling Type: Average - Plate Settlers Short Circuiting Factor: 0.5
Filtration (Pilot-scale)	Surface Area (ft^2): 0.20 Liquid Volume (gal): 2.4 Total Media Depth (in): 30 Media Type: Dual - Anthracite/sand Minimum Water Depth to Top of Media (in):
Cartridge Filtration (Bench-scale)	Surface Area: 6.6 sq. ft. Nominal Pore size (um): 1 Filter Material: Polypropylene Filter Life (gallons of processed water): 100, estimated

Table 10 - Summary of Laboratories Conducting Analyses for the Treatment Study

Laboratory	Address	Phone Number	Fax Number	Contact Person	Dates of Service	Analyses Performed
Passaic Valley Water Commission	P.O. Box 198 Little Falls, NJ 07424	(973) 890-2499	(973) 890-5723	Linda Tatro	Nov 16, 1994 - 31-Aug-95	Alkalinity, Ammonia. Calcium Hardness, Chlorine Residual, pH, Temperature, Total Hardness, Turbidity, UV-254
Montgomery Laboratories	555 East Walnut Avenue Pasadena, CA 91101	(818) 568-6489	(818) 568-6324	James Hein	Nov 16, 1994- 31-Aug-95	THM4, HAA5, TOC, TOX, Bromide

Table 11 - Analytical Methods and Minimum Reporting Levels (MRLs)

Analyte	Method	Minimum Reporting Level
Alkalinity	SM2320B	1.7 mg/L
Ammonia	SM4500-NH3D	0.007 mg/L
Bromide	EPA 300.A	0.04 mg/L
Calcium Hardness	SM3500-CaD	1.3 mg/L
Chlorine Residual, Free	SM4500-Cl G	-
Haloacetic Acid (6)	S6233B/552	1.0 ug/L each; 2.0 ug/L for MCAA
pH	EPA 150.1	Not Applicable
Temperature	SM2550B	Not Applicable
TTHM	EPA 502.1	0.5 ug/L each
TTHM	EPA 502.2	0.5 ug/L each
Total Hardness	SM2340C	1.9 mg/L
TOC	5310C	0.5 mg/L
TOX	5320B	10 ug/L
Turbidity	EPA 180.1	0.042 ntu
UV-254	SM5910	0.0009 cm^{-1}

***Pilot- and Bench-scale testing occurred prior to final promulgation of ICR**

Table 12 Pilot- and bench-scale GAC influent organic water quality parameters

	EBCT (min)	TOC (mg/L)	UV_{254} (1/cm)	TTHM† (µg/L)	HAA6† (µg/L)	TOX† (µg Cl⁻/L)
Pilot-Scale‡	20	2.7	0.055	73	47	211
Bench-scale						
November 1994	20	3.5	0.075	73	71	277
November 1994	10	3.2	0.075	85	75	300
February 1995	10	2.3	0.042	65	39	313
May 1995	10	3.7	0.075	101	84	317
August 1995	10	2.6	0.049	77	55	210

† SDS chlorination conditions

‡Values reported are averaged over the operation time of the pilot-scale system (November 1994 to August 1995)

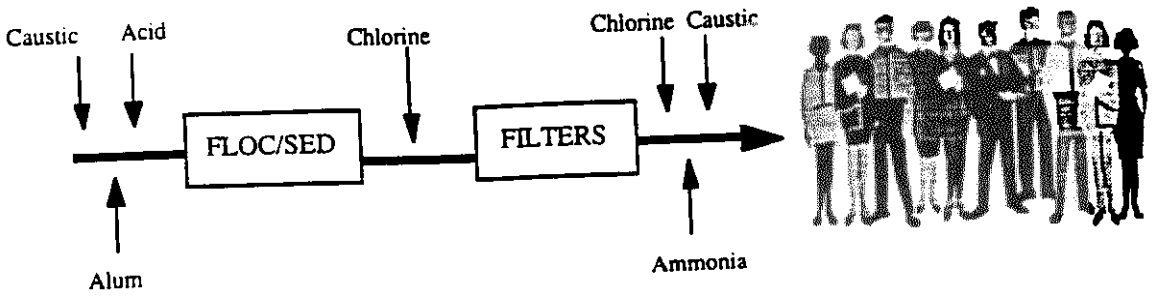
Table 13Pilot- and bench-scale GAC influent inorganic water quality parameters

	EBCT (min)	pH	Temp. (°C)	Turb. (NTU)	Hardness Total (mg/L $CaCO_3$)	Hardness Ca^{+2} (mg/L $CaCO_3$)	Alkalinity (mg/L $CaCO_3$)	Ammonia (mg/L N)	Br^- (mg/L)
Pilot-Scale†	20	6.6	13.8	0.113	103	72	43	0.082	0.061
Bench-scale									
November 1994	20	7.8	20.0	0.290	142	101	79	0.008	0.090
November 1994	10	7.8	20.0	0.290	142	101	79	0.008	0.090
February 1995	10	7.8	20.6	0.220	112	81	55	0.025	0.090
May 1995	10	7.3	21.1	0.185	115	82	59	0.158	0.070
August 1995	10	7.6	22.2	0.085	118	44	44	0.141	0.078

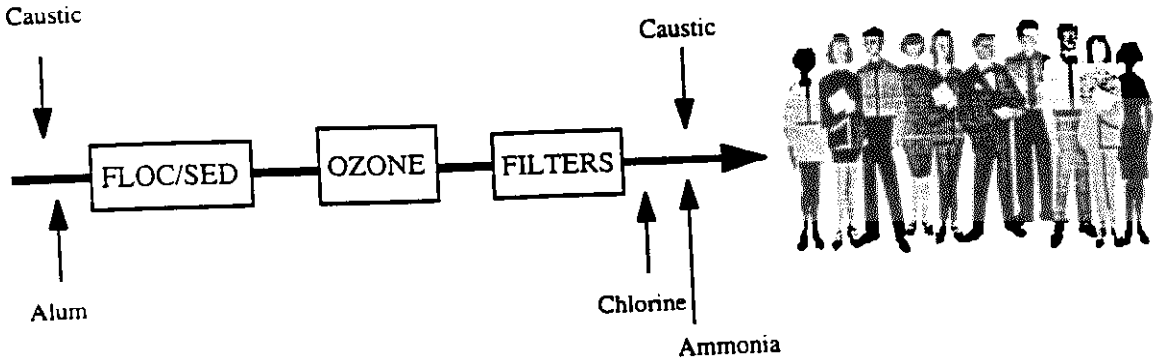
† Values reported are averaged over the operation time of the pilot-scale system (November 1994 to August 1995)

APPENDIX B

Process Trains for Evaluation



PROCESS TRAIN No. 1



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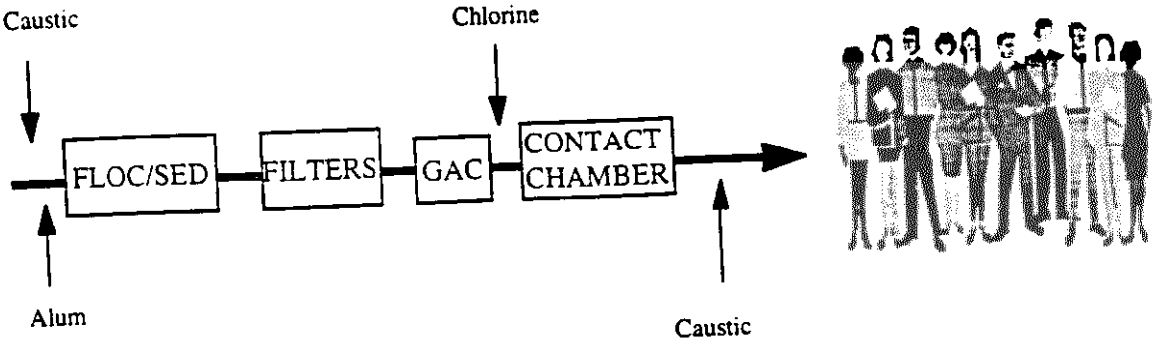

