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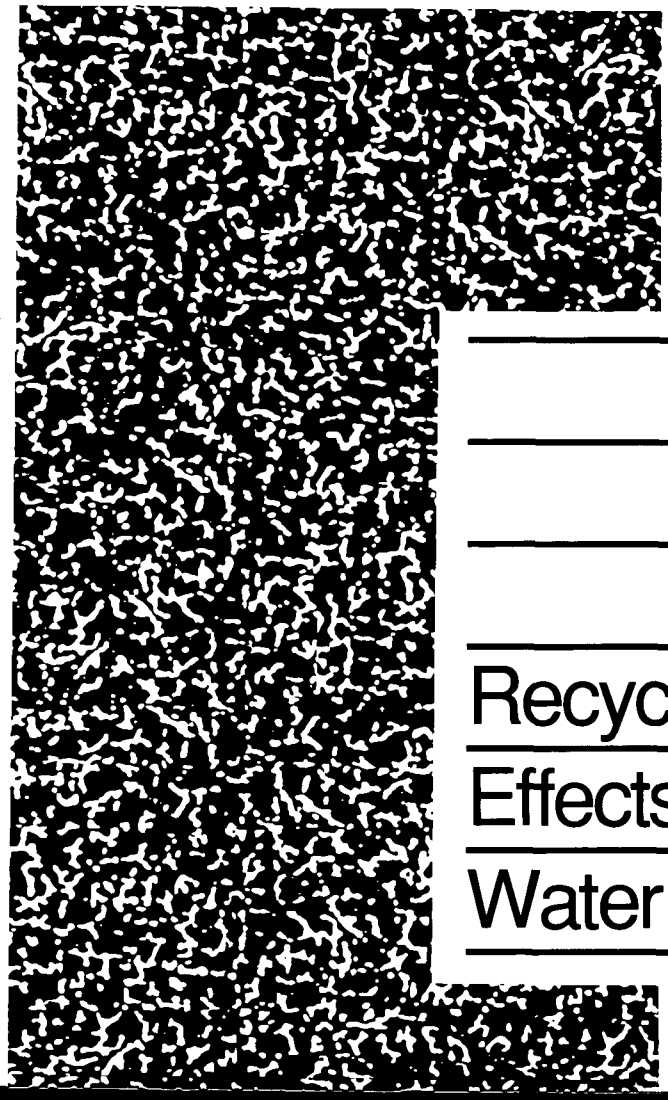
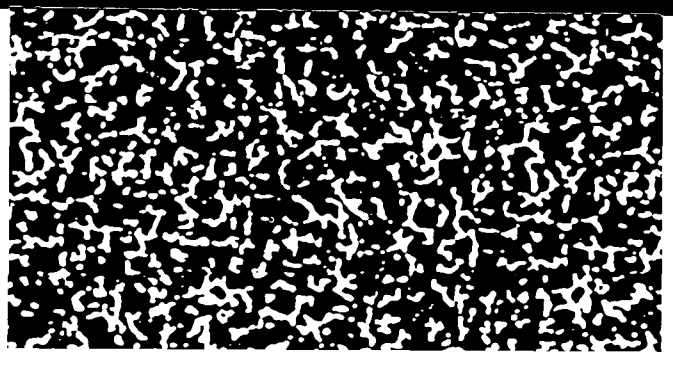


Recycle Stream Effects on Water Treatment



Subject Area:
Water Treatment
and Operations

Recycle Stream Effects on Water Treatment

The mission of the AWWA Research Foundation is to advance the science of water to promote the quality of life. Funded primarily through annual subscription payments from almost 700 utilities and consulting firms in North America and abroad, AWWARF sponsors research on all aspects of drinking water, including supply and resources, treatment, monitoring and analysis, distribution, management, and health effects.

From its headquarters in Denver, Colorado, the AWWARF staff directs and supports the efforts of over 300 volunteers, who are the heart of the research program. These volunteers, serving on various boards and committees, use their expertise to select and monitor research studies to benefit the entire drinking water community.

Research findings are disseminated through a number of technology transfer activities, including research reports, conferences, videotape summaries, and periodicals.

Recycle Stream Effects on Water Treatment

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Foreword

The AWWA Research Foundation is a nonprofit corporation that is dedicated to the implementation of a research effort to help utilities respond to regulatory requirements and traditional high-priority concerns of the industry. The research agenda is developed through a process of grass-roots consultation with subscribers, members, and working professionals. Under the umbrella of a Five-Year Plan, the Research Advisory Council prioritizes the suggested projects based upon current and future needs, applicability, and past work; the recommendations are forwarded to the Board of Trustees for final selection.

This publication is a result of one of those sponsored studies, and it is hoped that its findings will be applied in communities throughout the world. The following report serves not only as a means of communicating the results of the water industry's centralized research program but also as a tool to enlist the further support of the nonmember utilities and individuals.

Projects are managed closely from their inception to the final report by the foundation's staff and large cadre of volunteers who willingly contribute their time and expertise. The foundation serves a planning and management function and awards contracts to other institutions such as water utilities, universities, and engineering firms. The funding for this research effort comes primarily from the Subscription Program, through which water utilities subscribe to the research program and make an annual payment proportionate to the volume of water they deliver and consultants subscribe based on their annual billings. The program offers a cost-effective and fair method for funding research in the public interest.

A broad spectrum of water supply issues is addressed by the foundation's research agenda: resources, treatment and operations, distribution and storage, water quality and analysis, toxicology, economics, and management. The ultimate purpose of the coordinated effort is to assist water suppliers to provide the highest possible quality of water economically and reliably. The true benefits are realized when the results are implemented at the utility level. The foundation's trustees are pleased to offer this publication as a contribution toward that end.

Recycling water plant waste streams back to the head of the plant is an integral part of water plant operations and an important aspect of water conservation initiatives. This project takes a critical look at the quality of these recycle streams and determines proper pretreatment, operation, and monitoring requirements.

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We also acknowledge the work of William Becker and James DeWolfe, who were employees of the American Water Works Service Company, Inc., at the time of this project and worked on data collection and review. A very special thanks goes to Tim Bishop of Environmental Engineering & Technology, Inc., who spent many hours at each of the facilities collecting the samples and then reducing the data to usable form.

Finally, thanks go to the AWWARF project advisory committee: James Hall from the City of Chicago, Richard Talley from the City of Fort Worth, and the AWWARF project manager Elizabeth Kawczynski.

Executive Summary

Environmental Engineering & Technology, Inc., and the American Water Works Service Company conducted this study to determine the quality and characteristics of waste streams that are recycled to water treatment plants and to determine if the recycle can impact finished water quality or the treatment process itself. The study was carried out by evaluating the waste streams and recycle streams at eight utilities and by conducting laboratory treatability studies on several of the waste streams.

The following waste streams were analyzed as part of this research:

Spent filter backwash water
- with the solids from filtration
- without the solids from filtration (after settling)

Clarifier and sedimentation basin sludge
Sludge thickener overflows (supernatant)
Sludge lagoon overflows (supernatant)
Dewatering operation liquid wastes
- pressate from belt press
- centrate from centrifuge
- leachate from sand drying beds

Recycling of these waste streams has the potential to upset the treatment process itself or to affect the quality of the finished water. The impacts could be caused by the solids themselves, by constituents in the recycle streams, or by contaminants released from the sludge. Although some plants have experienced problems with recycle, very little literature has been published dealing with the characteristics of the recycle streams or requirements for effective side stream recycle.

The principal contaminants analyzed in this research were

Giardia and *Cryptosporidium* cysts
Particles, by size range
Manganese
Assimilable organic carbon
Total organic carbon
Total trihalomethanes
Total trihalomethane precursors
Turbidity
Aluminum

In the evaluations regarding *Giardia* and *Cryptosporidium* cysts, it was found that spent filter backwash water and sedimentation basin sludges can have very high cyst concentrations. For example, one plant studied had *Giardia* and *Cryptosporidium* concentrations of more than 150 cysts/L in the spent filter backwash water, as compared with 0.2 to 3 cysts/L in the raw water.

Laboratory- and full-scale confirmation showed that sedimentation was effective in reducing particles (and cyst levels) in the spent filter backwash prior to recycle. However, very low overflow rates (less than 0.05 gpm/ft^2 [0.12 m/h]) were required to achieve 70 to 80 percent particle removal in the cyst size range. A nonionic polymer was effective in increasing particle removals to more than 90 percent at overflow rates of 0.2 to 0.3 gpm/ft^2 (0.5 to 0.75 m/h).

A mass balance model was developed to estimate the increase in cyst loading to the plant due to recycle; the model was based on varying recycle ratios and varying degrees of cyst removal from the recycle stream prior to recycle. For example, it was found from the model that if a plant was recycling settled spent filter backwash water into the raw water line at a 20 percent ratio and was using a backwash clarifier designed for an overflow rate of 0.25 gpm/ft^2 (0.6 m/h) without polymer addition then the cyst loading to the treatment process could be 20 times that present in the source water. However, if the recycle ratio was reduced to 5 percent and the backwash water clarifier efficiency was increased with the use of polymer or with lower overflow rates, the increased cyst loading due to recycle would only be 1.1 times that of the source water. This analysis also discounts the additional disinfection that occurs as the cysts are recycled through the various treatment processes. These findings suggest that proper design, monitoring, and operation of recycle can reduce exposure to possible increased cyst loadings to the plant.

Manganese was evaluated at a number of facilities, which all showed similar results—the sludges contained high concentrations of manganese. Studies conducted on sludge storage showed that the sludge released manganese to the surrounding water. Quantities of dissolved manganese in the water surrounding the sludge samples were in the range of 1 to 7 mg/L and upon storage reached 20 to 30 mg/L. Studies conducted on manually cleaned sedimentation basins showed that as the sludge accumulated in these basins, the manganese levels in the clarified water gradually increased. Therefore, some manganese will be released to sludge thickener overflows and recycled to the plant or will be released in manually cleaned sedimentation basins to the clarified water. Normally the manganese concentrations are low unless large spikes of waste streams are recycled. However, if sludge accumulation were allowed to occupy a significant portion of the thickener or manually cleaned basin, or if a hydraulic upset occurred, a situation could develop where large concentrations of manganese could be recycled or released from the manually cleaned sedimentation basin.

It was generally found that if the solids were removed from the waste streams prior to recycle, total trihalomethane formation potential (TTHMFP) in the recycle streams was no higher than in the raw waters. The same was found for total organic carbon (TOC). However, without solids removal TTHMFP and TOC levels can be quite high in the waste streams. The recycle streams can contain preformed trihalomethane (THM), and therefore the THM concentration leaving the plant with recycle was sometimes found to be higher than that without recycle. This increase could impact a utility's distribution system THM average.

Assimilable organic carbon (AOC) was also high in the waste streams analyzed. It was found that recycle can increase the filtered water AOC. At the one plant where detailed evaluations were conducted, filtered water AOC levels were 5 to 6 times higher during recycle.

Overall, it was found that waste streams can contain high levels of the contaminants monitored and that it would be possible for the recycle to cause water quality problems. *However, none of the plants evaluated experienced finished water quality problems due to the recycle.* The use of equalized, continuous recycle, proper waste stream treatment prior to recycle, and characterization of waste stream quality through proper monitoring should be used in conjunction with recycle operations. If these recommendations are used, recycle can be an appropriate part of water treatment operations.

Chapter 1

Overview of Findings

The principal objective of this report was to evaluate the impact of recycling those waste streams that are produced by the water treatment process to the head of the plant. Recycle streams that were analyzed included spent filter backwash water (with and without solids removal), sludge thickener supernatant, lagoon overflow, belt press filtrate, and sand drying bed filtrate. The research also evaluated the effects of storing sludge in sedimentation basins. The main contaminants that were analyzed were categorized as follows:

Giardia and *Cryptosporidium* cysts
Manganese
Total trihalomethane (TTHM) and TTHM precursors
Assimilable organic carbon
Other

Field-scale evaluations were conducted at eight water plants, with the full-scale data supplemented by laboratory study. Key findings, grouped by contaminant, are discussed in this chapter.

Giardia and *Cryptosporidium* Recycle

Cyst concentrations were evaluated at two water plants, the Bangor Water Treatment Plant and the Moshannon Valley Water Treatment Plant. The Bangor plant is a direct filtration plant that recycles settled spent filter backwash water. At the Moshannon Valley plant, spent filter backwash water and clarifier sludge are combined and settled. The supernatant from the waste settling tank is recycled. In this research, the investigation evaluated the level of cysts in the waste streams and in the recycle water to help determine if recycle streams could cause an increase in parasite levels in the production stream. In addition to the collection of *Giardia* and *Cryptosporidium* cyst data, analysis of the streams for particle counts was carried out. Figures 1.1 and 1.2 show the data on cysts and particle counts collected at the Bangor and Moshannon Valley plants. In most of the data presented, results are shown for round 1 and round 2, two different sampling events.

The spent filter backwash water from both plants had high cyst concentrations compared with those in the raw water. Spent filter backwash water at Moshannon Valley had *Giardia* and *Cryptosporidium* levels of more than 150 cysts/L. Bangor had levels of 8 to 14 cysts/L in the spent filter backwash water. Raw water cyst concentrations for the two plants were in the range of 0.05 to 3 cysts/L. Recycle

streams at both plants, even after sedimentation, contained cyst levels higher than those of the raw water, and in general the recycle stream caused an increase in the cyst concentration in the treatment process feed water.

Particle count data were also collected on the recycle stream, raw water, and a mixture of the two, with key results shown in Figures 1.1 and 1.2. For Moshannon Valley, *Giardia*-size particles (5 to 15 μm) increased in the mixed water from about 500 counts/mL without recycle to between 1,300 and 1,500 counts/mL with recycle. *Cryptosporidium*-size particles (2 to 4 μm) increased from between 1,400 and 2,000 counts/mL to between 6,000 and 7,000 counts/mL. Both increased by about a factor of 3. At the Bangor plant, *Giardia*-size particles increased from about 450 to 1,800 counts/mL with recycle, and *Cryptosporidium*-size particles increased from 1,600 to 7,900 counts/mL.

Although both plants studied showed an increase in particles in the raw water during recycle, filtered water was not impacted. In fact, particle counts were slightly lower in the filtered water during recycle. Figure 1.3 summarizes the filter log removal efficiencies for *Giardia*-size particles at these plants. These results reflect the increased removal efficiency of the filters during recycle.

The Surface Water Treatment Rule (SWTR) requires a minimum 3-log removal-inactivation of *Giardia* cysts and 4-log removal-inactivation of enteric viruses; the *Guidance Manual* for the SWTR (USEPA 1989) suggests that greater removal-inactivation may be appropriate, depending on raw water quality. The following summarizes the manual's recommendations for overall treatment that should be provided based on an estimate of the *Giardia* cyst concentration in the source water.

	Geometric mean of allowable daily average cyst concentration (cysts/100 mL)		
Cyst	<1	>1 to 10	>10 to 100
Giardia cyst removal-inactivation	3 log	4 log	5 log
Virus removal-inactivation	4 log	5 log	6 log

The fact that the level of cyst removal-inactivation recommended for water treatment plants is based on the concentration of cysts in the raw water supply could impact plants utilizing or considering recycling. Studies of the Bangor Water Treatment Plant and Moshannon Valley Water Treatment Plant showed increased particle counts and cysts at the raw water sampling points during the recycling operation; however, at neither plant did the concentrations increase to more than 1 cyst/100 mL (10/L). Thus a higher level of cyst removal-inactivation was required. It may be possible, however, for such a situation to exist at some plants given the trends found in this research. For example, if a raw water source contains 1 to 10 cysts/100 mL, the guidelines recommend a 4-log removal efficiency for *Giardia* inactivation, but a 5-log removal is suggested if the raw water contains more than 10 cysts/100 mL. Recycling spent filter backwash could increase the cyst concentration in the process water during recycle. The guidelines do not address such an intermittent increase in cyst concentration, and so it would be left to the regulatory agency to determine if the cyst concentration during recycle should be used to determine the level of treatment needed to assure cyst removal-inactivation.