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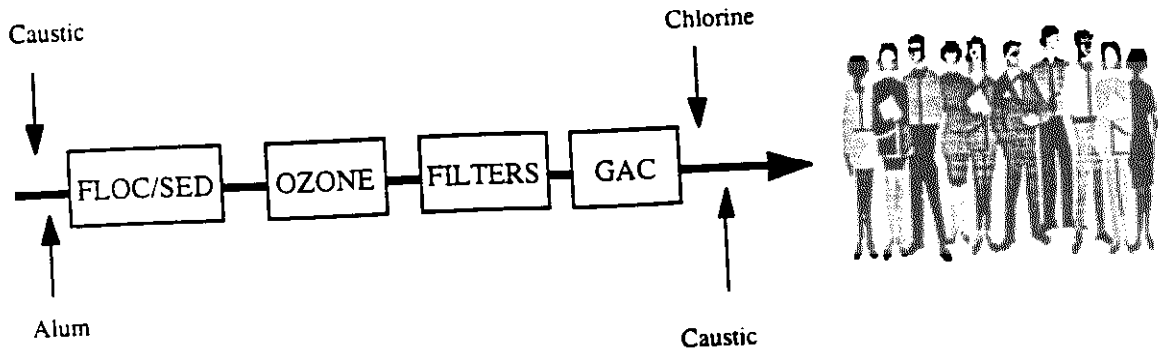


PROCESS TRAIN No. 4

Figure 1

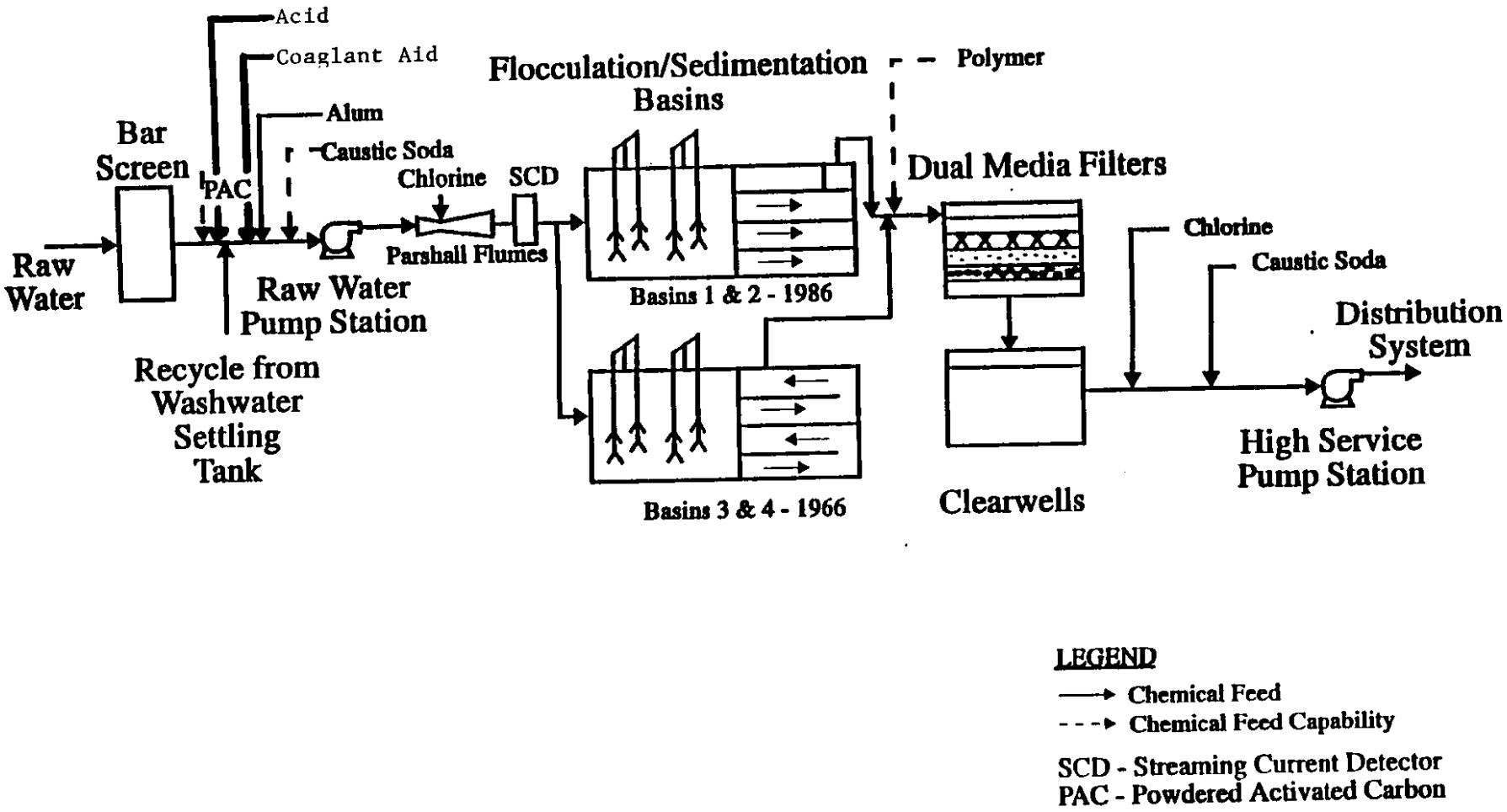


Figure 2 - Little Falls Filtration Plant Process Schematic

Monthly

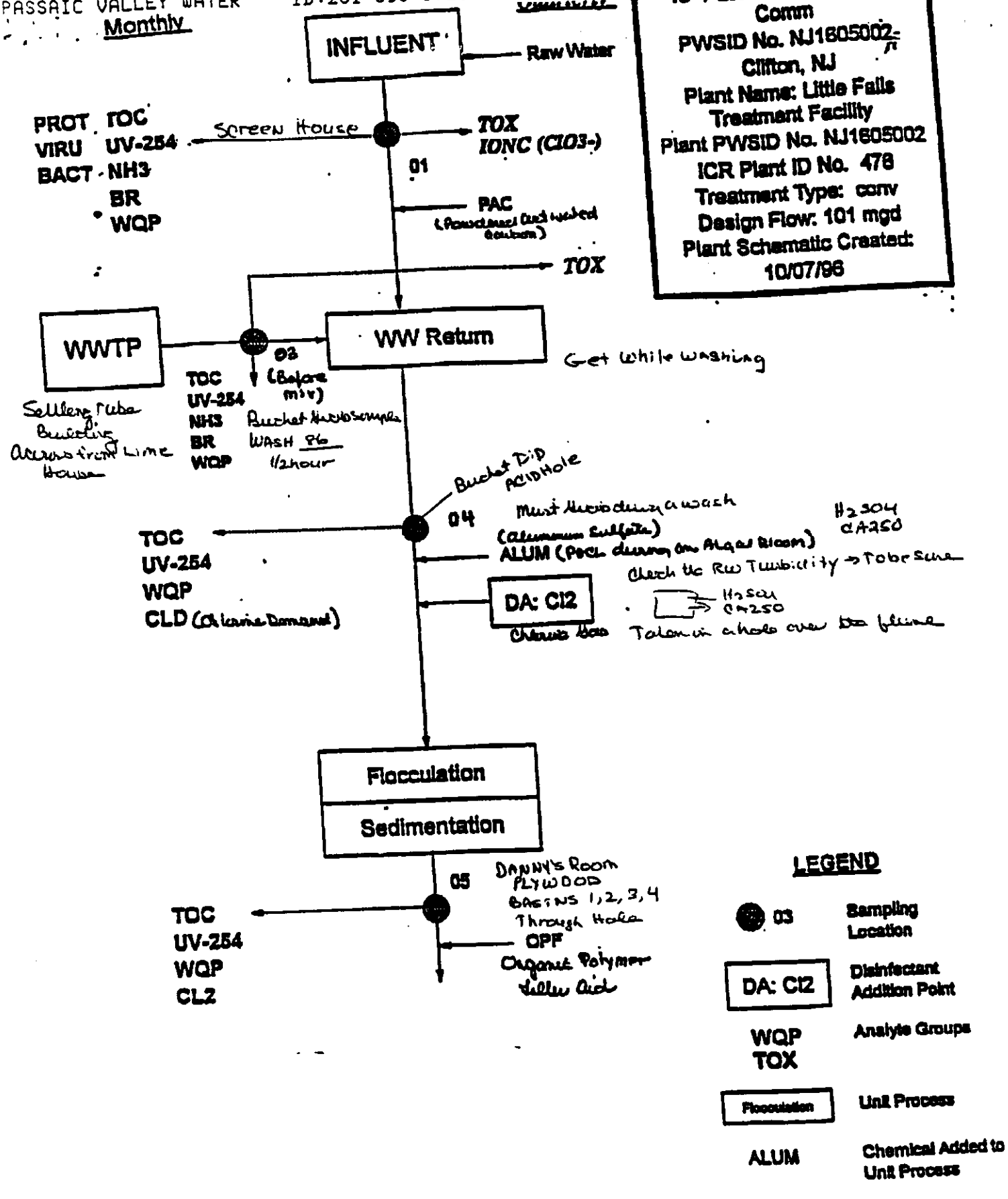


Figure 3-a

Monthly

Quarterly

Comm

PWSID No. NJ1605002
Clifton, NJ