Both of the plants studied used sedimentation of the waste streams prior to recycle. Both had relatively large settling tanks, and the solids removal efficiency was very good. At Moshannon Valley, recycle only increased the raw water turbidity from 0.6 to 0.8 ntu. At Bangor the increase was from about 0.3 to 1.3 ntu. These low turbidity increases are indicative of the efficient settling of the spent backwash water prior to recycle. Laboratory settling studies were conducted at both plants to assess the importance of sedimentation of the waste streams prior to recycle in reducing cyst-size particles. An example of typical findings is shown for Bangor in Figure 1.4. This figure shows particle removal in the *Giardia* size range for different clarifier loading rates and at different polymer doses.

During round 2 sampling at the Bangor Water Treatment Plant, the backwash settling tank was tested for particle counts immediately after filter backwash and after 2 hours of settling. These data showed a reduction of *Giardia*-size particles due to sedimentation of 85.2 percent. The backwash holding tank utilized by the Bangor facility has a capacity of 155,770 gal (590 m^3) and a surface area of 1,225 ft^2 (114 m^3). During round 2 sampling at the plant, the recycle flow rate was approximately 83.3 gpm (22.5 m^3/h), which resulted in an overflow rate of 0.07 gpm/ft^2 (0.17 m/h) for the backwash water holding tank. This overflow rate is quite low for a thickener; hence the high efficiency of particle removal. Laboratory settling curves were developed in this research to assess particle removal efficiency for different clarifier overflow rates. Figure 1.4 shows the results from one such study that used spent filter backwash water from Bangor. Utilizing the laboratory work in Figure 1.4, it can be seen that the particle removal rate of approximately 85 percent determined in the field is similar to the value found for the sample without polymer addition in the laboratory at an overflow rate of 0.07 gpm/ft^2 (0.17 m/h).

An evaluation of actual *Cryptosporidium* removal with sedimentation of spent filter backwash water was also conducted at Bangor. Spent backwash water contained 8.47 *Cryptosporidium* cysts/L. After the backwash water was allowed to settle quiescently for 2 hours, the supernatant was resampled. The *Cryptosporidium* cyst level had only dropped to 6.26/L. Laboratory study using particle count analysis and 2-L Gator jars predicted less than 10 percent removal of *Cryptosporidium* cysts, again in the range of that found in full-scale studies. The laboratory study therefore gave an acceptable prediction of full-scale performance, and it was concluded that high overflow rates could result in low sedimentation efficiency and therefore higher cyst concentrations in the recycle stream. In fact, only very low overflow rates were successful in reducing cyst-size particles in the waste streams. Figure 1.4 also shows that nonionic polymer addition was very useful in reducing the *Giardia*-size particles, as was found with all tests conducted. The same polymer was also useful in reducing *Cryptosporidium*-size particles.

A mass balance was computed using the flow diagram of Figure 1.5 to determine the increase in cyst concentration loaded onto the filters for different recycle ratios and for different degrees of settling efficiency of the spent filter backwash water. In order to calculate the loading to the filters, two assumptions were made. First, it was assumed that the filters removed all the cysts and that therefore all the cysts applied to the filters ended up in the spent filter backwash water. Second, it was assumed that no removal took place in the coagulation-sedimentation tank. This latter assumption is equivalent to an assumption that removal does take place during coagulation and that sludge from the sedimentation tank is also recycled. However, if coagulation removes cysts and the sludge is wasted rather than recycled, this mass balance does not apply.

Using these assumptions, two scenarios were analyzed. The first was a steady-state situation wherein the spent filter backwash water flow (Q_{BW}) equalized over a 24-hour period was equal to the recycle flow (Q_R). This would be a continuous recycling situation. The second situation involved intermittent recycle (with spent filter backwash water treated and stored for periodic recycle). The following symbols were used:

Q = raw water flow
C_i = cyst concentration in raw water
Q_R = recycle flow
C_R = cyst concentration in recycle
C_A = cyst concentration in filter applied water
Q_{BW} = spent filter backwash flow, equalized
C_{BW} = cyst concentration in spent filter backwash water
K = fraction of cysts remaining after treatment of spent filter backwash water

For continuous recycle, the following would apply:

$$Q_R = Q_{BW} \tag{1.1}$$

$$C_{BW} = C_A \frac{Q + Q_R}{Q_{BW}} \tag{1.2}$$

$$C_R = KC_{BW} \tag{1.3}$$

The mass balance equation was formulated as

$$QC_i + Q_RC_R = (Q + Q_R)\, C_A \tag{1.4}$$

which resulted in

$$\frac{C_i}{C_A} = 1 + \frac{Q_R}{Q} - \frac{KQ_R}{Q}\left(\frac{Q + Q_R}{Q_R}\right) \tag{1.5}$$

This could be considered a simple expression:

$$C_A = f_1C_i \tag{1.6}$$

where f_1 represents the factor increase in cyst concentration in the applied water due to recycle. If there was no recycle, $f_1 = 1$ and $C_A = C_i$.

The intermittent recycle scenario considered a plant that recycled off and on throughout the day. In this case it was assumed that the operation had been steady, so that the cyst concentration in the recycle stream had equalized (equations (1.2) and (1.3) apply) and so that the only variables were the recycle flow rate and removal efficiency. In this case, equation (1.4) was used, rearranged as

$$C_A = \frac{QC_i + Q_RC_R}{Q + Q_R} \tag{1.7}$$

and C_R was found from equations (1.2) and (1.3). The results could be expressed as

$$C_A = f_2 C_i \tag{1.8}$$

where f_2 is defined as before.

An example use of the continuous recycle situation is illustrated for a 3 percent backwash water use ($Q_R = Q_{BW} = 0.03Q$) and a spent filter backwash water clarifier that is 90 percent efficient (K = 0.1) in removing cysts. By equation 1.5,

$$\frac{C_i}{C_A} = 1 + \frac{0.03Q}{Q} - 0.1\left(\frac{0.03Q}{Q}\right)\left(\frac{Q + 0.03Q}{0.03Q}\right)$$

$$\frac{C_i}{C_A} = 1 + 0.03 - 0.1 = 0.93$$

$$C_A = 1.08\ C_i$$

or the applied cyst concentration was only 1.08 times greater with recycle than in the source water. However, if the removal efficiency dropped to 30 percent (K=0.7), then

$$\frac{C_i}{C_A} = 1 + 0.03 - 0.72 = 0.31$$

In this case, the applied cyst concentration was 3.2 times higher with recycle than without.

Figure 1.6 graphically shows various treatment efficiencies. This figure shows that the percent increase in cyst loading to the filters is very dependent on settling efficiency but nearly independent of recycle ratio. Note that backwash water usage is generally in the range of 3 to 5 percent of plant flow.

For the intermittent recycle condition, consider $Q_{BW} = 0.03Q$, as in the above example, but now the spent filter backwash water is held and fed back into the plant at 20 percent of the raw flow ($Q_R = 0.2Q$). The value for C_R is found from equations 1.2, 1.3, and 1.6. For 90 percent treatment efficiency (K = 0.1),

$$C_{BW} = KC_A \frac{Q + Q_{BW}}{Q_{BW}}$$

and it was already found that C_A at steady state equals 1.08 C_i,

$$C_R = 0.1(1.08C_i) \frac{Q + 0.03Q}{0.03Q}$$

$$C_R = 3.71C_i$$

From equation 1.7,

$$C_A = \frac{QC_i + 0.2Q(3.71C_i)}{Q + 0.2Q}$$

$$C_A = 1.45\ C_i$$

or the slug loading to the filters with 20 percent recycle is about 1.5 times the level without recycle and compares to 1.08 times with continuous recycle. At 30 percent treatment efficiency,

$$C_R = 0.7(3.2C_i)\ \frac{Q + 0.03Q}{0.03Q}$$

$$C_R = 76.91C_i$$

and

$$C_A = \frac{QC_i + 0.2\,Q(76.91C_i)}{Q + 0.2Q}$$

$$C_A = 13.7C_i$$

Figure 1.7 shows the significant effect that treatment of the recycle stream had on intermittent recycle operations. As treatment of the spent filter backwash water was reduced, tremendous cyst loading to the filters could result.

This research showed that waste streams can have significant concentrations of *Giardia* and *Cryptosporidium* cysts. Particle counts in the size range of these cysts were also elevated in the waste streams. Without any removal of these particles from the waste stream prior to recycle, the increased loading to the plant could be very high. Plain sedimentation of the spent filter backwash water, particularly in the range of typical overflow rate design, may be very inefficient in removing the cysts. A plant removing only 20 percent of the particles prior to recycle and operating with an intermittent 20 percent recycle ratio could load the plant at more than 15 times the cyst concentration present in the original source water. The important factors in reducing the loading are first to equalize the recycle rate so that recycle is continuous rather than intermittent, and second to properly treat the waste streams for cyst removal prior to recycle. With continuous recycle and 80 percent treatment efficiency, the increased loading to the plant would only be about 1.2 times the source loading, which would probably be acceptable for most plants.

Manganese Recycle

The potential of manganese recycle was evaluated at a number of facilities, and several types of waste streams were evaluated. Evaluations were also conducted at two plants to determine if manganese was released from sludge stored in manually cleaned sedimentation basins. Some of the possible effects of sludge storage in sedimentation basins have previously been reported by Hoehn et al. (1987). They reported significant releases of manganese, iron, and total organic carbon from sludges held in manually cleaned sedimentation basins. They concluded that sludge stored in lagoons can also be expected to degrade the overlying water, thus complicating the discharge or recycle of this supernatant.

Data from the Mianus Water Treatment Plant and the New Castle Water Treatment Plant, two of the plants that were sampled for manganese, are used to illustrate manganese levels obtained in various waters. Figures 1.8 and 1.9 show the waste stream–handling schematics for these plants and the total and dissolved

manganese concentrations of each waste stream analyzed. Both plants have methods for settling the waste streams before recycle. Both treatment plants had raw water manganese concentrations in the 0.2- to- 0.3-mg/L range at the time of sampling. The figures show that the sludge from the clarifiers at both plants had very high concentrations of total manganese; New Castle had levels of 65 to 75 mg/L and Mianus reached 180 mg/L. Dissolved manganese levels in these streams were also quite high when compared to the raw water levels. Dissolved manganese was in the range of 1 to 7 mg/L in the sludge waste stream. In the recycle stream itself, soluble manganese was of most concern because presumably this manganese was in the +2 valence state and required proper oxidation and sedimentation for removal. For the two samples at New Castle, the recycle streams contained soluble manganese levels of 0.2 and 3 mg/L, and at Mianus the levels were 0.07 to 0.3 mg/L.

The levels that were found indicated the large amount of manganese present in the solids of the waste stream and the potential for this manganese to be released to the water surrounding the sludge solids. Anaerobic conditions should theoretically promote the release of manganese from the solids into the dissolved, liquid state, and therefore storage time would be a variable in promoting the dissolution of manganese from the solids in the sludge.

In order to assess the impacts of storage in manganese release, several sludges were collected and stored in the laboratory, and dissolved manganese values were recorded over time. Figure 1.10 shows the results for four different sludges stored for approximately 3 months. All sludges showed the same trend of releasing substantial amounts of manganese. The release began almost immediately and for most of the sludges increased throughout the storage period. Clearly, manganese will continue to be released from sludge that is stored on a thickener. As the sludge ages, the concentration of manganese in the supernatant water increases.

If manganese could be released from sludge stored in a thickener, it could also be released from sludge stored in a manually cleaned sedimentation basin. Sludge was stored in manually cleaned sedimentation basins at two plants, and manganese levels into and out of the basin were monitored. Results from the Appomattox River Water Treatment Plant are shown in Figure 1.11. The data showed that the dissolved manganese concentration leaving the sedimentation basin containing accumulated sludge was continually rising and was consistently higher than the manganese concentrations leaving the continuously cleaned basin. In fact, the dissolved manganese level in the settled water leaving the manually cleaned basin was higher than the level in water entering the basin, indicating a release from the stored sludge into the basin effluent. Dissolved oxygen (DO) profiles for the manually cleaned basin are given in Figure 1.12, showing that anaerobic conditions existed within the sludge blanket.

From these data it was concluded that sludge contained in sludge thickeners or stored in sedimentation basins from manganese removal plants is characterized by low DO conditions and high concentrations of dissolved manganese in the water surrounding the sludge solids. The manganese concentration within the "sludge water" will increase with storage time as more manganese is released from the solids. Some manganese will therefore be released to the thickener overflow and recycled to the head of the plant or will be released in the sedimentation basin and increase the applied filter manganese concentrations. Normally the manganese concentrations are low and controllable if properly monitored and treated, as was the case at the plants investigated in this research. However, if the sludge accumulation were allowed to occupy a significant portion of the thickener or basin, or if a hydraulic upset were to occur, a situation could develop where the large concentrations of manganese present

in the sludge water could be flushed into the recycle stream or the sedimentation basin effluent. Plants should carefully monitor sludge blanket levels (which can be done with a DO profile) and manganese concentrations, and basins should be cleaned as often as possible. Careful consideration should be given to the use of manually cleaned sedimentation basins.

Total Trihalomethane and Total Trihalomethane Formation Potential Recycle

Total trihalomethane (TTHM) concentrations and precursors for trihalomethanes (as measured by TTHM formation potential [TTHMFP]) were evaluated at several facilities and on a number of different types of waste streams. Figures 1.13 and 1.14 show the range of TTHMFP values found at various points in the Mianus and New Castle water plants. At the Mianus plant, raw water TTHMFP ranged from 150 to 195 µg/L, and filtered values were between 120 and 150 µg/L without recycle and betweem 120 and 190 mg/L with recycle. The pressate, sludge thickener overflow, clarifier sludge, and spent filter backwash water all had TTHM precursor concentrations greater than those of the raw or finished water levels. The thickener overflow had low solids concentrations, and the TTHMFP in that stream was primarily associated with the liquid phase. Because the TTHMFP was higher in these streams than in the raw water, it appears that there was some precursor release from the solids into the thickener overflow. The excess TTHMFP associated with the clarifier flush and the spent filter backwash appeared to be associated with the solids with little release to the liquid phase because settling of these wastes resulted in TTHMFP levels almost the same as those of the raw or filtered water. Recycle of settled waste streams had very little, if any, impact on filtered TTHMFP. The New Castle plant showed very similar results. The waste streams with solids contained high TTHMFP, but settled streams had TTHMFP levels near that of the raw water. However, at New Castle one round of sampling did show elevated levels of TTHMFP in the recycle stream.

The recycle streams contained TTHM, which can form in waste tanks when chlorinated backwash water is used. When the recycled water is mixed with the raw water, the net TTHM concentration in the plant influent will increase by the recycle ratios.

$$TTHM_M = \frac{TTHM_R\, Q_R + TTHM_i Q}{Q_R + Q}$$

where $TTHM_M$ = mixed TTHM concentration with recycle
$TTHM_R$ = TTHM concentration in the recycle stream
$TTHM_i$ = TTHM concentration in the raw water without recycle
Q_R = recycle flow rate
Q = source water flow rate

Given this relationship, the influent water TTHM concentration will increase, and depending upon formation kinetics, the finished water TTHM level may also be higher. Figure 1.15 shows examples found at two of the plants studied. At the Kanawha Valley Water Treatment Plant the influent water TTHM concentration

increased from 14 to 29 µg/L with the introduction of spent backwash water. This approximately 20-µg/L differential was carried through the plant such that the filtered water had a TTHM concentration of 73 µg/L without recycle, compared to 95 µg/L with recycle. Note that there were no additional precursors recycled, so that the TTHMFP was the same with or without recycle. This is graphically illustrated in Figure 1.15. The current TTHM regulations require sampling at different distances in the distribution system. At the Kanawha Valley plant the first sampling points would show higher TTHM levels with recycle, whereas the farther points would be about the same. One could envision situations when the recycle stream could cause an increase in a system's four-point TTHM average and cause a violation of the TTHM regulation.

At the New Castle plant, the influent TTHM increased from 15 to 36 µg/L with recycle, as shown in Figure 1.15. However, at this plant no impact on finished or distribution system TTHM levels was observed.

Assimilable Organic Carbon Recycle

Assimilable organic carbon (AOC) was monitored at the Swimming River Water Treatment Plant and the New Castle Water Treatment Plant. Examples of AOC levels found in the waste streams at the two plants are shown in Figures 1.16 and 1.17. Generally, the waste streams had AOC levels much higher than those of the raw water. The waste streams at Swimming River had AOC levels between 270 and 740, as compared to raw water levels between 75 and 150. Levels in the waste streams were particularly high at the New Castle Water Treatment Plant during the July sampling event shown in Figure 1.17. The raw water AOC was 200, as compared to 3,600 in the sludge, 2,200 in the pressate, and 1,000 in the spent filter backwash water.