Plant Name: Little Falls Treatment Facility
Plant PWSID No. NJ1605002
ICR Plant ID No. 476
Treatment Type: conv
Design Flow: 101 mgd
Plant Schematic Created: 10/07/96

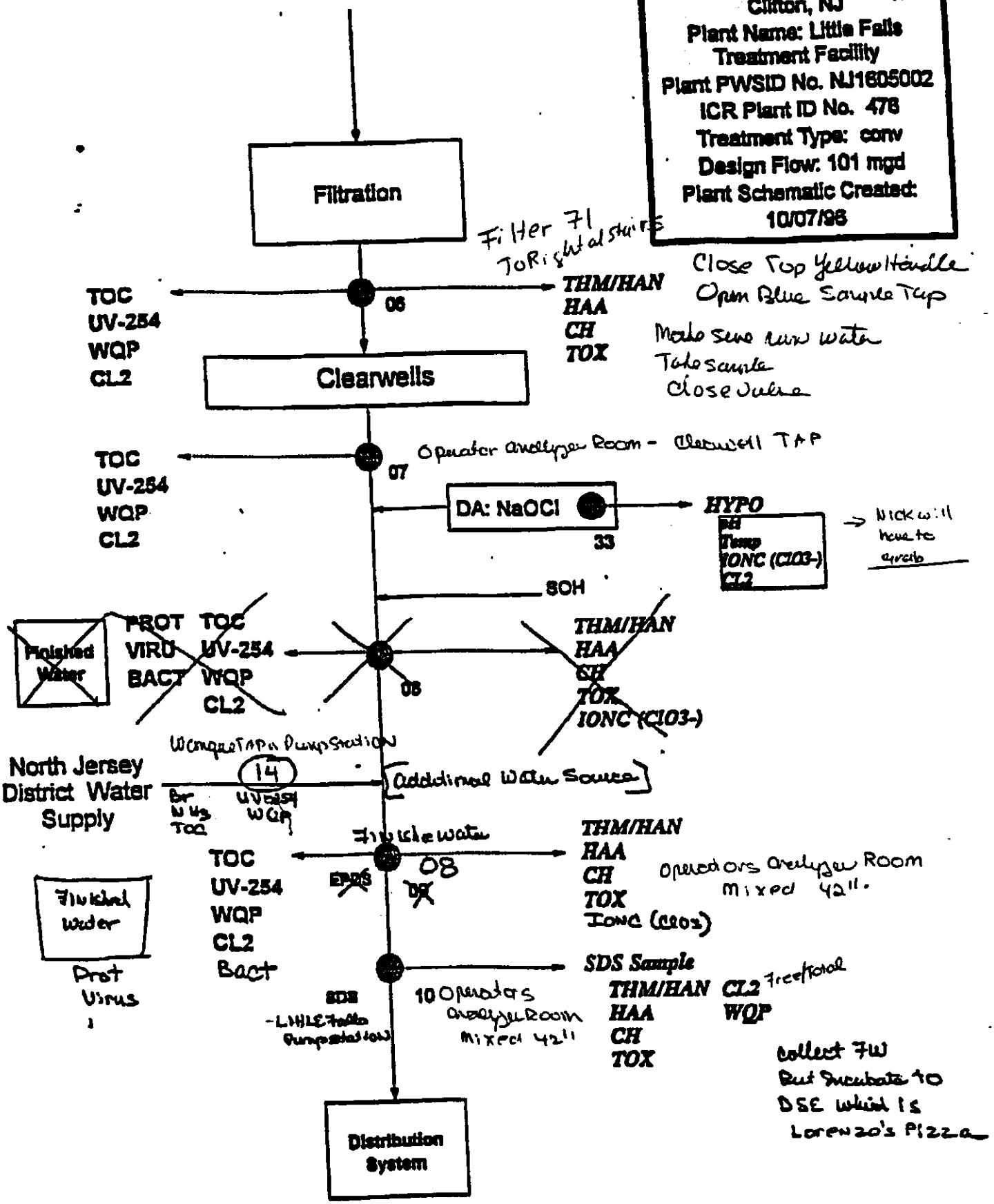
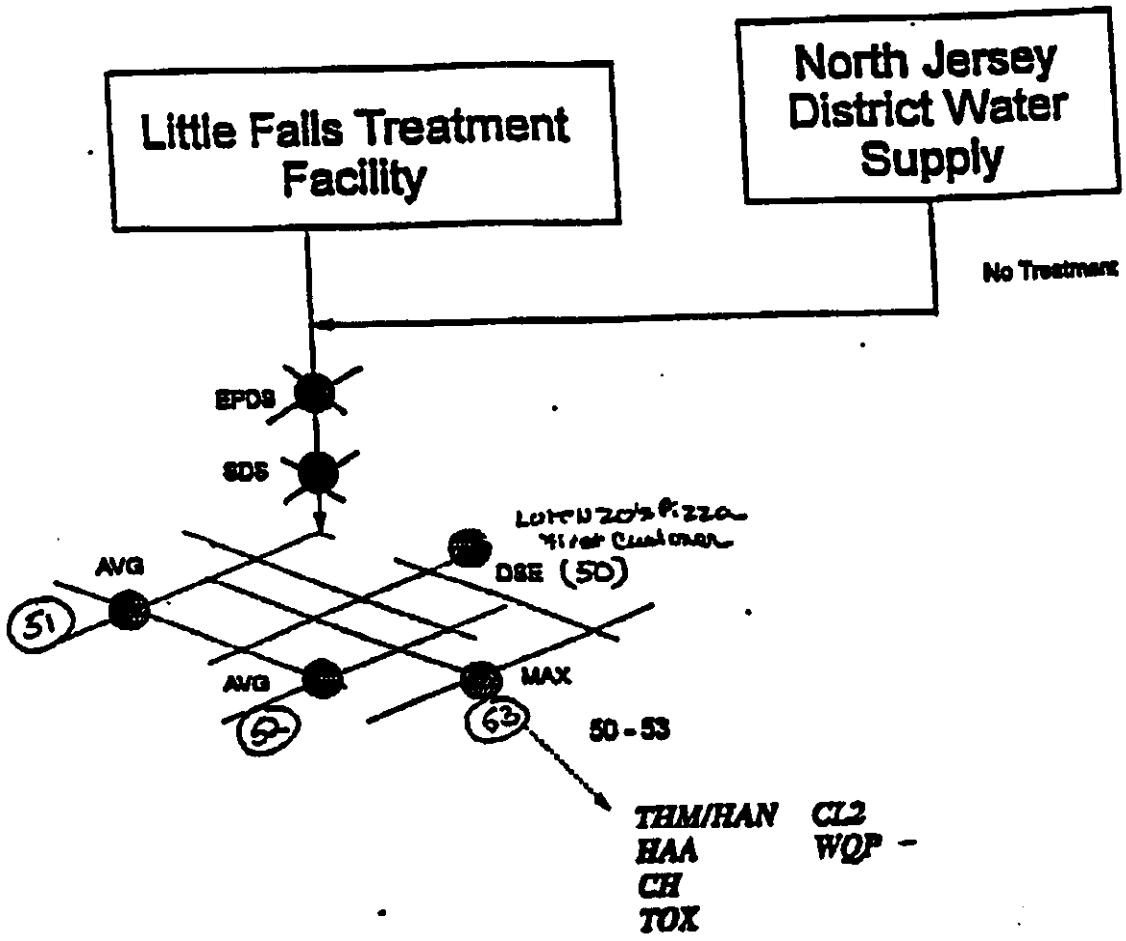


Figure 3-b

Comm

PWSID No. NJ1605002
Clifton, NJ
System Schematic Created:
10/07/96

Quarterly



LEGEND

50 - 53	Sampling Locations
DSE	Distribution System Equivalent--Corresponds to SDS Residence Time
AVG	Average Residence Time in the Distribution System
MAX	Maximum Residence Time in the Distribution System

Distribution System ID No. 86

Figure 3-c

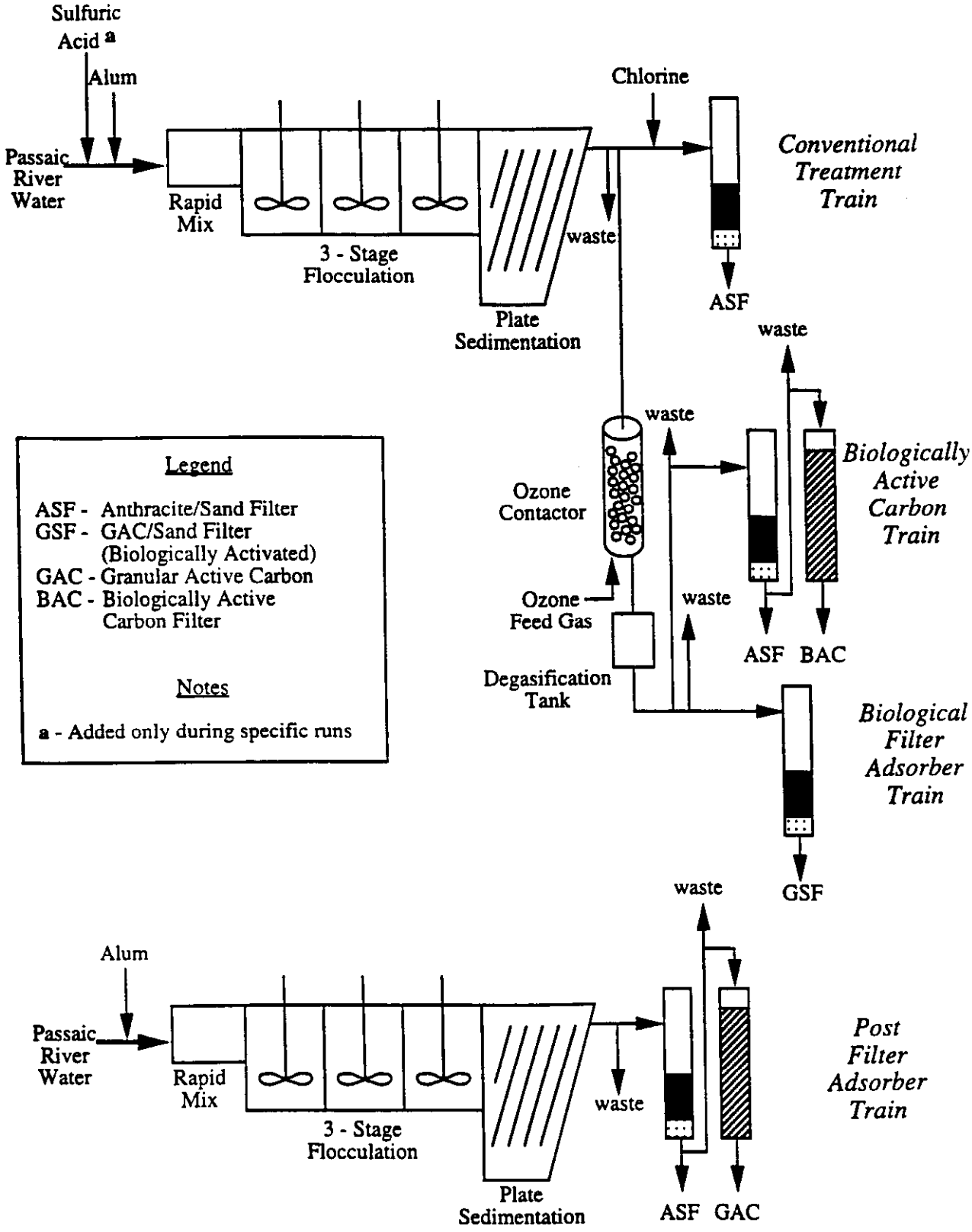


Figure 4 PVWC Phase II - Pilot Study Process Schematic

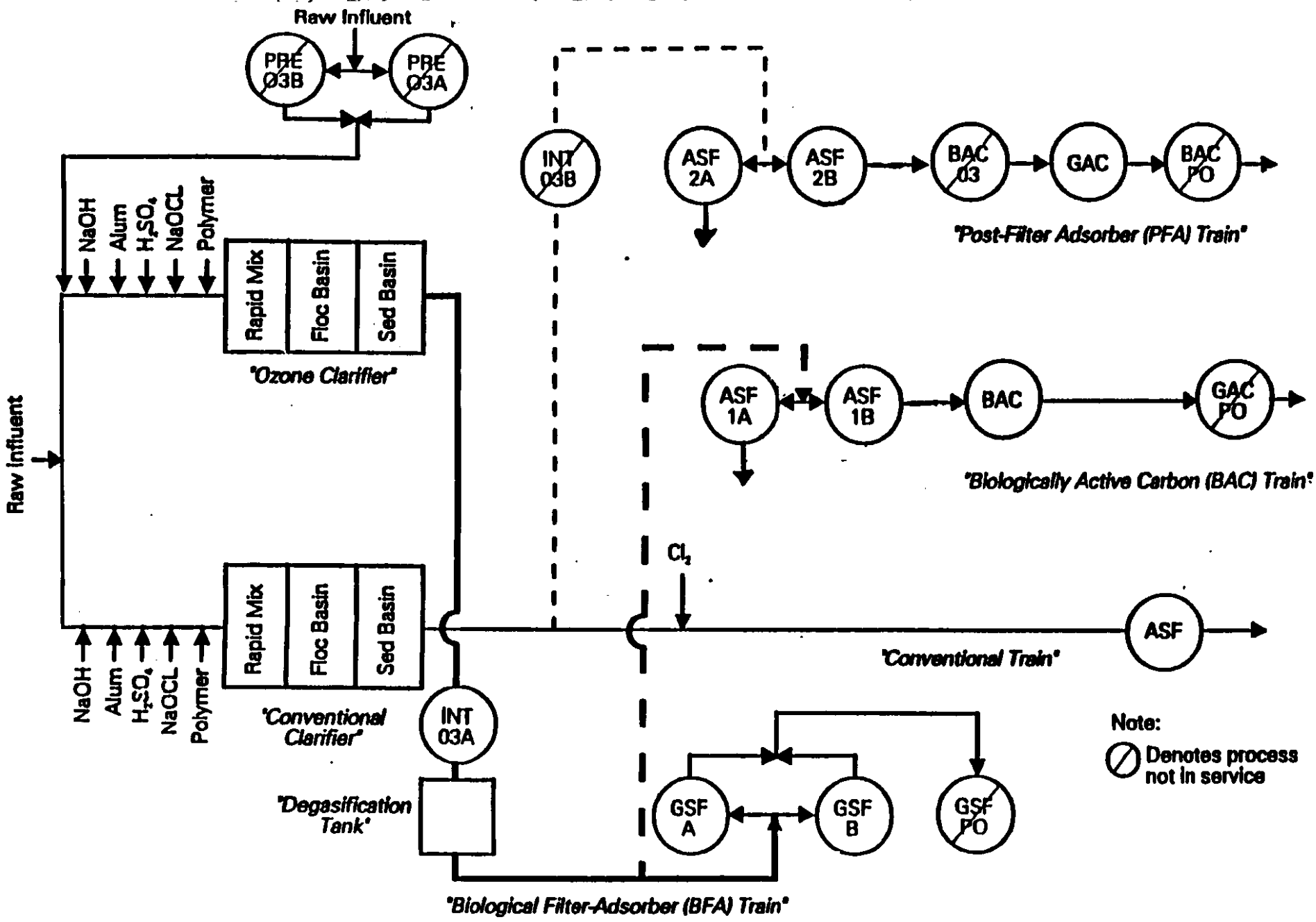


Figure 5 **PVWC Phase II pilot plant schematic**

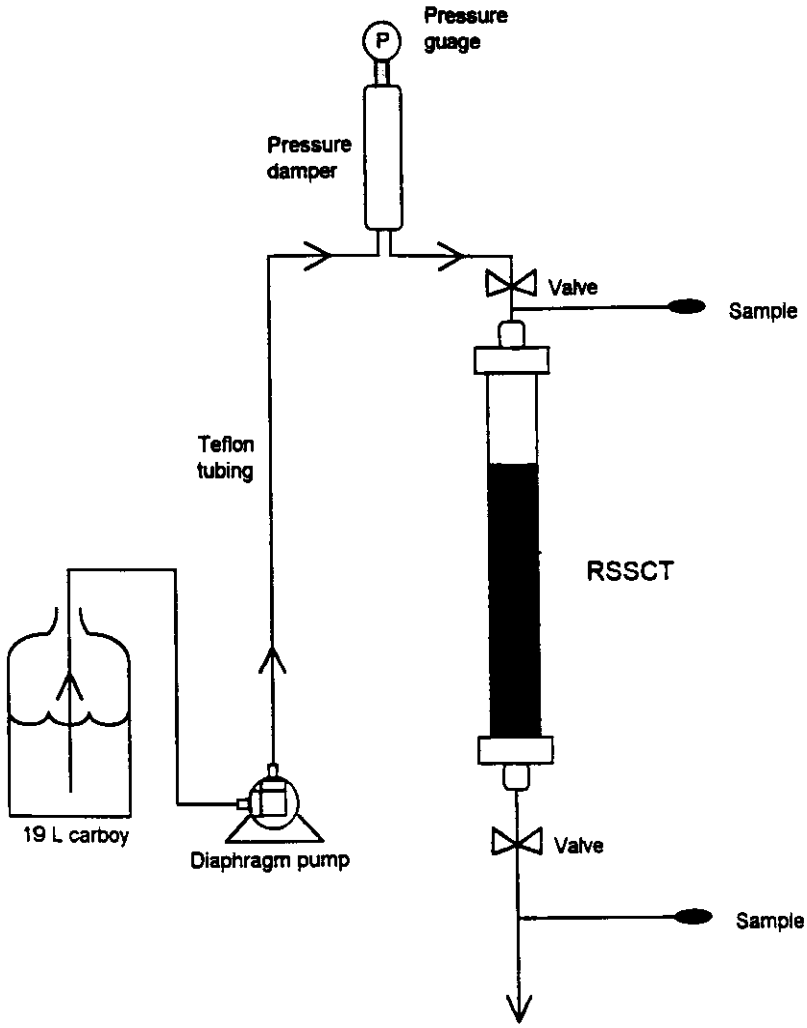


Figure 6 **RSSCT set-up**

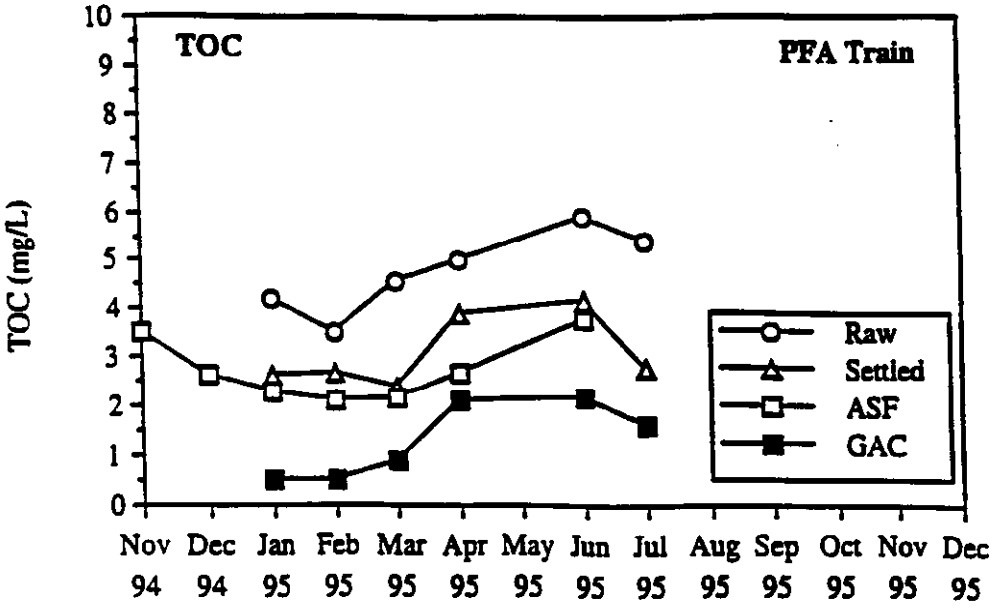


Figure 7 Seasonal raw, settled, anthracite/sand filtered and GAC adsorbed TOC concentrations under normal coagulation conditions.

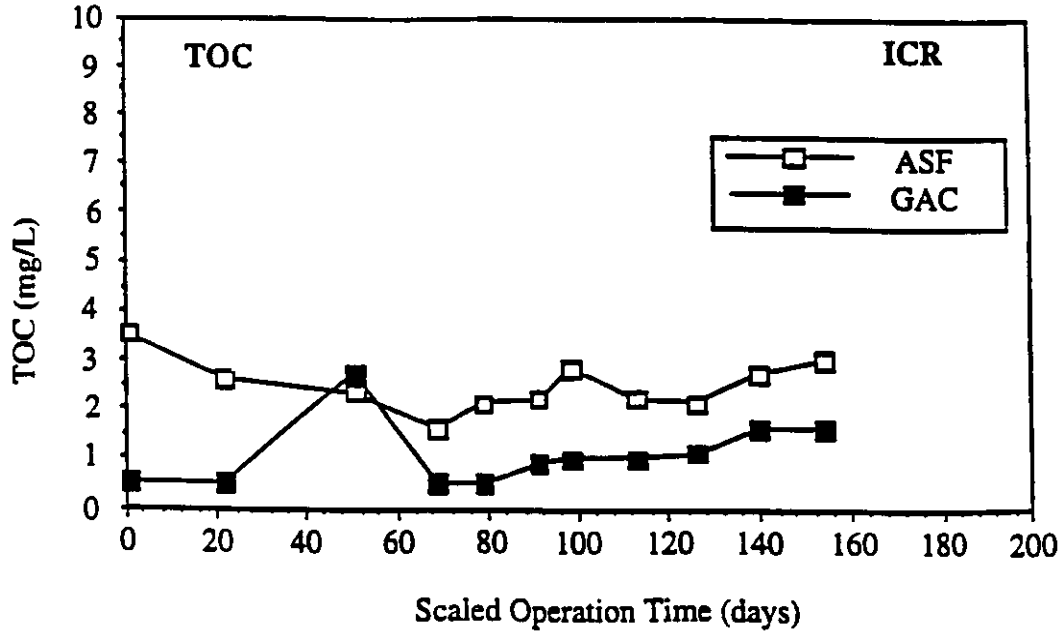


Figure 8 Seasonal anthracite/sand filtered and GAC adsorbed TOC concentrations, collected for the ICR pilot study, under normal coagulation conditions.