Filtered water AOC levels increased as a result of recycle at New Castle, it was found in the January follow-up sampling (see Figure 1.18). The raw water had a total AOC of about 350 during this sampling event. Without recycle, the filtered water AOC was reduced by treatment to about 60. With recycle, the filtered water AOC was almost 400. In a May sampling, the filtered water AOC was 24 without recycle and 107 with recycle.

It appears that waste streams do contain AOC at levels higher than the raw water levels. The recycle of AOC can increase the filtered water AOC, which may promote regrowth problems in the distribution system.

Other Effects of Recycle

Aluminum

The Swimming River, New Castle, and Mianus water treatment plants all use alum as the coagulant. The waste streams, recycle streams, raw waters, and filtered waters were all sampled for total and dissolved aluminum concentrations. Naturally, the sludge and spent backwash water had high concentrations of total aluminum, and on occasion had high levels of dissolved aluminum also. Pressate also had high levels of dissolved aluminum. However, none of the three plants showed an increase in filtered water aluminum (total or dissolved) with recycle. In these plants, the recycled aluminum was effectively precipitated and removed in the treatment process.

Total Organic Carbon

Several plants were sampled for total organic carbon (TOC) in the waste streams and within the treatment process. Many of the waste streams showed elevated TOC levels; however, most of the TOC was associated with the solids and readily settled out. TOC levels in some wastes were higher than 200 mg/L, which could impact disinfectant by-product formation if the solids were not settled out prior to recycle. Filtered water TOC levels were not affected at any of the plants.

Studies that evaluated long-term sludge storage showed a small release of dissolved TOC to overlying water. Therefore there is some potential for TOC release in thickeners, lagoons, or manually cleaned basins that have long storage times.

Turbidity

The recycle of any sludge or backwash water that is not settled will increase influent water turbidity. Some of the plants studied showed that raw water and settled water turbidities increase with recycle. However, none of the plants showed an increase in filtered water turbidity during recycle.

Algae, Taste and Odor, Excess Polymer, Viruses

Algae, taste and odor, excess polymer, and viruses, all of which could be present in waste streams, were not evaluated. During the course of the research, discussions with plant operators revealed concern about the possible recycle of algae and taste-and-odor compounds. Good characterization of any recycle stream is necessary for overall water quality management.

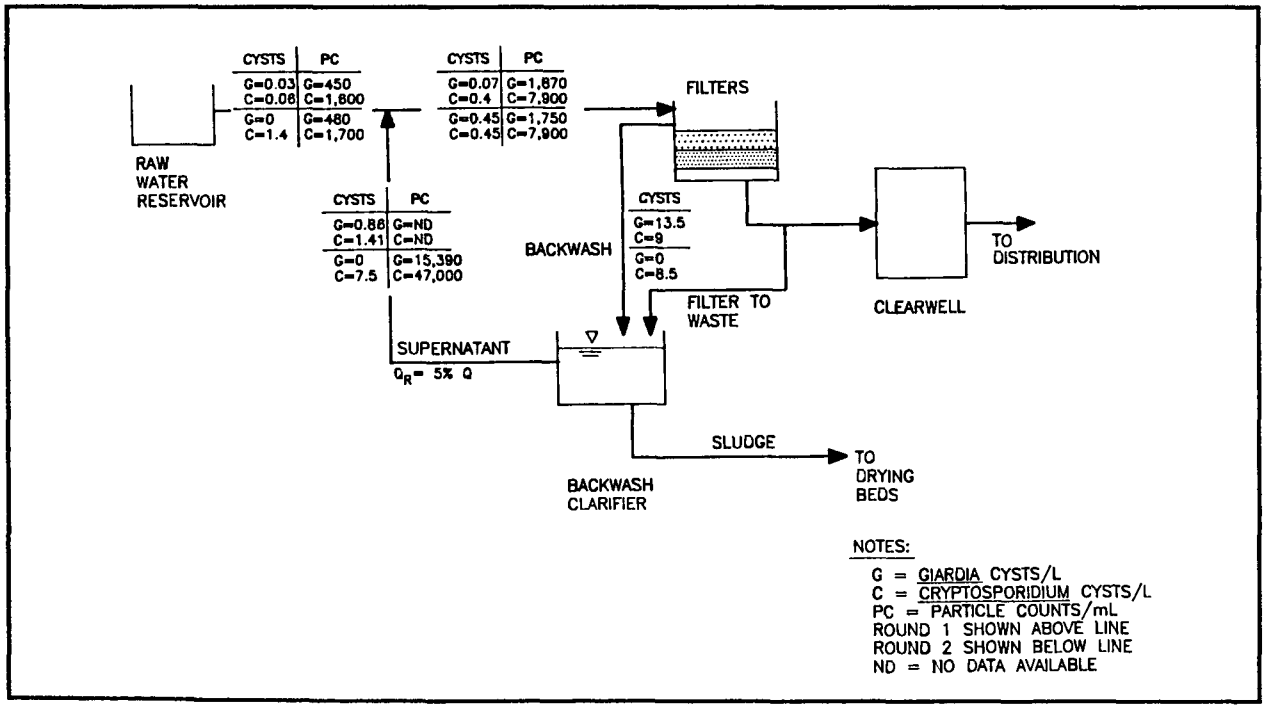


Figure 1.1 Bangor Water Treatment Plant cyst mass balance

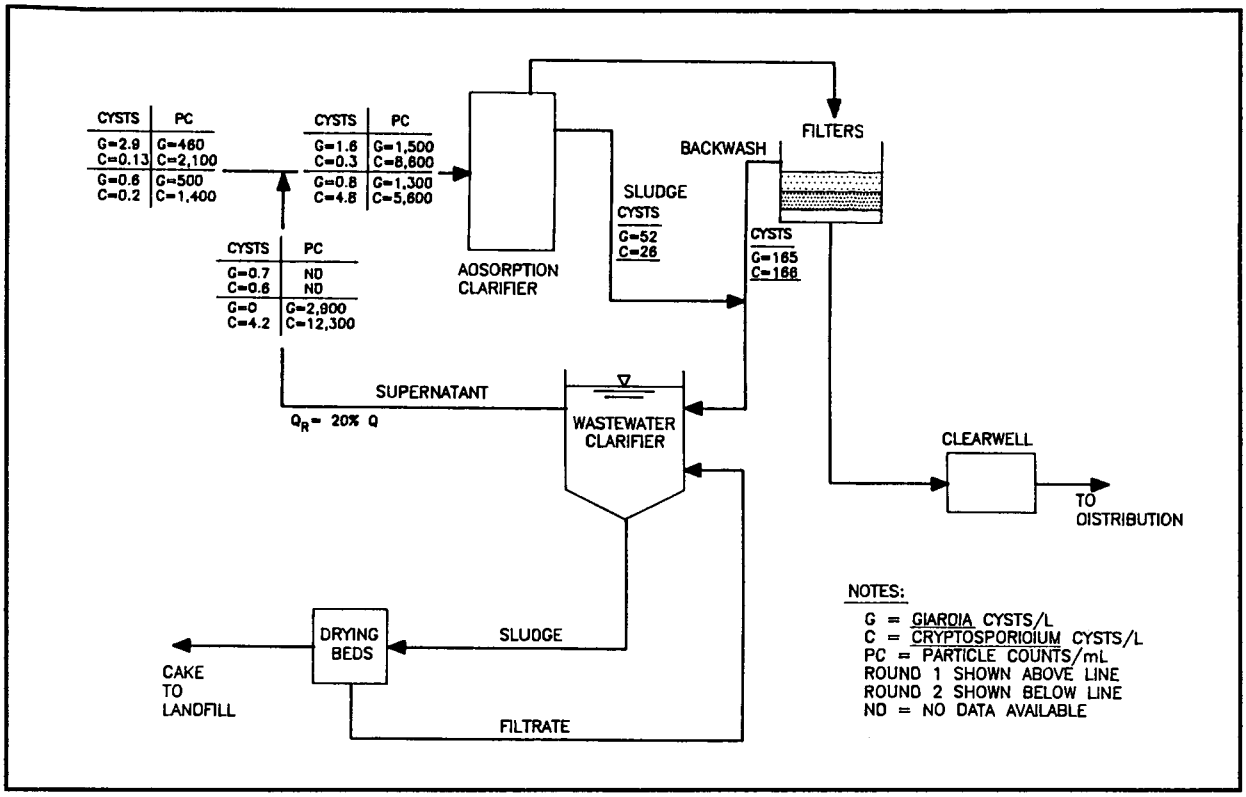


Figure 1.2 Moshannon Valley Treatment Plant cyst mass balance

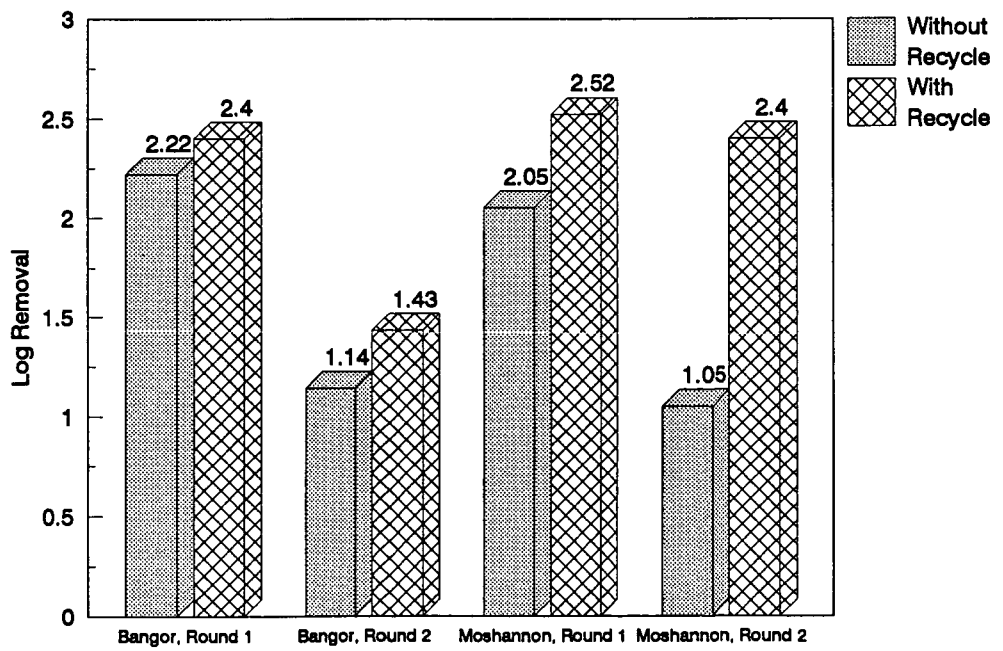


Figure 1.3 Filter removal efficiencies for *Giardia-size* particles (5–15 µm) at Bangor and Moshannon Valley water treatment plants

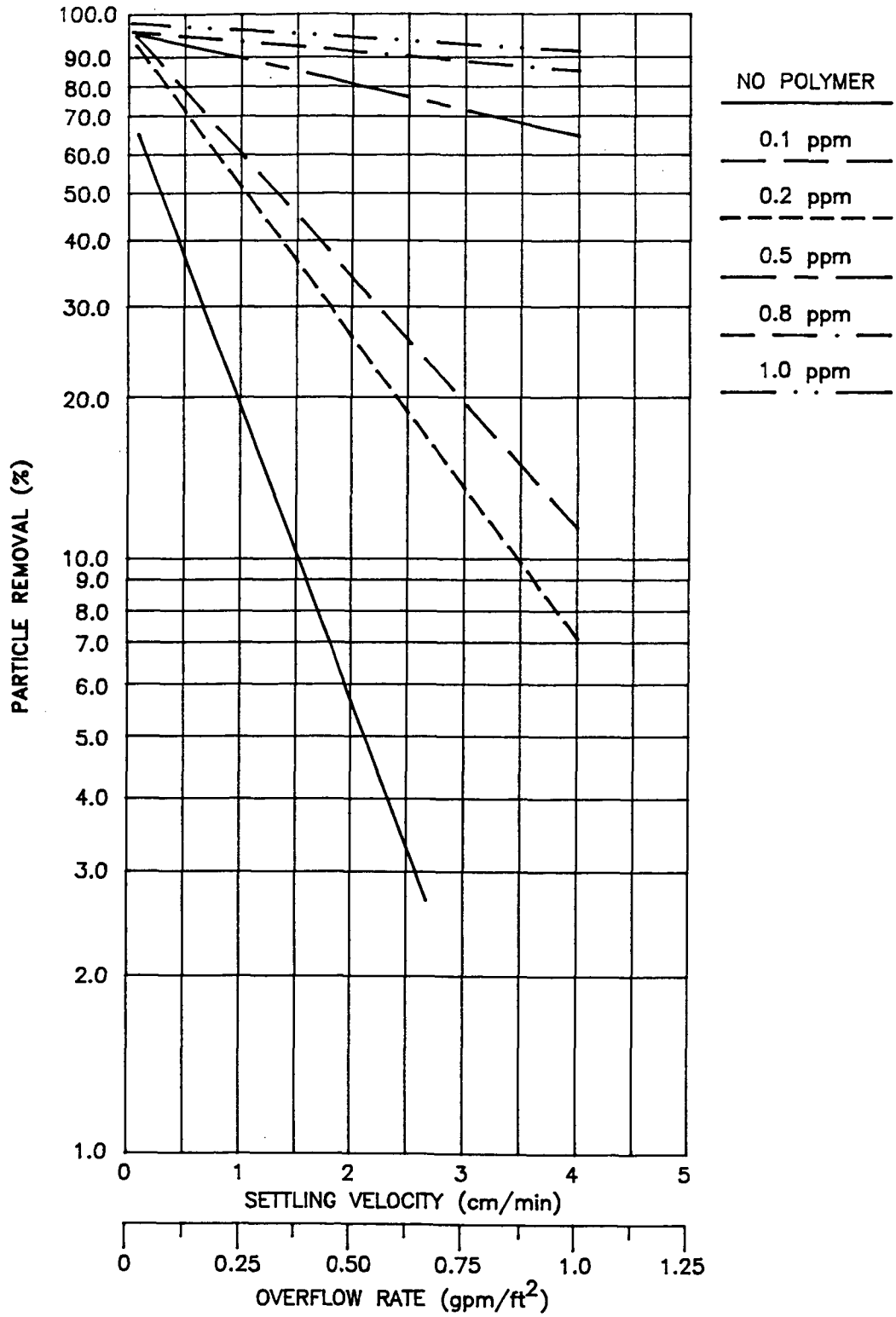


Figure 1.4 Removal of *Giardia-size* particles (5-15 μm) from spent backwash water at Bangor Water Treatment Plant using sedimentation (polymer: POL-E-Z 652)