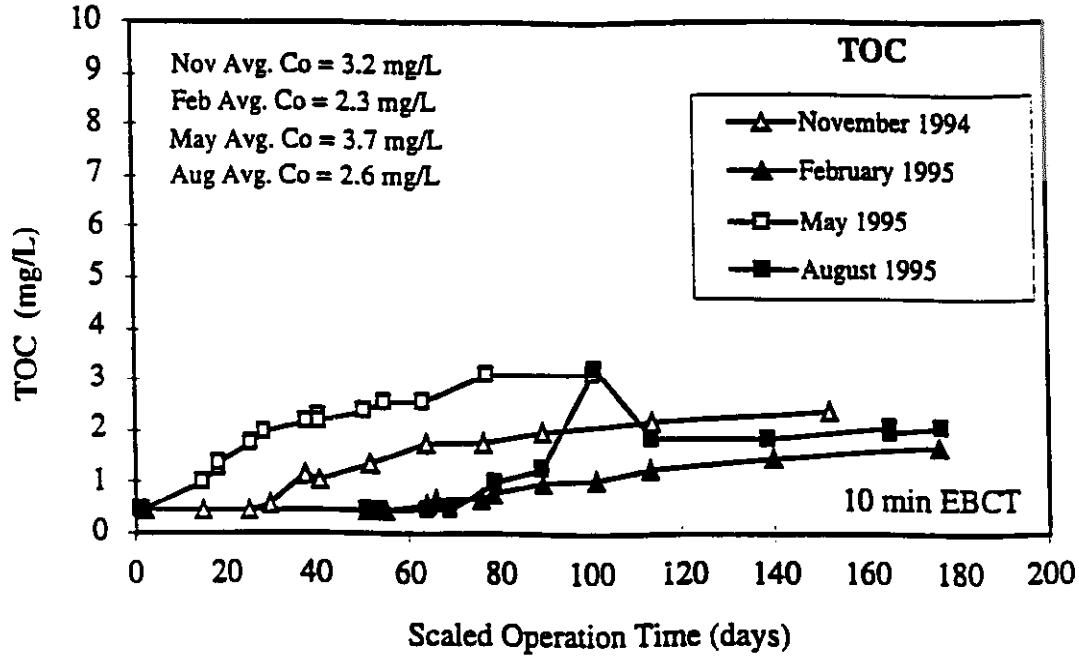


Figure 9 Seasonal TOC breakthrough using the RSSCT

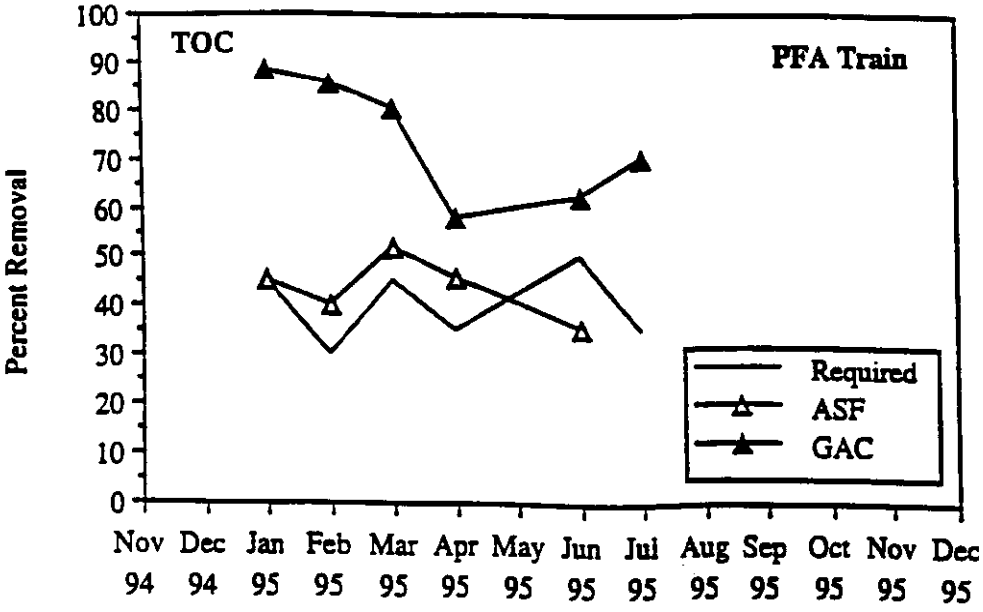


Figure 10 Seasonal percent TOC removal from raw water through anthracite/ sand filtration and GAC adsorption under normal coagulation conditions.

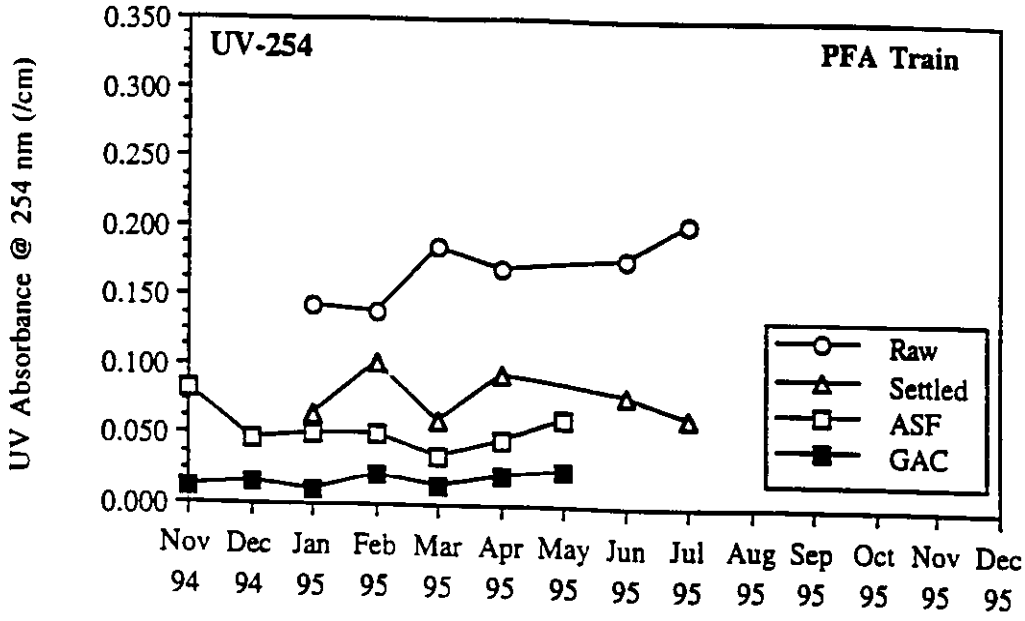


Figure 11 Seasonal raw, settled, anthracite/sand filtered, and GAC adsorbed UV-254 under normal coagulation conditions.

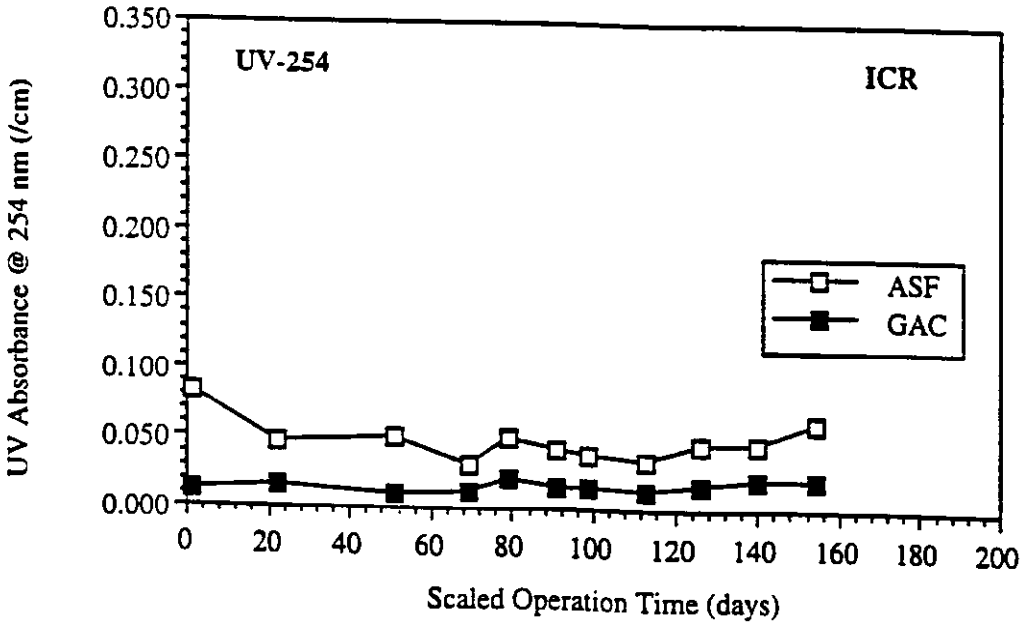


Figure 12 Seasonal anthracite/sand filtered and GAC adsorbed UV-254, collected for the ICR pilot study, under normal coagulation conditions.