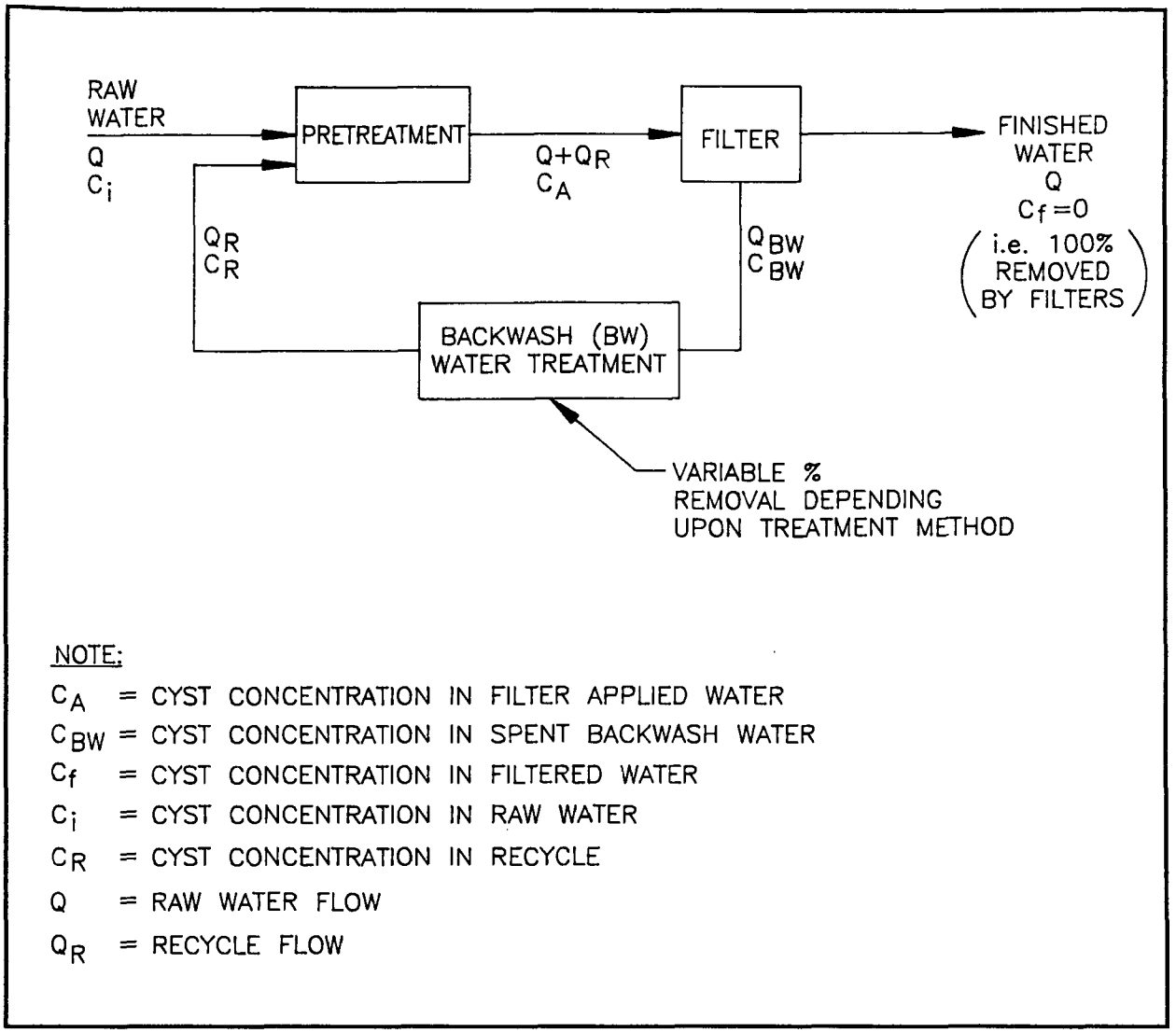


Figure 1.5 Flow diagram used for cyst mass balance calculations

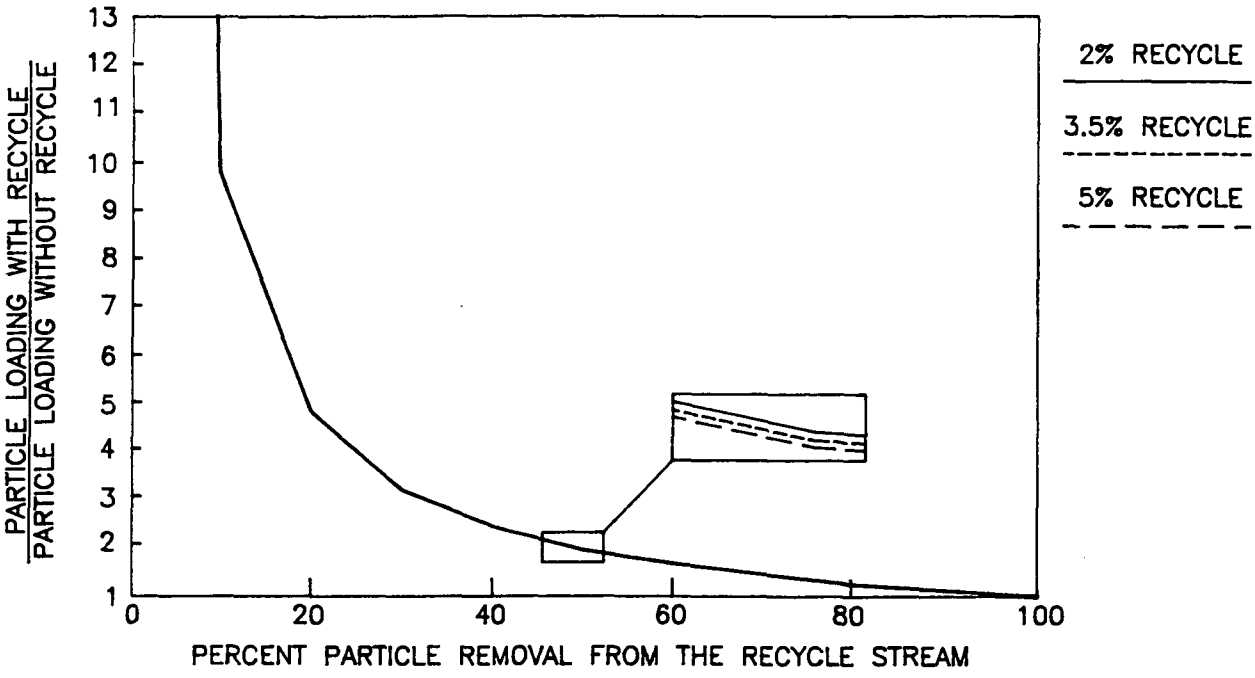
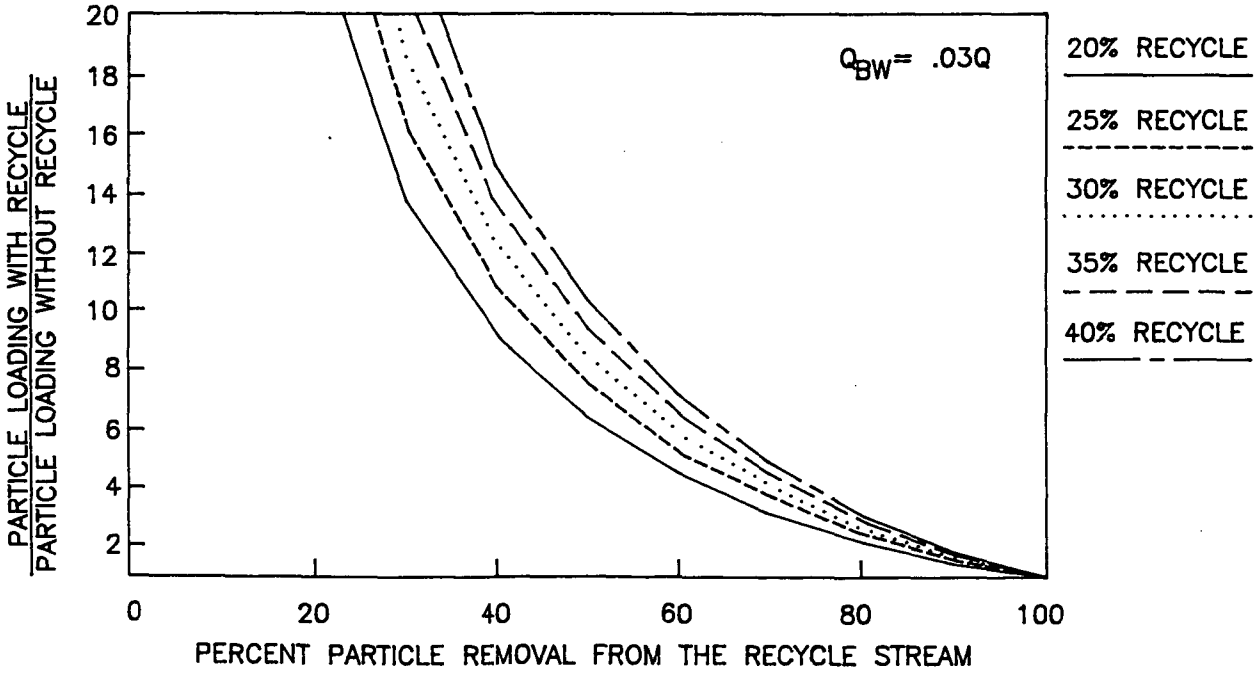
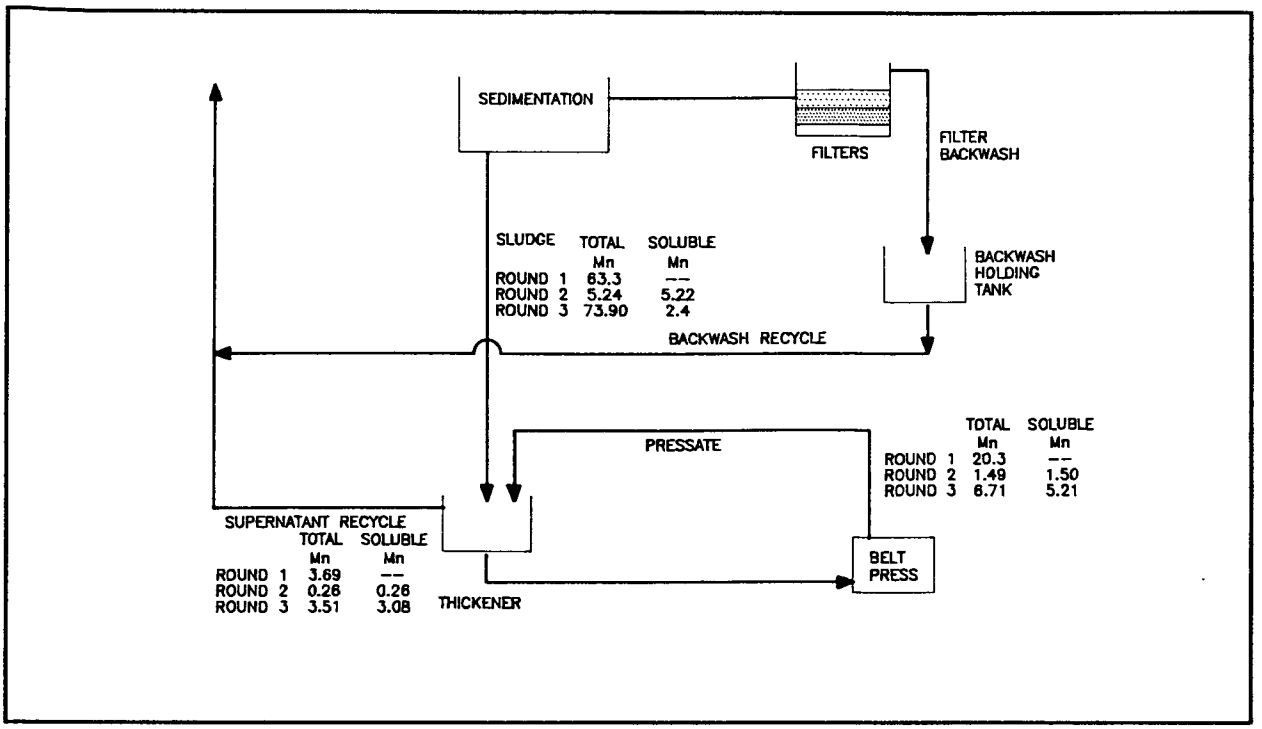


Figure 1.6 Particle loading to the treatment process with continuous recycle



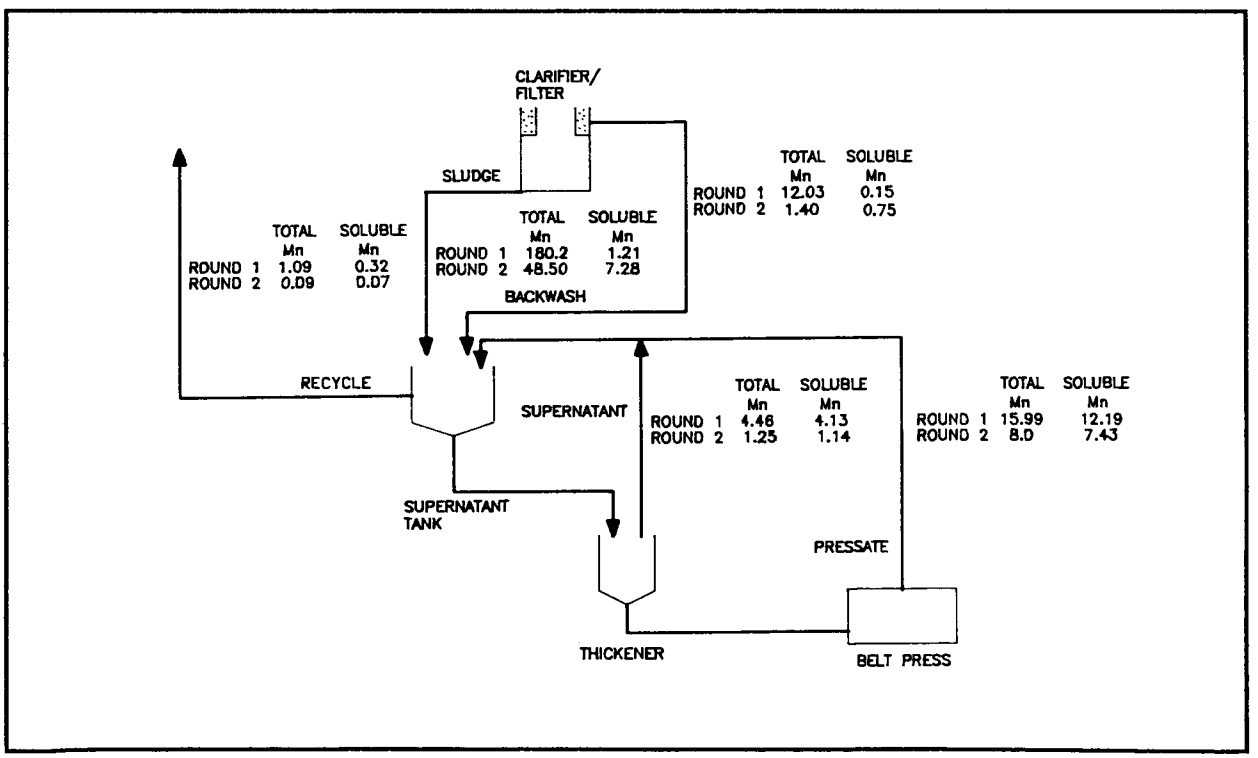
Note: Q_{BX} = spent filter backwash flow, equalized; Q = raw water flow.

Figure 1.7 Particle loading to the treatment process with intermittent recycle



Note: All units are mg/L.

Figure 1.8 Mass diagram of manganese at New Castle Water Treatment Plant



Note: All units are mg/L.

Figure 1.9 Mass diagram of manganese at Mianus Water Treatment Plant

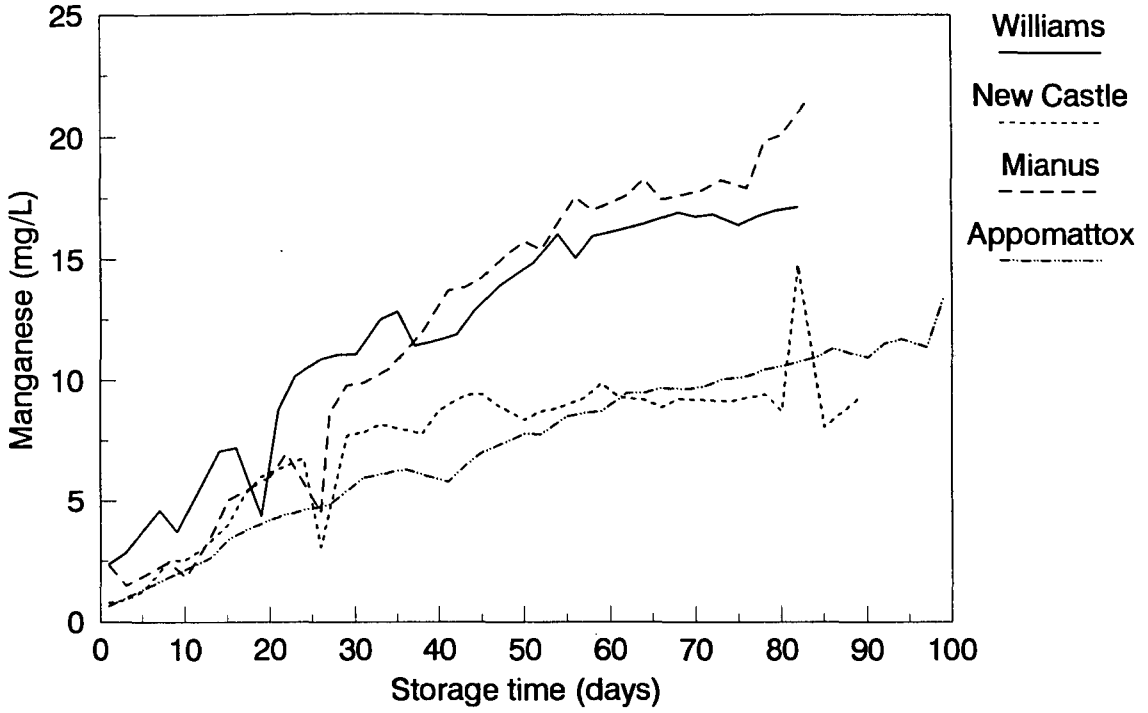
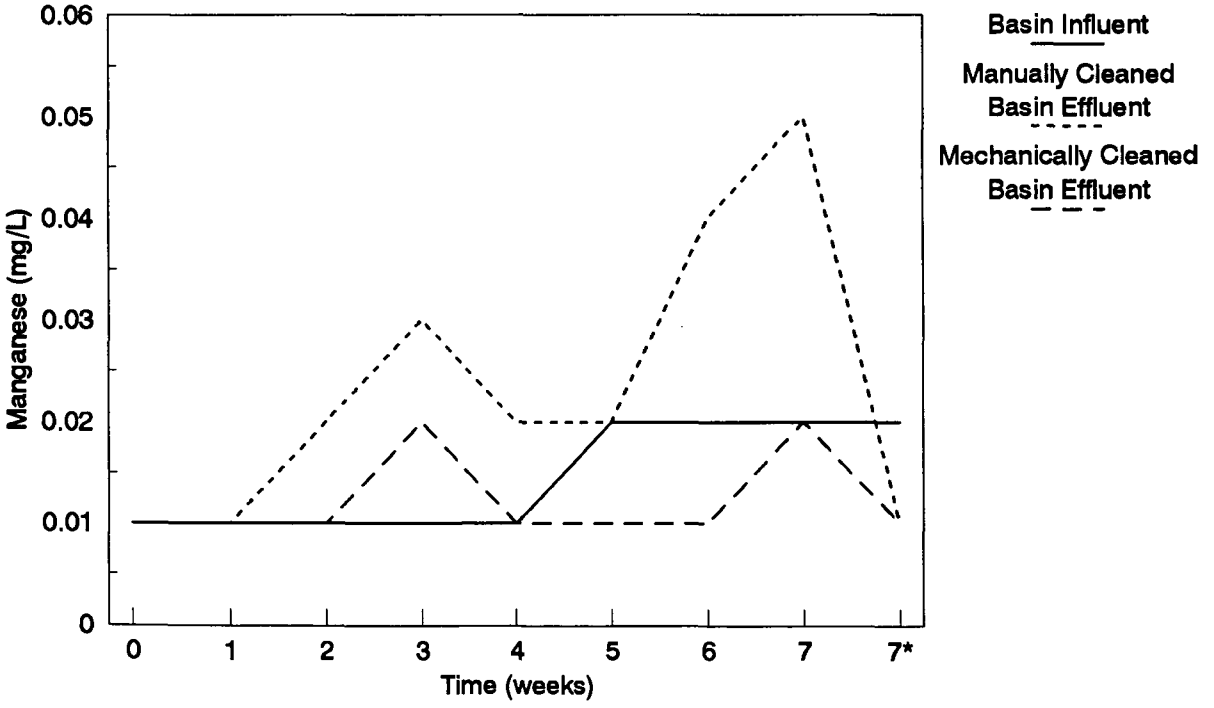


Figure 1.10 Release of manganese during storage from several sludges



*Sample taken just after basin was cleaned.

Figure 1.11 Example of manganese released from Appomattox River Water Treatment Plant

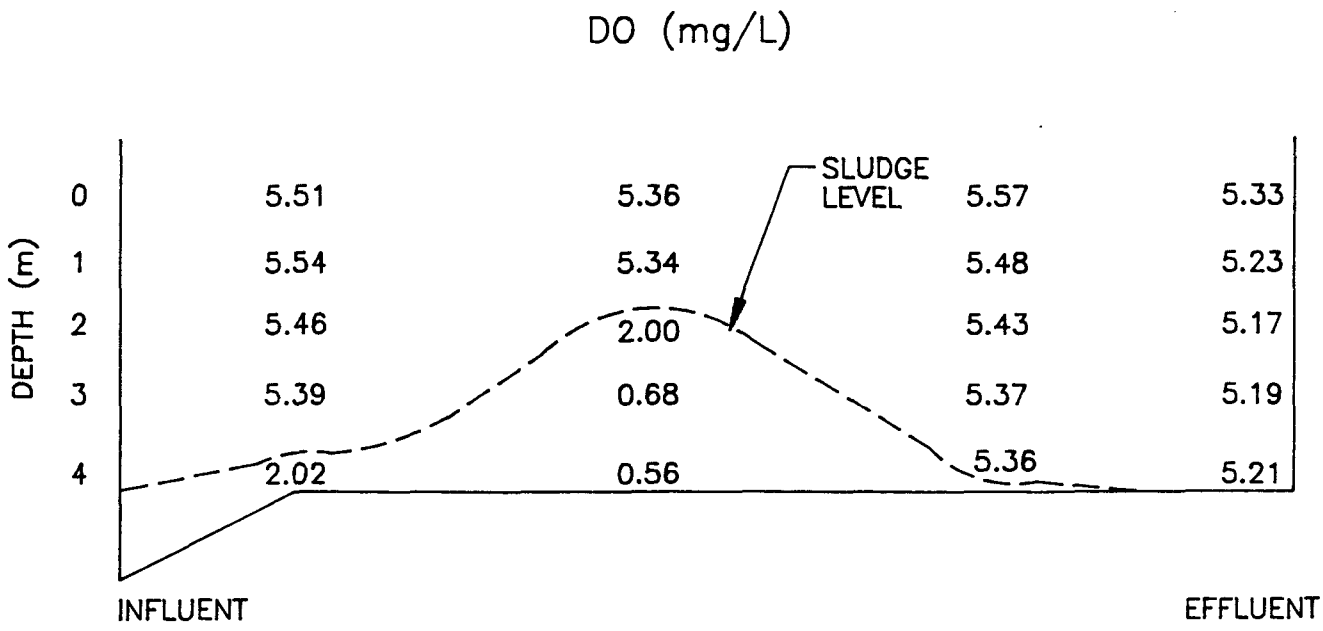


Figure 1.12 Example of dissolved oxygen (DO) concentrations in manually cleaned sedimentation basins (Appomattox River Water Treatment Plant)

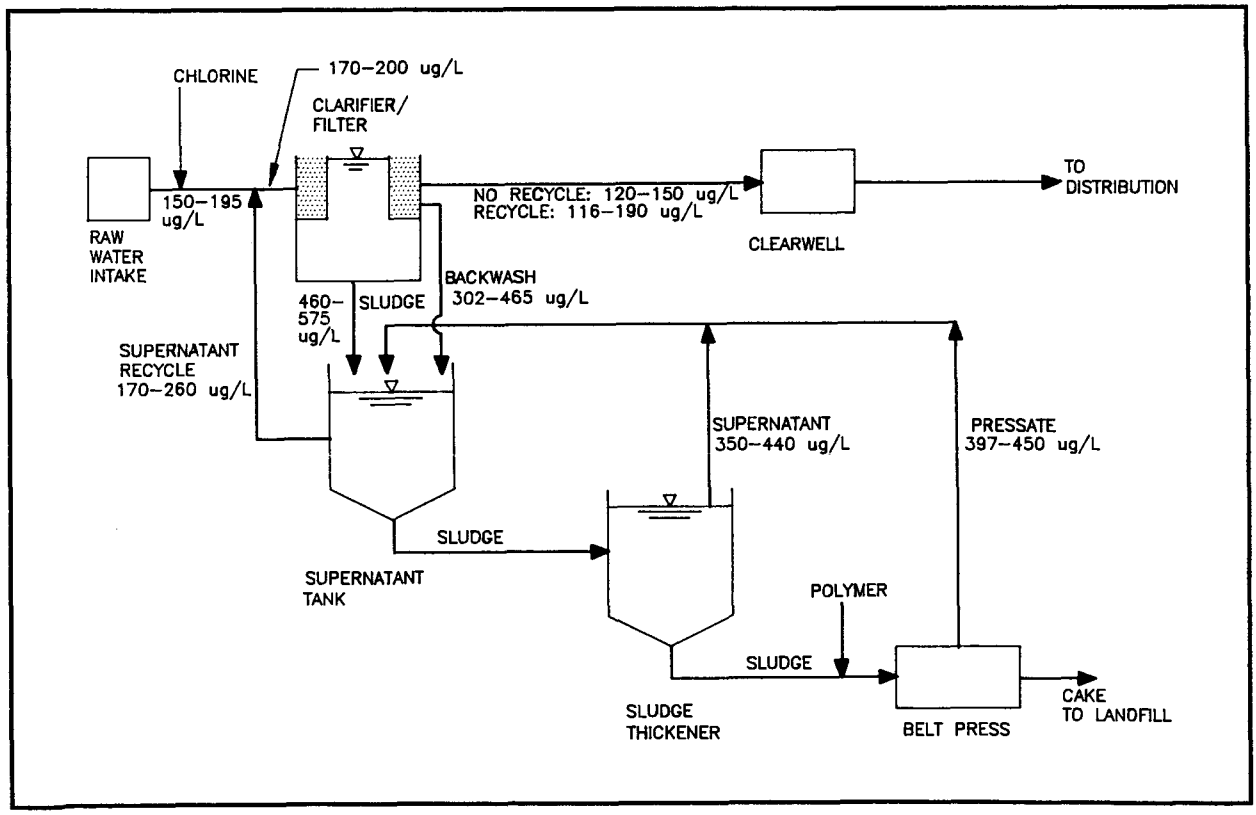


Figure 1.13 TTHMFP mass diagram for Mianus Water Treatment Plant

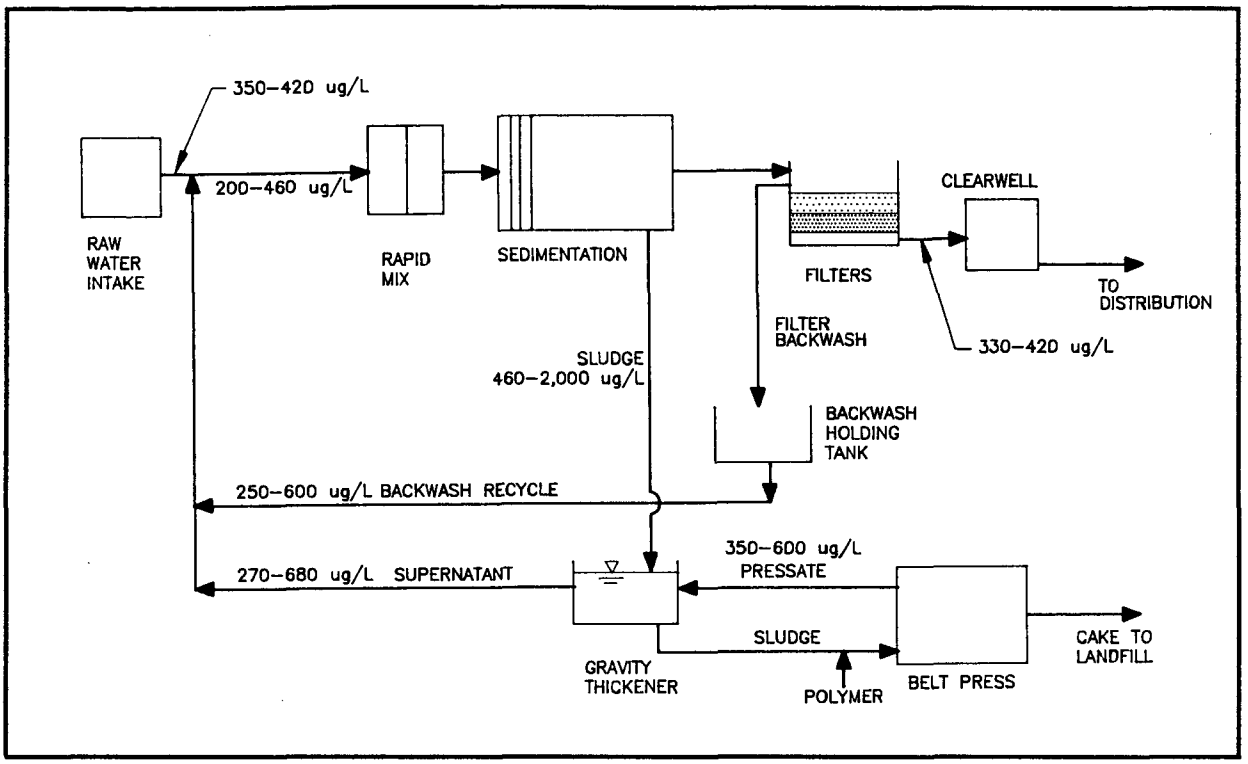


Figure 1.14 TTHMFP mass diagram for New Castle Water Treatment Plant

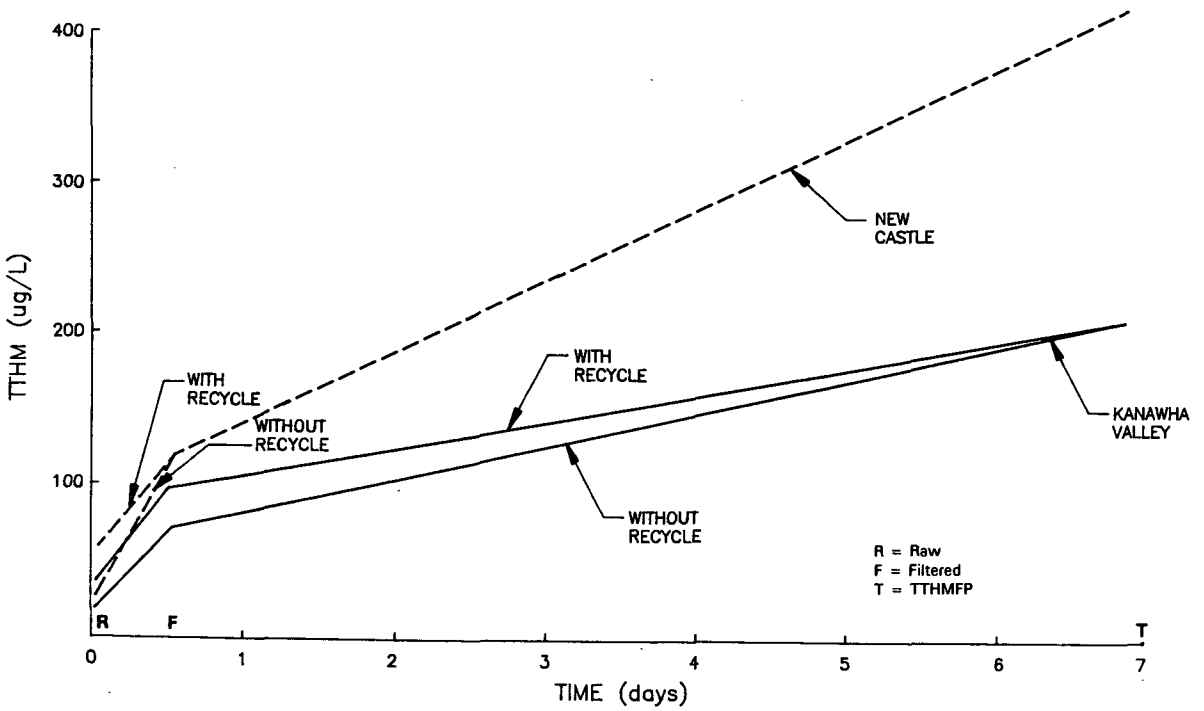


Figure 1.15 TTHM formation kinetics with recycle at Kanawha Valley and New Castle plants