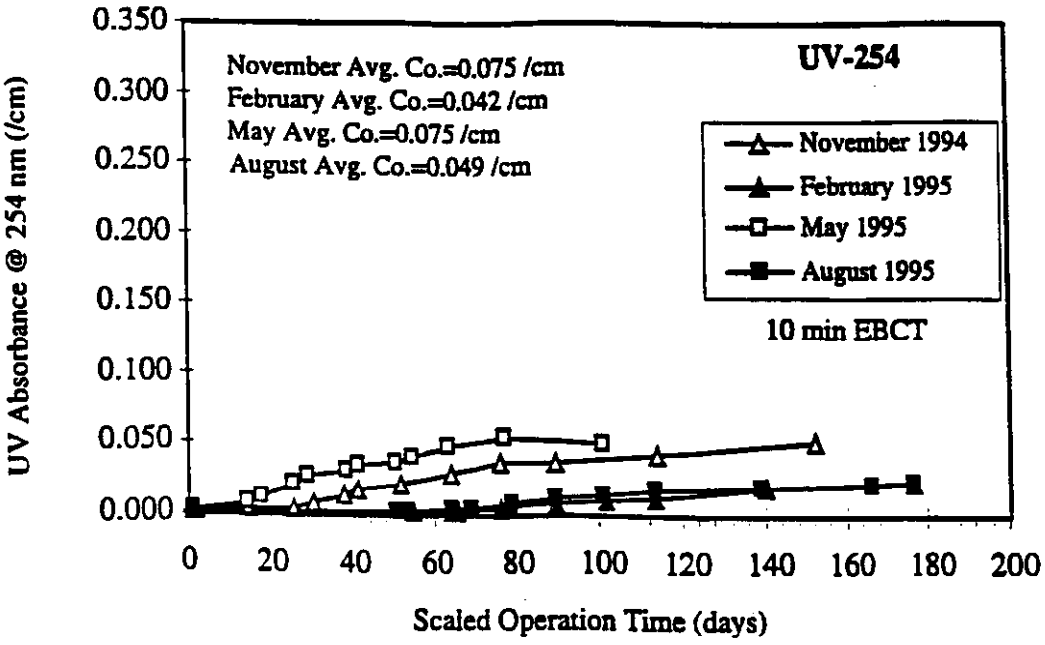


Figure 13 Seasonal UV-254 breakthrough using the RSSCT.

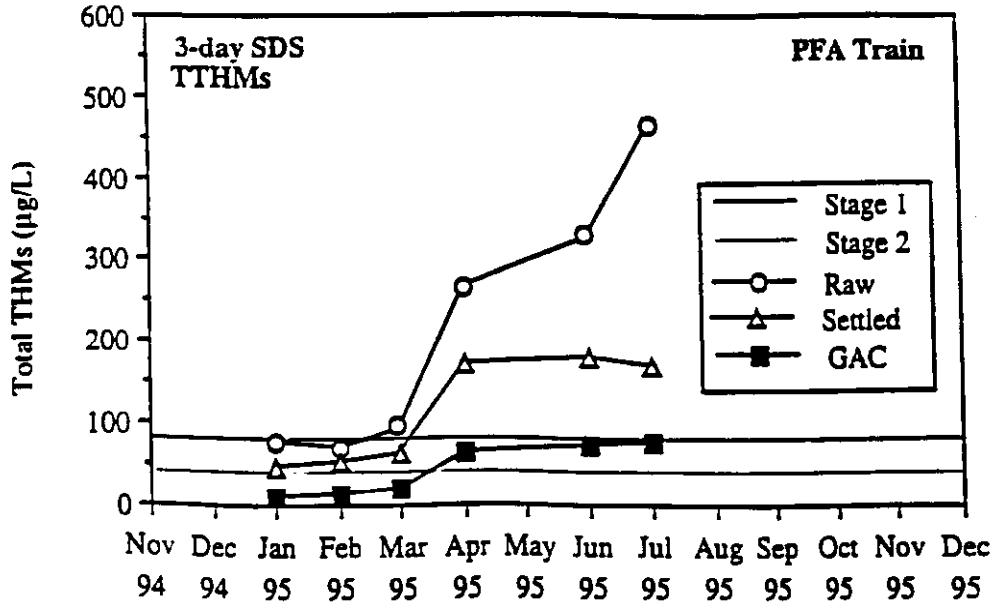


Figure 14 Seasonal raw, settled and GAC adsorbed TTHM-SDS concentrations under normal coagulation conditions.

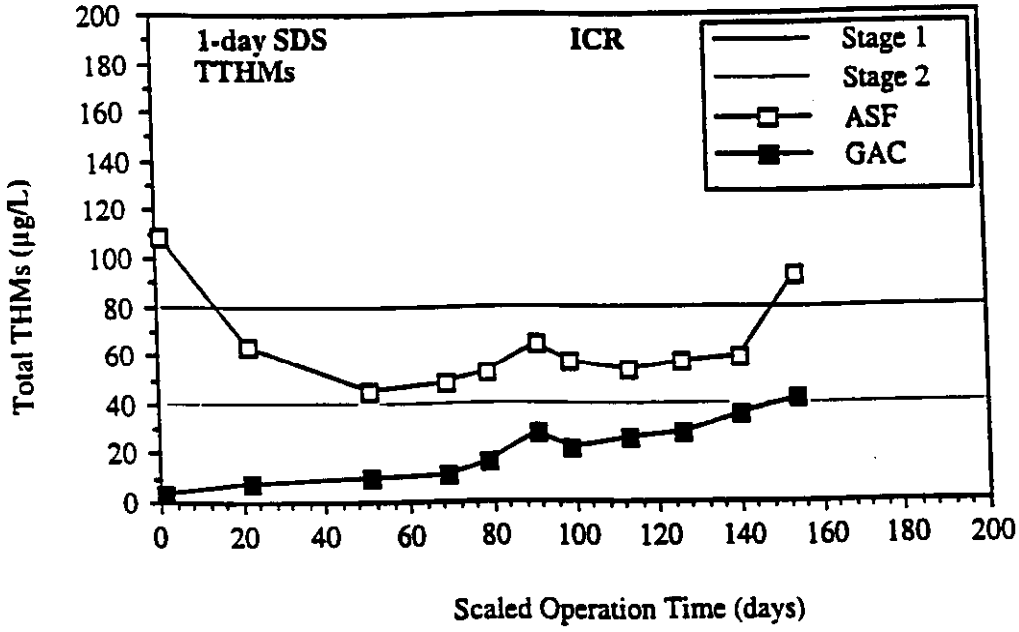


Figure 15 Seasonal anthracite/sand filtered and GAC adsorbed 1-day TTHM-SDS concentrations, collected for the ICR pilot study, under normal coagulation conditions.