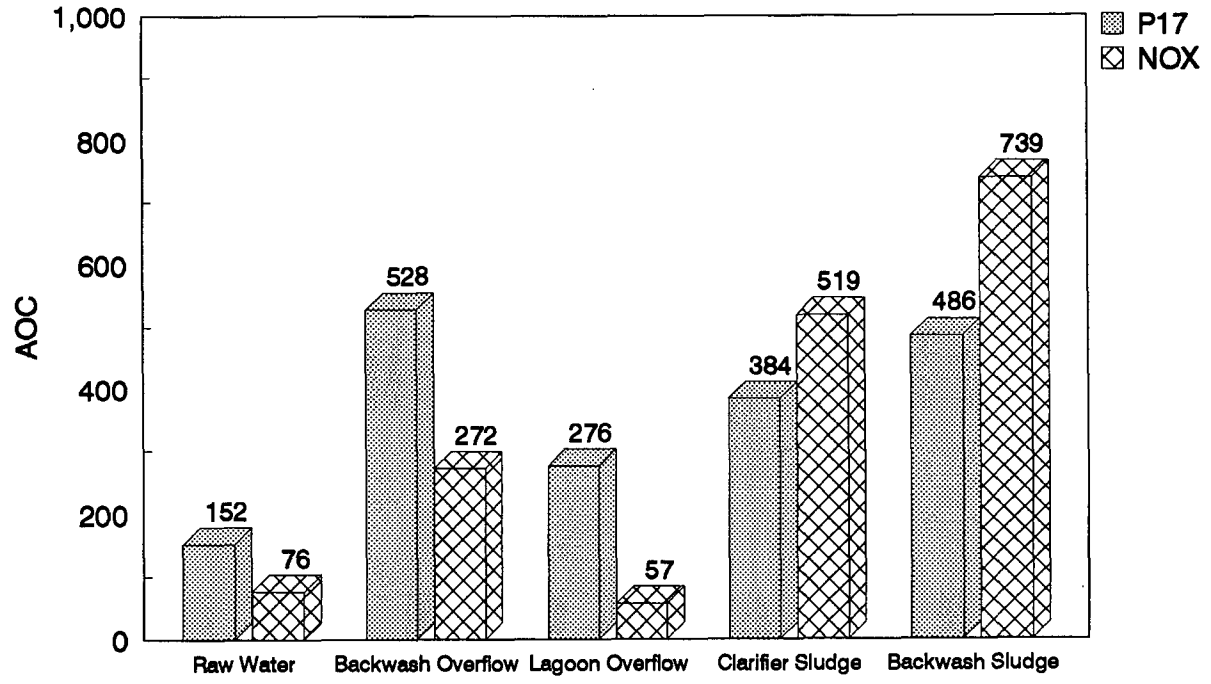


Figure 1.16 Example of Swimming River waste stream AOC concentrations

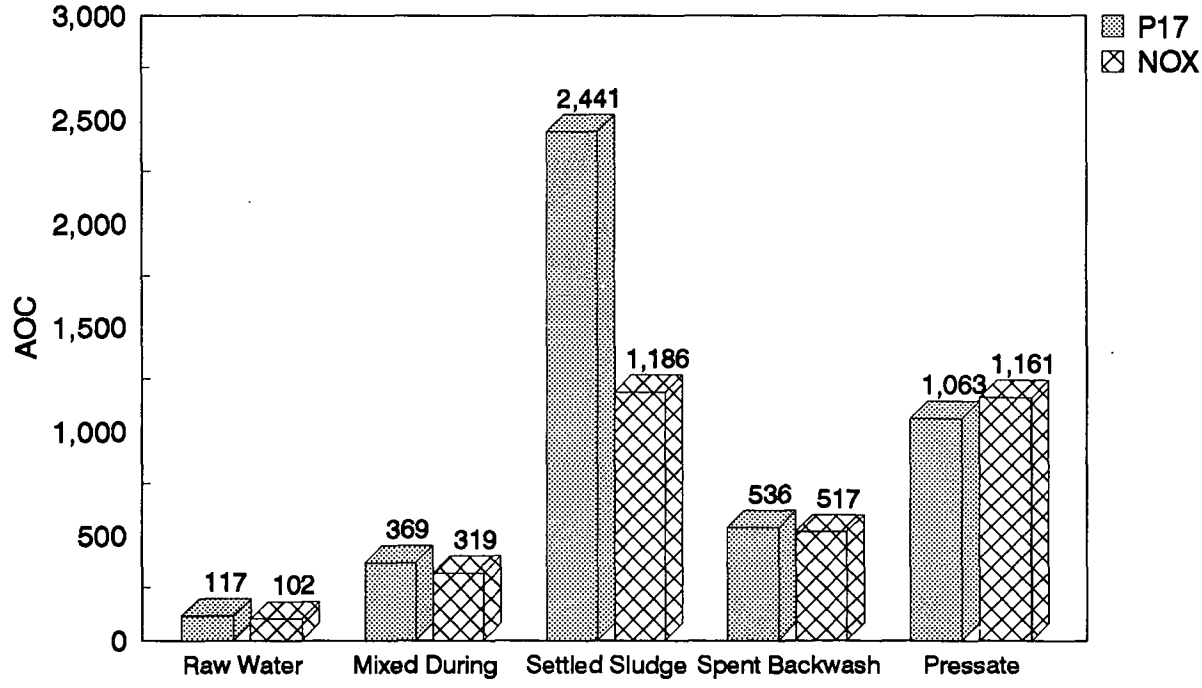


Figure 1.17 Example of New Castle water stream AOC concentrations

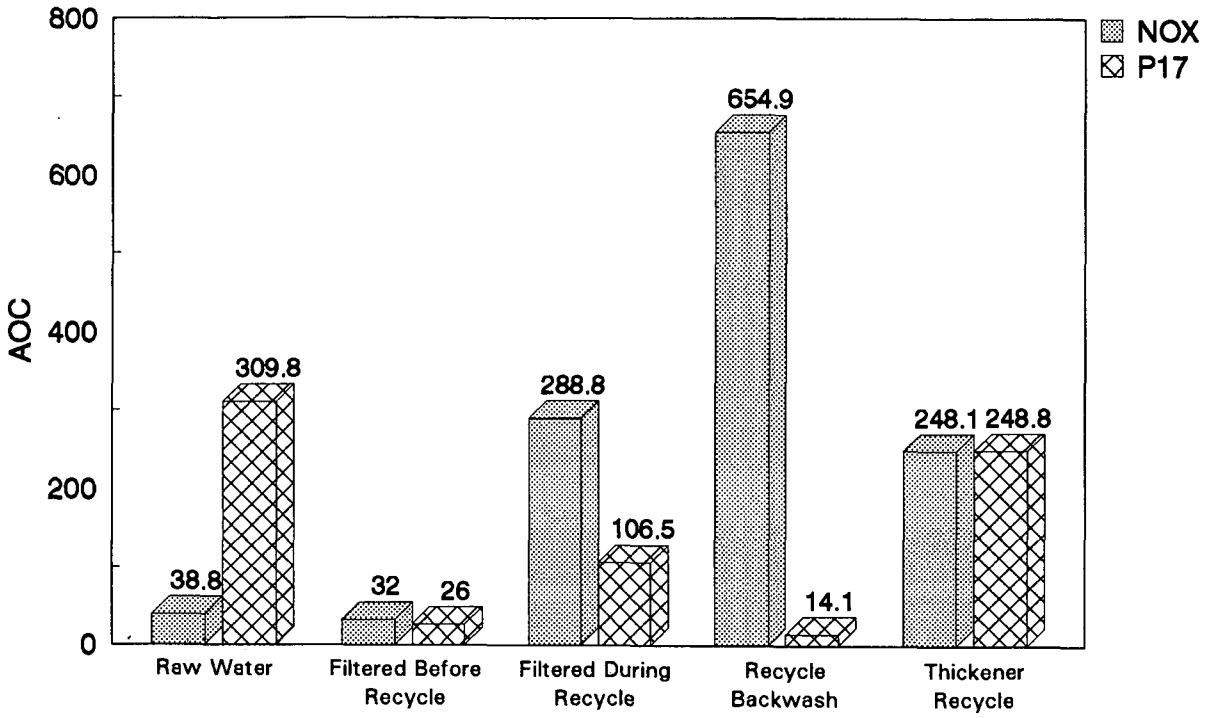


Figure 1.18 Example of New Castle Water Treatment Plant AOC concentrations with and without recycle

Chapter 2

Objectives and Plant Selection

Water treatment plants produce various waste streams during the water production process as well as during subsequent waste-handling procedures. Waste streams can be large, such as spent filter backwash water, which can make up more than 3 percent of plant production, or very small, like small side streams of filtrate from a filter press, which may represent less than 0.1 percent of plant production. For the purposes of the present research the primary waste streams that can be recycled to the water treatment process were classified as follows:

Spent filter backwash water
- with solids from filtration
- without solids from filtration (after settling)

Sludge thickener overflow (supernatant)
Sludge lagoon overflow (supernatant)
Dewatering liquid wastes
- pressate from filter press
- pressate from belt press
- centrate from centrifuge
- leachate from sand drying beds

Spent filter backwash water has been classified separately from the other wastes because it is often handled alone, because it represents a large volume of water, and because it is generally considered the cleanest of the waste streams. The classification of spent filter backwash water has been subdivided into that water containing the solids removed during filtration and that water resulting from a separation step wherein the solids have been removed prior to recycle.

Thickener overflow results from the thickening of sedimentation sludge or the thickening of sedimentation sludge plus spent filter backwash water. In the latter case, the spent filter backwash water is not considered separately because it has been mixed with sedimentation basin sludge. This overflow may also contain side streams from dewatering processes. Lagoon overflow is essentially the same as thickener overflow except that the solids storage time is considerably longer in a lagoon than in a thickener. This long storage time may alter the characteristics of the sludge and facilitate release of contaminants to the supernatant that is recycled. The final waste stream category is the side streams associated with dewatering activities. These include the liquid streams that result from mechanical dewatering operations such as centrifugation or belt filter pressing or nonmechanical methods such as sand drying beds.

The research also considered potential contamination of the treatment process resulting from storage of sludge in sedimentation basins. This in-basin sludge storage has the potential to directly impact the treatment process because of releases from the sludge into the settling basin overflow or clarified water.

Waste streams can be discharged to a sewer, discharged to a stream, or recycled within the treatment plant. If a sewer is available and the sewage plant can accept the waste, the discharge of small quantities of waste streams by this method may be an appropriate disposal solution. Discharge of large quantities of wastes (e.g., spent filter backwash water) may not be acceptable or economically desirable.

Direct discharge to waterways of clarified waste streams is a widely practiced alternative disposal method. Generally, a discharge permit will set an allowable suspended solids limit (e.g., 30 mg/L) and an allowable pH value (e.g., 6 to 9) for the water discharged. Several states are adding metal, chlorine, and toxicity standards to the discharge permit, making it increasingly difficult to discharge water treatment plant liquid wastes. Several plants are already considering zero discharge (complete plant recycle) as the only available option. Unfortunately, this option is complicated by some state health departments that are reluctant to permit recycle systems.

Recycling waste streams has the potential to upset the treatment process itself or to affect the quality of the finished water. The impacts can be caused by the solids themselves, constituents in the waste, or contaminants released from the sludge into the overlying water. Examples of undesirable constituents in waste include *Giardia* and *Cryptosporidium* cysts, manganese, iron, TOC, TTHM precursors, and taste and odor. Although some plants have experienced problems with recycling waste streams, little published literature directly deals with the characteristics, problems, and requirements for effective side stream recycle.

Some of the possible effects of sludge storage in sedimentation basins were reported by Hoehn, Novak, and Cumbie (1987). They found significant releases of manganese, iron, and TOC from sludge in manually cleaned sedimentation basins. Manganese concentrations in the water applied to the filters were higher than concentrations in the raw water. The researchers concluded that sludge stored in lagoons can be expected to degrade the overlying waters, thus complicating the discharge or recycle of this supernatant.

The American Water Works Service Company (AWWSC), which is made up of over 100 water plants, also has experienced benefits and problems associated with waste stream recycle. More than 20 of these plants that treat surface water recycle one or more waste streams into the treatment process. Although operating personnel obviously carry out the process carefully to avoid any significant impact, there have been indications of problems. A number of plants have reported adverse impacts as a result of waste stream recycle. These reports suggest that there may be optimum operating or water quality conditions for minimizing any adverse impact. Several reported impacts from recycle are summarized below by AWWSC plant location.

New Castle, Pa. The streaming current detector (SCD) used for coagulation control at the New Castle plant indicated there was a reduced coagulant demand during the 2-hour recycle period. The SCD was not in a control mode, and no attempts had been made to reduce the coagulant feed during this period. Another impact resulted from the recycle of filter press filtrate because of the press polymer used. When this material was recycled to the rapid mix, a much heavier floc settled out in the flocculation basin.

Terre Haute, Ind. Recycling backwash water from an iron-manganese greensand filter to a surface water plant at the Terre Haute facility resulted in the SCD control dramatically reducing the alum feed. This had a negative impact on the clarification process because of the reduced coagulant feed.

Kokomo, Ind. Recycling washwater from iron removal filters at the Kokomo plant would at times cause the coagulant pumps to underfeed as a result of SCD control. The SCD apparently picked up the charge from recycled iron and reduced the alum feed.

Charleston, W.Va. The Charleston plant used no inorganic coagulant, relying totally on polymer for clarification. Unsettled backwash water was recycled to the raw water intake, and negative impacts on clarification were observed if the recycle flow exceeded 5 percent of the plant flow.

Mystic, Conn. The recycling of settled backwash water at the Mystic facility, resulted in a reduced alum feed because of the signal from the SCD controller. This reduction had no adverse impact on clarification, and the reduction in chemical costs was beneficial.

As the first phase of this project, a survey was taken of 24 AWWSC plants that had previously been identified as recycling one or more waste streams. A survey form was sent to each of the operating companies. All the forms were completed and returned. The 24 plants, with their identification numbers, are listed below.

Connecticut–American
- 1 Mianus
- 2 Mystic

Illinois–American
- 3 Granite City

Indiana–American
- 4 Kokomo
- 5 Muncie
- 6 Richmond
- 7 Terre Haute

Kentucky–American
- 8 Richmond Road
- 9 River Plant

Maryland–American
- 10 Winters Run

Missouri–American
- 11 Joplin

New Jersey–American
- 12 Jumping Brook
- 13 Swimming River

Pennsylvania–American
- 14 Bangor
- 15 Butler
- 16 Canonsburg
- 17 Moshannon Valley
- 18 New Castle

West Virginia–American
- 19 Gassaway
- 20 Hamlin
- 21 Hinton

West Virginia–American
- 22 Kanawha Valley
- 23 Montgomery
- 24 Webster Springs

The survey data are summarized in Tables 2.1 through 2.5. Tables 2.1 and 2.2 contain raw and finished water quality data for each of the plants. Table 2.3 outlines the physical characteristics of each of the plants. Table 2.4 identifies the types of recycle streams, flow rates, and operator-noted impacts of the recycle. Table 2.5 contains data that were collected on the quality of the recycle water. Finally, Table 2.6 contains a quick reference matrix of the plants surveyed and the type of recycle streams at each plant.

The next task associated with this phase of the work was to select approximately 12 plants that would be used for the first round of water quality sampling. In order to help rank the plants they were categorized by potential impact areas, as follows:

Manganese recycle
TTHM or TTHM precursor recycle
Giardia or *Cryptosporidium* recycle
Recycle effects on AOC
Turbidity recycle
Effect of settling versus not settling backwash water
Thickener and lagoon overflow
Dewatering side streams

On the basis of this analysis, the following 13 plants were selected for the preliminary sampling phase:

1 Connecticut–American, Mianus
4 Indiana–American, Kokomo
5 Indiana–American, Muncie
6 Indiana–American, Richmond
8 Kentucky–American, Richmond Road
11 Missouri–American, Joplin
13 New Jersey–American, Swimming River
14 Pennsylvania–American, Bangor
15 Pennsylvania–American, Butler
17 Pennsylvania–American, Moshannon Valley
18 Pennsylvania–American, New Castle
20 West Virginia–American, Hamlin
22 West Virginia–American, Kanawha Valley

Preliminary sampling consisted of collecting a one-time grab sample of the recycle waste stream and of a process stream (usually settled water). The process stream was sampled before and during recycle in order to quantify impacts of recycle. The sampling results, along with system knowledge of the plants, were used to select six plants to study for the remainder of this project. The plants selected and the key selection parameters for further study are presented in Table 2.7.

Plant selection was also based on plant facilities, so that a variety of plant types and waste-handling equipment would be included. For example, the group includes an in-line filtration plant (Bangor), an adsorption clarifier plant (Moshannon Valley), a conventional sedimentation plant (New Castle), and three sludge blanket plants. Three plants (Swimming River, Mianus, and New Castle) have belt filter presses and two (Moshannon Valley and Bangor) have sand drying beds.

A detailed plant description including raw and effluent water quality, chemicals used, initial sampling results, and a discussion of solids handling and the recycle process for each plant is presented in the discussions of the individual plants in Chapters 3 through 8.

In addition to these six plants, two non-AWWSC plants were used to study the effect of sedimentation basin sludge storage. These were the Williams Water Treatment Plant in Durham, N.C., and the Appomattox River Water Authority plant in Petersburg, Va. They are discussed in Chapters 9 and 10.

Table 2.1 Waste stream recycle project survey data: Raw water quality

Plant number	Source	Turbidity (ntu)	Color (cu)	Iron (mg/L)	Manganese (mg/L)	pH	Alkalinity (mg/L $CaCO_3$)	Ammonia (mg/L)	Coliform (number/100 mL)	TOC (mg/L)	TTHMFP (µg/L)
1	Stream	3	14	0.13	0.11	6.8	29	0.32	3,000	NA	NA
2	Lake	1.24	71	0.33	0.04	6.6	10	0.49	317	NA	NA
3	River	150	NA	0.05	<0.02	8.1	168	NA	1,000	NA	NA
4	Ground, river	14.5	9	NA	NA	8.1	201	0.16	1,504	NA	NA
5	River, ground	14	15	0.22	NA	8.1	250	NA	12,300	NA	NA
6	Stream	4	10	<0.1	<0.02	7.7	270	NA	150	NA	950
7	Ground, river	56	NA	0.13	0.04	8.0	225	NA	5,943	NA	NA
8	Stream	9.2	NA	0.24	0.15	7.6	89	0.42	155	NA	NA
9	River	24	NA	0.37	0.32	7.7	66	0.39	504	NA	NA
10	Stream	50	NA	<0.1	NA	6.9	28	NA	162	NA	NA
11	River	8.67	NA	1.21	0.273	8.0	125.6	0.15	848	NA	NA
12	Ground, river	10.2	NA	2.7	0.085	6.8	26.4	NA	163	3.4	NA
13	Stream	10.3	NA	0.96	0.09	7.2	37.4	NA	29	3.1	NA
14	Stream, ground	0.3	NA	<0.1	<0.02	6.3	6	NA	NA	NA	NA
15	Stream	7.6	NA	0.17	0.07	7.3	33.3	NA	160	NA	NA
16	River, lake	12	NA	0.3	0.4	7.8	155	0.25	2,100	NA	NA
17	Ground, stream	1.2	NA	0.11	0.04	6.8	14	NA	28	NA	NA
18	River	15	NA	0.6	0.2	7.5	70	NA	200	NA	NA
19	River	4.5	NA	<0.1	NA	6.8	23	NA	1,400	NA	NA
20	Ground	1.02	NA	6.65	0.17	7.0	153	NA	<10	NA	NA
21	River	2.6	NA	0.11	0.03	7.6	66	NA	750	NA	NA
22	River	11	NA	<0.1	<0.02	6.9	23	NA	3,700	NA	NA
23	River	4.9	NA	<0.1	<0.02	7.4	42	NA	2,300	NA	NA
24	River	3.2	NA	<0.1	NA	7.6	33	NA	285	NA	NA

NA = no data available

Table 2.2 Waste stream recycle project survey data: Finished water quality

Plant number	Source	Turbidity (ntu)	Color (cu)	Iron (mg/L)	Mn (mg/L)	pH	Alkalinity (mg/L $CaCO_3$)	Ammonia (mg/L)	Aluminum (mg/L)	TOC (mg/L)	TTHM (µg/L)	Free Cl_2 (mg/L)	Total Cl_2 (mg/L)
1	Stream	1	2	0.02	<0.02	8.0	35	NA	0.019	NA	57	0.75	NA
2	Lake	0.26	3	0.3	0.03	7.2	26	NA	0.04	NA	42	2.05	2
3	River	0.18	NA	<0.1	<0.02	7.6	161	NA	0.135	NA	57	0.5	2.2
4	Ground, river	0.31	3	<0.1	NA	7.4	225	NA	NA	NA	77	2.54	NA
5	River, ground	0.2	1	<0.1	<0.02	7.5	252	NA	0.069	NA	67	0.8	NA
6	Stream	0.34	2	<0.1	<0.02	7.3	240	NA	0.2	NA	45	1.8	1.9
7	Ground, river	0.17	3	<0.1	<0.02	7.5	272	NA	0.098	NA	34	1.9	NA
8	Stream	0.3	NA	<0.1	<0.02	8.0	87	<0.1	0.149	NA	47	2.3	2.5
9	River	0.27	NA	<0.1	<0.02	8.1	71	<0.1	0.14	NA	59	2.5	NA
10	Stream	0.15	NA	<0.1	<0.02	8.5	36	2.4	0.22	NA	50	1.5	1.7
11	River	0.087	NA	<0.1	<0.02	7.7	121	2	0.112	NA	36	1.15	NA
12	Ground, river	NA	NA	<0.1	<0.02	8.4	44	NA	0.049	2.6	NA	NA	1.3
13	Stream	NA	NA	<0.1	<0.02	8.4	44	NA	0.049	2.6	NA	NA	1.3
14	Stream	0.13	NA	<0.1	<0.02	7.2	20	NA	NA	NA	NA	1.7	NA
15	Stream	0.27	NA	<0.1	<0.02	8.4	37	NA	0.09	NA	60	1.96	2.12
16	River, lake	0.2	NA	<0.1	<0.02	7.1	145	<0.1	0.1	NA	75	1.8	1.9
17	Ground	0.12	NA	<0.1	<0.02	7.3	18	NA	0.05	NA	NA	2.2	2.3
18	River	0.4	NA	<0.1	<0.02	7.2	70	NA	0.1	NA	95	1.5	1.7
19	River	0.13	NA	<0.1	<0.02	8.7	33	NA	0.34	NA	52	1.3	NA
20	Ground	0.45	NA	0.11	<0.02	8.4	155	NA	0.1	NA	43	1.8	NA
21	River	0.33	NA	<0.1	<0.02	7.7	66	NA	0.9	NA	74	2.4	NA
22	River	0.02	NA	<0.1	<0.02	9.0	30	NA	0.01	NA	77	1.51	NA
23	River	0.29	NA	<0.1	<0.02	8.5	47	NA	0.45	NA	75	1.6	NA
24	River	0.27	NA	<0.1	<0.02	8.6	47	NA	0.11	NA	40	1.5	NA

NA = no data available

Table 2.3 Waste stream recycle project survey results: Plant characteristics

Plant number	Coagulants	Oxidants	Other chemicals	Clarification	Filter media	Filtration rate (gpm/ft²)
1	Alum	$KMnO_4$, chlorine		Solids contact	Anthracite, sand	2.0
2	Alum	Chlorine	Polymer	Conventional	Anthracite, sand	2.0
3	Alum	Chlorine, $KMnO_4$	Polymer	Conventional	GAC, sand	2.0
4	$FeSO_4$	Chlorine	Polymer	Conventional	Anthracite, sand	2.5
5	Alum	Chlorine, $KMnO_4$		Conventional, tubes	Anthracite, sand	2.9
6	Alum, ferric sulfate	Chlorine	Polymer	Solids contact	Anthracite, sand	4.0
7	Alum	Chlorine	Polymer	Conventional	Anthracite, sand	2.8
8	Alum	$KMnO_4$, Cl_2, NHCL		Conventional	GAC	2.0
9	Alum	Chlorine, $KMnO_4$	Polymer	Conventional	Tri-media	4.0
10	Alum	Chlorine	Lime, carbon	Conventional	Sand	3.3
11	Alum	Chlorine	Lime, carbon, polymer	Conventional	Sand	3.0
12	$FeCl_3$	Chlorine, ClO_2	Polymer	Solids contact	Anthracite, sand	2.0
13	Alum	Chlorine, ClO_2	Polymer	Solids contact	Tri-media	4.0
14	Alum	Chlorine	Polymer	None	Tri-media	4.0
15	Alum	$KMnO_4$, chlorine		Conventional	Anthracite, sand	4.0
16	Ferric sulfate	Chlorine, $KMnO_4$	Polymer	Solids contact	GAC, sand	2.0
17	Alum	Chlorine	Caustic soda	Solids contact	Tri-media	3.0
18	Alum	Chlorine, ClO_2, $KMnO_4$	Polymer	Conventional	GAC, sand	4.0
19	None	Chlorine, $KMnO_4$	Soda ash, lime	Conventional	Sand	2.0
20	None	Chlorine, $KMnO_4$, air	Filter aid, KOH	Conventional	Anthracite, greensand	2.0
21	Alum	Chlorine	PAC, sodium hydroxide	Conventional	Anthracite, sand	2.4
22	Cationic polymer	Chlorine, ClO_2	Lime, PAC	Solids contact	Anthracite, sand	2.0
23	Alum	Chlorine	Lime	Conventional	Sand	2.0
24	Alum	Chlorine	Lime, soda ash	Conventional	Sand	2.5

GAC = granular activated carbom
NA = no data available
PAC = powdered activated carbon

Table 2.4 Waste stream recycle project survey results: Recycle information

Plant number	Recycle stream description	Plant flow (mgd)	Recycle flow (gpm)	Recycle time (min/d)	SCD	SCD effect	Impacts of recycle on: THM	Iron	Mn	Turbidity	Other
1	Settled Backwash, sludge, and belt press filtrate	4.8	627	330	NA	NA	NA	No	No	Inc 2–3	Inc color 0.2–0.6
2	Backwash	1.3	150	120	Yes	More neg	NA	NA	NA	NA	NA
3	Settled backwash water	10	400	625	No	NA	No	No	No	No	NA
4	Backwash, lagoon and thickener supernatant	11	1,740	75	Yes	More pos	NA	No	NA	Beneficial	NA
5	Settled backwash water	10	1,400	90	NA	NA	NA	NA	NA	Inc	NA
6	Backwash water	4	500	90	NA	NA	No	No	No	Inc	NA
7	Backwash from groundwater plant only	5	2,175	75	NA	NA	NA	NA	NA	NA	NA
8	Filter backwash supernatant	5.8	2,350	100	NA	NA	NA	NA	NA	NA	NA
9	Settled backwash, lagoon supernatant	26	4,200	30	Yes	More pos	NA	NA	NA	NA	NA
10	Settled backwash	1.3	55	240	NA	NA	NA	NA	NA	NA	pH and alkalinity
11	Backwash water	10.2	750	240	NA	NA	Inc	Inc	NA	Inc	NA
12	Backwash water	10	4,000	120	Yes	Varies	NA	No	No	No	No
13	Settled backwash, sludge, and belt press filtrate	28	694	120	Yes	None	NA	NA	NA	No	NA
14	Backwash water	0.7	110	420	NA	NA	NA	Inc	Inc	Inc	NA
15	Settled backwash water	7.1	3,500	50	NA	NA	NA	NA	NA	Slight	Higher pH Cl_2 residual
16	Backwash water	4.2	650	180	NA	NA	NA	NA	NA	Yes	NA
17	Settled backwash and settled roughing	1.8	450	150	Yes	More neg	NA	Inc	No	Inc	NA
18	Backwash water, belt press, filtrate, thickener overflow	8	550	140	Yes	None	NA	No	No	No	No
19	Backwash water	0.106	0.2	0.1	NA	NA	NA	NA	NA	NA	NA
20	Backwash water	0.187	140	60	NA	NA	NA	Inc	Inc	Inc	NA
21	Backwash water	0.325	140	90	NA	NA	NA	NA	NA	NA	NA
22	Backwash water	28	2,000	NA	Yes	More pos	NA	NA	NA	Inc	NA
23	Backwash water	0.447	250	60	NA	NA	NA	NA	NA	Inc	NA
24	Backwash water	0.187	80	120	NA	NA	NA	NA	NA	Inc	NA

Inc = increase
NA = no data available
neg = negative
pos = positive

Table 2.5 Waste stream recycle project survey results: Recycled water quality

Plant number	Turbidity (ntu)	Color (cu)	Iron (mg/L)	Mn (mg/L)	pH	Alkalinity (mg/L)	Ammonia (mg/L)	Aluminum (mg/L)	Chlorine (mg/L)	Total suspended solids (TSS) (mg/L)	TTHMFP (µg/L)
1	3.6	20	0.81	0.8	5.8	10	NA	16.1	NA	NA	NA
2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3	4	NA	NA	NA	8.0	NA	NA	NA	0.5	NA	NA
4	4.3	17	0.52	NA	7.53	227	0.06	NA	0.7	NA	NA
5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6	400	700	<0.1	0.03	7.51	250	NA	0.4	1	4,000	800
7	40	50	10.75	7.85	7.34	320	NA	NA	1.6	NA	NA
8	146	NA	NA	6.6	7.85	NA	NA	46.9	NA	437	NA
9	119	NA	NA	3.7	7.8	NA	NA	34.7	1.3	350	NA
10	10	NA	NA	NA	8.3	34	NA	NA	2	NA	NA
11	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
13	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
14	9.4	NA	0.3	<0.02	7	16	NA	0.18	0.4	NA	NA
15	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
16	30	NA	7.5	1.2	7.8	175	NA	NA	0.1	NA	NA
17	4.3	NA	0.23	0.05	6.8	13	NA	0.04	0.8	NA	NA
18	8	NA	0.2	0.2	7.4	70	NA	NA	0.15	10	NA
19	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
20	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
21	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
22	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
23	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
24	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

NA = no data available

Table 2.6 Sources of recycled waste stream

Plant number	Plant	Unsettled backwash water	Settled backwash water	Lagoon overflow	Lagoon–drying bed underflow	Thickener overflow	Belt press filtrate	SCD*
	Connecticut–American							
1	Mianus		X			X	X	M
2	Mystic	X						M,C
	Illinois–American							
3	Granite City		X					M
	Indiana–American							
4	Kokomo		X	X	X			C
6	Richmond	X						
5	Muncie		X					M
7	Terre Haute	X						M
	Kentucky–American							
9	River Plant		X	X				M
8	Richmond Road		X			X	X	M,C
	Maryland–American							
10	Winters Run		X					C
	Missouri–American							
11	Joplin	X			X (2 times/year)			
	New Jersey–American							
13	Swimming River		X	X	X			M
12	Jumping Brook		X			X	X	M
	Pennsylvania–American							
14	Bangor		X		X			
18	New Castle		X			X	X	M,C
17	Moshannon Valley		X		X			M,C
16	Canonsburg	X						
15	Butler		X					
	West Virginia–American							
22	Kanawha Valley		X					M
23	Montgomery		X					
19	Gassaway		X					
20	Hamlin		X					
21	Hinton		X					
24	Webster Springs		X					

*Streaming current detector: M = monitor; C = control.

Table 2.7 Parameters for evaluation at the six plant sites

Plant number	Plant	Turbidity	THM	Mn	AOC	Parasites	Pressate	Drying bed filtrate
1	Mianus		X	X			X	
13	Swimming River		X	X	X		X	
14	Bangor	X				X		
17	Moshannon Valley	X				X		X
18	New Castle		X	X	X		X	
22	Kanawha Valley	X	X					

Chapter 3

Mianus Water Treatment Plant

Plant Description

Treatment Process

The Mianus Water Treatment Plant, located in Greenwich, Conn., is a surface water plant utilizing conventional treatment. The raw water is drawn from the Mianus River, which is adjacent to the plant. Raw water flows by gravity into two Aldrich reactor units. Pretreatment chemicals are fed into the raw water line upstream of these reactors. Each Aldrich unit consists of a slow mixing zone in the center of a clarifying zone. Clarified water flows over a weir and enters the filters that are contained in the outer ring of the unit. The filters were recently rehabilitated using anthracite and sand media. The filtered water flows into a clearwell and is then pumped into the distribution system. Figure 3.1 is a process flow schematic of the Mianus Water Treatment Plant.