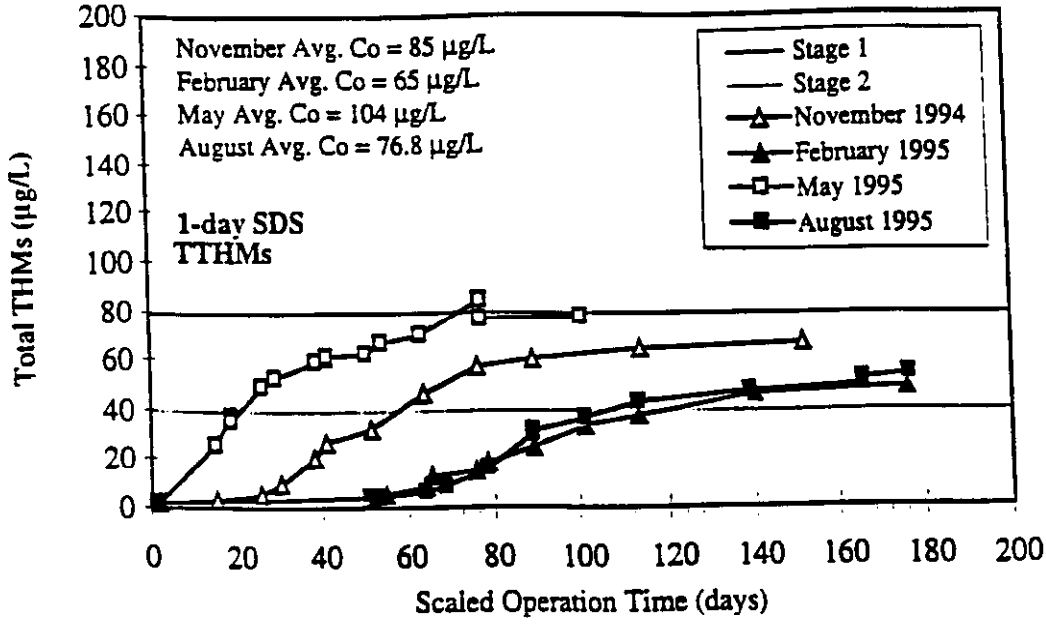


Figure 16 Seasonal 1-day TTHM-SDS breakthrough using the RSSCT.

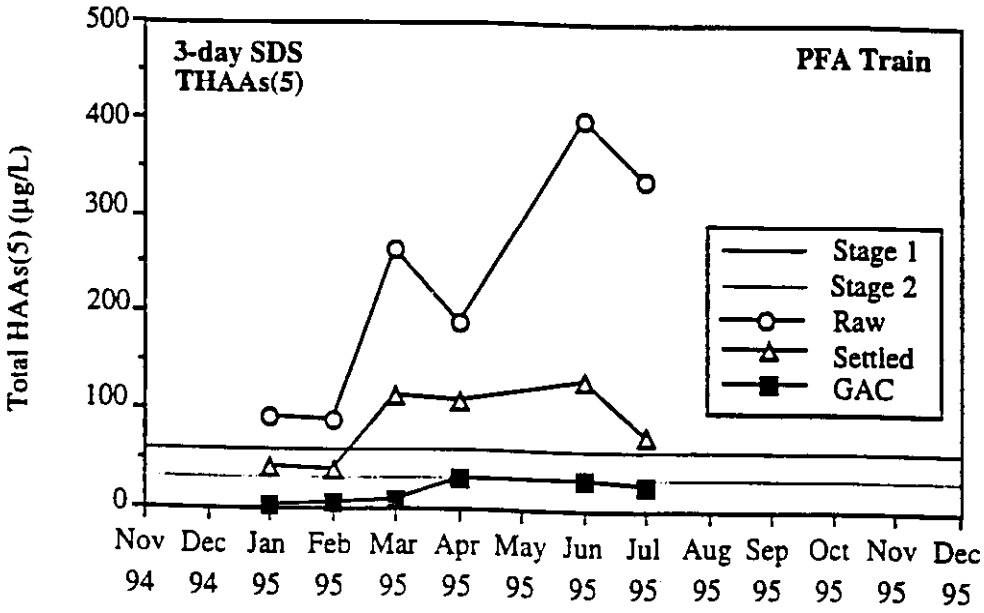


Figure 17 Seasonal raw, settled and GAC adsorbed THAAs (5)-SDS concentrations under normal coagulation conditions.

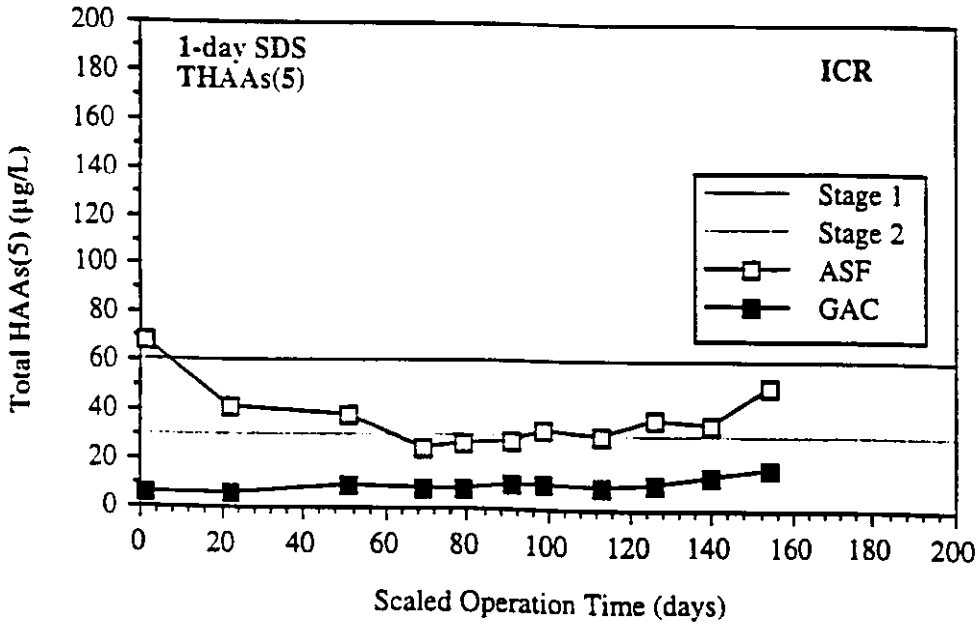


Figure 18 Seasonal anthracite/sand filtered and GAC adsorbed 1-day THAAs (5)-SDS, collected forthe ICR pilot study, under normal coagulation conditions.

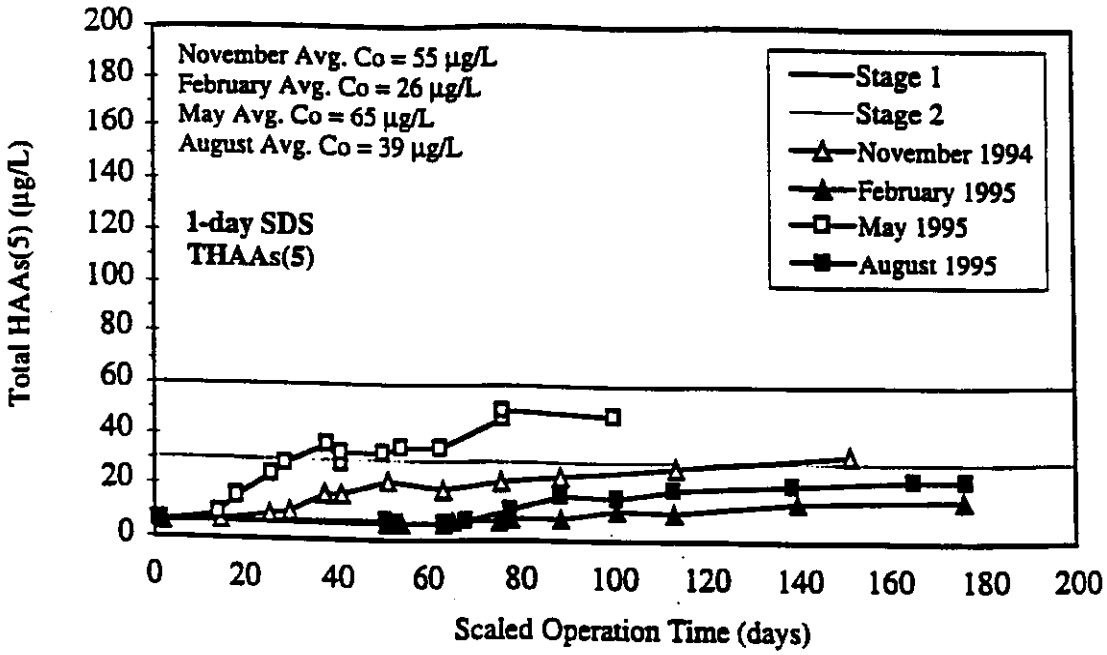


Figure 19 Seasonal THAAs (5)-SDS breakthrough using the RSSCT