Plant Flow

The plant is rated at 6 mgd (946 m^3/h). Winter flow is approximately 4 mgd (631 m^3/h), and summer flow can be as high as 8 mgd (1,260 m^3/h). Plant flow is controlled by an influent flow controller, and the filters operate by constant level control. Because the clearwell is small and distribution system storage is limited, large flow variations through the treatment plant occur between peak and off-peak demand hours. The production rate can vary by as much as 2 to 4 mgd (315 to 631 m^3/h) during the day.

Chemical Feed

Raw water chemical treatment consists of the addition of lime, chlorine, and alum on a regular basis, along with the addition of potassium permanganate and powdered activated carbon (PAC) on a seasonal basis. Filtered water at the plant is treated by the addition of lime, fluoride, chlorine, and corrosion inhibitor. Chemical feed doses are summarized in Table 3.1.

Solids Handling

Solids-handling equipment consists of a supernatant tank, sludge thickener, and belt press. Waste streams include

Settled solids from Aldrich units
Spent filter backwash water

Belt press pressate
Thickener overflow

The settled solids from the Aldrich units flow by gravity to the supernatant tank. Accumulated sludge in the Aldrich units is drained every 2 to 3 days. The filters are backwashed using head from the washwater tank, and the spent filter backwash water flows to the supernatant tank. The pressate and sludge thickener supernatant also go to the supernatant tank (see Figure 3.1).

The filters are backwashed every 24 hours between 11:00 P.M. and 1:00 A.M. The belt press is operated 4 to 6 days a week, an average of 8 hours per day. The sludge thickener is filled once a week with settled solids from the supernatant tank. The sweeps in the thickener operate every night while the press is off. It takes 4 to 6 days to dewater one tank of thickened solids.

Recycle

The plant recycles water from the supernatant tank to the raw water line approximately 5 to 8 hours per day (4:00 A.M. to 12:00 noon). The supernatant tank is allowed to settle 2 to 3 hours before recycle occurs. Because increased turbidity occurs in the settled water when recycling begins, the operators monitor finished water turbidity closely. Recycle begins by using one 400-gpm (91 m^3/h) pump. At a 6-mgd (946 m^3/h) treatment rate, recycle water is equivalent to about 10 percent of the total flow (referred to as a 10 percent recycle rate). A second recycle pump may be operated, depending on the effects of the recycle stream on treatment at that time. The recycle line enters the raw water line downstream of the chemical injection point.

During recycling, chemicals may be adjusted manually to maintain good treatment. Most times the alum dose is lowered due to excessive polymer in the recycle stream. The polymer originates from the pressate of the belt filter press.

Water Quality

Typical raw and finished water quality data for the Mianus Water Treatment Plant are summarized in Table 3.2. Parameters of particular interest for the recycle evaluation include the medium to high levels of manganese in the raw water and the levels of TTHM in the finished water. Recycle of waste streams could have effects on both these parameters throughout the treatment process.

In order to initially investigate the effects of the recycle stream on treatment or finished water quality, preliminary sampling was performed at the site. Sampling consisted of collecting a one-time grab sample of the recycle waste stream and the finished water. The finished water was sampled with and without recycle. Table 3.3 summarizes the results of this preliminary investigation, which results show high levels of TTHM and TTHMFP in the recycle water and in the filtered water due to recycle. Also of interest is the increase in aluminum and manganese during recycle.

Comprehensive Sampling Program

Overview

Two rounds of detailed field sampling and analysis were performed at the Mianus Water Treatment Plant. The parameters for which the water was analyzed

and the sampling points used were derived from a review of the water quality information supplied by the operators of the Mianus facility and the results of the preliminary sampling. In addition to the two rounds of field sampling and analysis performed, sludge from the Mianus plant was collected for bench-scale evaluation of the release of manganese.

Round 1 Sampling

Plant operation was reported to be typical at the time of sampling. Plant flow ranged from 6.1 to 6.5 mgd (962 to 1025 m^3/h) and the recycle flow was 0.5 mgd (79 m^3/h) (8 percent recycle). Settled and filtered turbidities were normal and all processes were in operation. Round 1 sampling was performed over a 2-day period during the summer.

The water quality parameters evaluated at this facility were

TTHM
TTHMFP
TOC
Manganese
Aluminum
Turbidity
pH
Chlorine residual

The sample locations for these parameters are listed below. Numbers in parentheses indicate the sampling locations as shown in Figure 3.1.

Raw (1)
Mixed water before recycle (7)
Mixed water during recycle (7)
Filtered water before recycle (8)
Filtered water during recycle (8)
Spent backwash water (3)
Clarifier sludge (4)
Supernatant recycle (2)
Thickener supernatant (5)
Belt press pressate (6)

As mentioned previously, typical operation of this plant is to wash both filters during the night shift, let the wastewater settle for 2 to 3 hours, and then begin recycle, which lasts approximately 5 to 8 hours. This was the operating procedure utilized during the sampling program.

Single grab samples were collected from all of the waste streams. For samples within the treatment process, several grab samples were collected and composited. Figure 3.1 shows the sampling points for round 1 sampling. The results of this sampling are shown in Table 3.4.

Round 2 Sampling

Waste stream–handling operations were slightly different during round 2 sampling. Sludge from the clarifier, which previously went to the supernatant tank, was instead discharged to the thickener. This change in procedure was made to

improve the operation of the decant pumps from the supernatant tank and to reduce the raw water turbidity spike. Sampling methods were similar to round 1 sampling; however, composite samples were taken for the backwash stream and clarifier sludge by collecting one sample every minute for the duration of the cycle.

Plant operations were normal at the time of sampling. Plant flow was approximately 3.5 mgd (552 m^3/h), corresponding to a recycle of 14 percent. Round 2 sampling took place in January.

The results from round 2 sampling are shown in Table 3.5.

Laboratory-Scale Analysis

Sludge collected from the Mianus plant clarifier was put into two 4-L beakers and held in the laboratory at ambient room conditions. Samples were analyzed for pH and DO once a week and for manganese levels three times a week. DO was sampled in both the supernatant and the settled sludge, whereas manganese and pH were sampled in the supernatant only. One beaker was kept at a pH of approximately 5.5 and one at a pH of approximately 7.0, representing the low and high pH conditions for most sludges. Reported manganese values are for dissolved manganese.

Trends

TTHM

Both round 1 and round 2 showed high TTHM concentrations in the waste streams (200 to 500 µg/L) and elevated finished water levels during recycle. The thickener supernatant and clarifier sludge showed very high but variable TTHM concentrations. The water being recycled also showed the presence of preformed TTHM in the range of 80 to 120 µg/L. Figure 3.2 graphically shows the TTHM values from all the waste streams. The addition of the recycle stream to the treatment process did result in increased TTHM levels in the plant influent and finished water. The plant influent water's TTHM levels increased from between 8 and 20 µg/L without recycle (raw water chlorination is practiced) to between 20 and 50 µg/L with recycle. However, the filtered water showed only a slight increase in TTHM concentration due to recycle, indicating that TTHM formation in the source water was rapid enough that adding preformed TTHM had only a minor effect on finished water quality. Figures 3.3 and 3.4 show the effects of recycle on the plant influent and filtered water TTHM levels, respectively.

TTHMFP

TTHMFP indicates the formation potential for recycle precursors that could ultimately increase TTHM levels. TTHMFP in the waste streams was in the 300-to-500-µg/L range (Figure 3.5). The TTHMFP values were much lower in the recycle stream (150 to 250 µg/L) than in the other waste streams, indicating that much of the TTHMFP was associated with the solids and was reduced by settling. The addition of the recycle stream to the head of the plant showed little effect on the TTHMFP of the water at the mixing or filtering stages of treatment. Figures 3.6 and 3.7 show the effect of the addition of the recycle stream on TTHMFP levels at the influent and filtered water sampling points. With appropriate settling it appears that TTHM precursors were not recycled.

TOC

TOC levels were elevated in several of the waste streams. Spent backwash water and clarifier sludge had TOC levels of 5 to 8 mg/L, as compared to raw water levels of 4 mg/L. The pressate and the clarifier sludge seemed to show the highest levels of TOC, at 20 mg/L and 6 to 9 mg/L, respectively. Again, settling was effective in reducing the TOC, as the recycle stream contained only 2.5 to 4 mg/L TOC. There was no impact on the finished water TOC due to recycle. TOC concentrations from round 1 and round 2 testing are shown in Figures 3.8 and 3.9, respectively.

Manganese

Manganese showed elevated levels in all the waste streams. The highest levels of manganese present were in the pressate (dissolved Mn of 7 to 12 mg/L) and clarifier sludge (total Mn of 40 to 180 mg/L). The thickener supernatant showed higher concentrations of dissolved manganese than did the recycle stream, probably due to the longer sludge storage time in the thickener. Figure 3.10 shows the manganese results from round 1 and round 2 sampling of the waste streams. The elevated manganese levels present in the recycle stream increased the manganese concentration in raw water at the mixing zone. Fortunately, the plant treatment was adequate to handle the increased manganese, and no noticeable effects on filtered water were found. Figures 3.11 and 3.12 show the effects of recycling on manganese levels of the influent and filtered water sampling points.

It appeared that sludge storage time had a large effect on the release of manganese from the sludge, as evidenced by the high concentration in the thickener supernatant. Therefore, bench tests were conducted on manganese release from sludge with time to better assess storage impacts. The manganese levels in the supernatant showed steady increases over time for both the sludge samples. Figure 3.13 graphically shows these increases. Manganese levels increased in the supernatant from between 2 and 5 mg/L at the start of the study to between 20 and 30 mg/L after 80 days. Figure 3.14 shows the corresponding downward trend for DO levels in the settled sludge. As the DO levels decreased and the sludge became anaerobic, manganese levels increased in the supernatant. Figure 3.13 shows that the manganese released was higher in the lower pH sample. As the storage time reached 1 to 2 months, very high levels of manganese were found in the supernatant.

Aluminum

Figure 3.15 shows the aluminum concentrations in the waste and recycle streams. Most aluminum is associated with the solids, but the recycle stream did contain 0.32 mg/L of dissolved aluminum. Although dissolved aluminum concentrations increased at the mixing zone, no increases were found in the filtered water due to recycle. Figures 3.16 and 3.17 show aluminum concentrations before and during the recycle operation.

Table 3.1 Chemical feed data for Mianus Water Treatment Plant

Location	Chemical	Dose (mg/L)
Raw	Alum	4–10
	Chlorine	2.5–6
	Lime	6–20
	Carbon (seasonal)	1–3
	$KMnO_4$ (seasonal)	8–10
Filtered	Chlorine	0.5–1.5
	Corrosion inhibitor, ZOP	0.5
	Fluoride	0.5
	Lime	4–8

ZOP = zinc orthophospate

Table 3.2 Average annual water quality data for Mianus Water Treatment Plant

Parameter	Raw	Finished
Turbidity, ntu	3.0	0.10
Color, cu	14	2
Iron, mg/L	0.13	<0.05
Manganese, mg/L	0.11	<0.02
pH	6.8	8.0
Alkalinity, mg/L $CaCO_3$	29	35
Ammonia, mg/L	0.32	<0.01
Aluminum, mg/L	NA	0.019
Coliform, number /100 mL	3,000	<1
TOC, mg/L	NA	<0.2
TTHM, µg/L	NA	57
Free Cl_2, mg/L	NA	0.75

NA = no data available

Table 3.3 Preliminary sampling results for Mianus Water Treatment Plant

		Filtered water	
Parameter	Recycle stream	Without recycle	With recycle
Aluminum, mg/L	0.099	0.10	0.29
Iron, mg/L	<0.05	<0.05	<0.05
Manganese, mg/L	<0.02	<0.02	<0.02
TSS, mg/L	3	1	8
TOC, mg/L	4.7	3.5	NA
TTHM, µg/L	115	143	239
TTHMFP, µg/L	456	513	624

NA = no data available

Table 3.4 Round 1 sampling results for Mianus Water Treatment Plant

Sample site	Turbidity (ntu)	pH	Free Cl_2 (mg/L)	TTHM (µg/L)	TTHMFP (µg/L)	TOC (mg/L)	Aluminum		Manganese	
							Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)	Total (mg/L)
Day 1										
Raw (1)*	3.3	7.1	NA	<0.5	195	3.6	NA	0.36	0.03	0.29
Mixed B (7)	4.5	6.5	1.8	19	200	4.4	0.026	2.2	0.16	0.24
Mixed D (7)	5.6	6.5	1.9	48	201	3.3	0.017	2.5	0.25	0.5
Filtered B (8)	0.2	6.4	0.8	71	154	3.1	<0.001	0.04	0.03	<0.02
Filtered D (9)	0.2	6.5	0.2	85	187	2.6	<0.001	0.02	<0.02	<0.02
Backwash (3)	68	6.8	0.3	93	465	7.1	0.033	76	0.15	12
Clarifier sludge (4)	NA	NA	NA	189	788	8.7	0.056	1,500	1.2	180
Recycle (2)	0.9	6.5	<0.1	127	259	4.4	<0.001	2.3	0.32	1.1
Thickener supernatant (5)	5.0	6.7	<0.1	186	426	5.0	<0.001	0.18	4.1	4.5
Pressate (6)	35	7.2	<0.1	132	397	9.2	0.021	31.8	12.2	16
Day 2										
Raw (1)	3.1	7.1	<0.1	<0.5						
Mixed B (7)	4.8	6.4	1.8	17						
Mixed D (7)	6.4	6.4	2.0	37						
Filtered B (8)	0.3	6.5	0.5	78						
Filtered D (9)	0.2	6.6	0.3	73						
Backwash (3)	97	6.8	0.3	97						
Clarifier sludge (4)	NA	NA	NA	197						
Recycle (2)	2.5	7.0	<0.1	104						
Thickener supernatant (5)	4.8	6.6	<0.1	164						
Pressate (6)	40	7.1	<0.1	128						

B = before recycle
D = during recycle
NA = no data available

*Numbers in parentheses indicate sampling locations as shown in Figure 3.1

Table 3.5 Round 2 sampling results for Mianus Water Treatment Plant

Sample location	Turbidity (ntu)	pH	Free Cl_2 (mg/L)	TOC (mg/L)	TTHM (µg/L)	TTHMFP (µg/L)	Manganese		Iron		Aluminum*	
							Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)
Day 1												
Raw (1)*	1.2	6.4	NA	3.62	<0.5	175	0.04	0.03	0.27	0.13	0.17	.004
Mixed B (7)	7.1	5.5	1.6	2.37	8	169	0.04	0.04	0.23	0.18	3.6	3.3
Mixed D (7)	4.4	5.7	1.5	3.28	22	183	0.09	0.05	0.38	0.28	5.9	5.3
Filtered B (8)	0.08	6.0	0.9	2.35	27	122	0.02	<0.02	0.23	<0.05	0.95	0.66
Filtered D (9)	0.02	6.1	1.1	1.78	29	116	0.03	<0.02	0.24	<0.05	0.28	0.08
Backwash (3)	76	6.6	0.6	5.54	51	307	1.40	0.75	3.19	2.60	55	49.6
Clarifier sludge (4)	NA	6.0	<0.1	22.9	492	595	46.50	7.28	222.0	6.47	2,567	1,089
Recycle (2)	1.2	7.2	<0.1	2.60	81	170	0.09	0.07	0.13	<0.05	1.0	0.32
Thickener supernatant (5)	0.70	6.0	<0.1	4.87	525	444	1.25	1.14	0.08	<0.05	0.62	0.27
Pressate (6)	30	6.8	<0.1	5.82	276	448	8.0	7.43	0.66	<0.05	6.4	0.81
Day 2												
Raw (1)	6.5	6.4	NA	3.96	<0.5	196						
Mixed B (7)	10.0	5.7	1.4	3.07	9	194						
Mixed D (7)	9.4	5.5	1.5	3.44	26	199						
Filtered B (8)	1.1	6.0	0.8	1.96	30	134						
Filtered D (9)	0.5	5.8	1.1	2.89	30	128						
Backwash (3)	0.57	6.2	0.6	5.54	46	302						
Clarifier sludge (4)	NA	6.0	<0.1	21.7	406	551						
Recycle (2)	0.8	6.5	<0.1	2.86	88	185						
Thickener supernatant (5)	1.8	6.2	<0.1	3.75	156	349						
Pressate (6)	Not operating on Day 2											

B = before recycle
D = during recycle
NA = no data available

*Numbers in parentheses indicate sampling locations shown in Figure 3.1

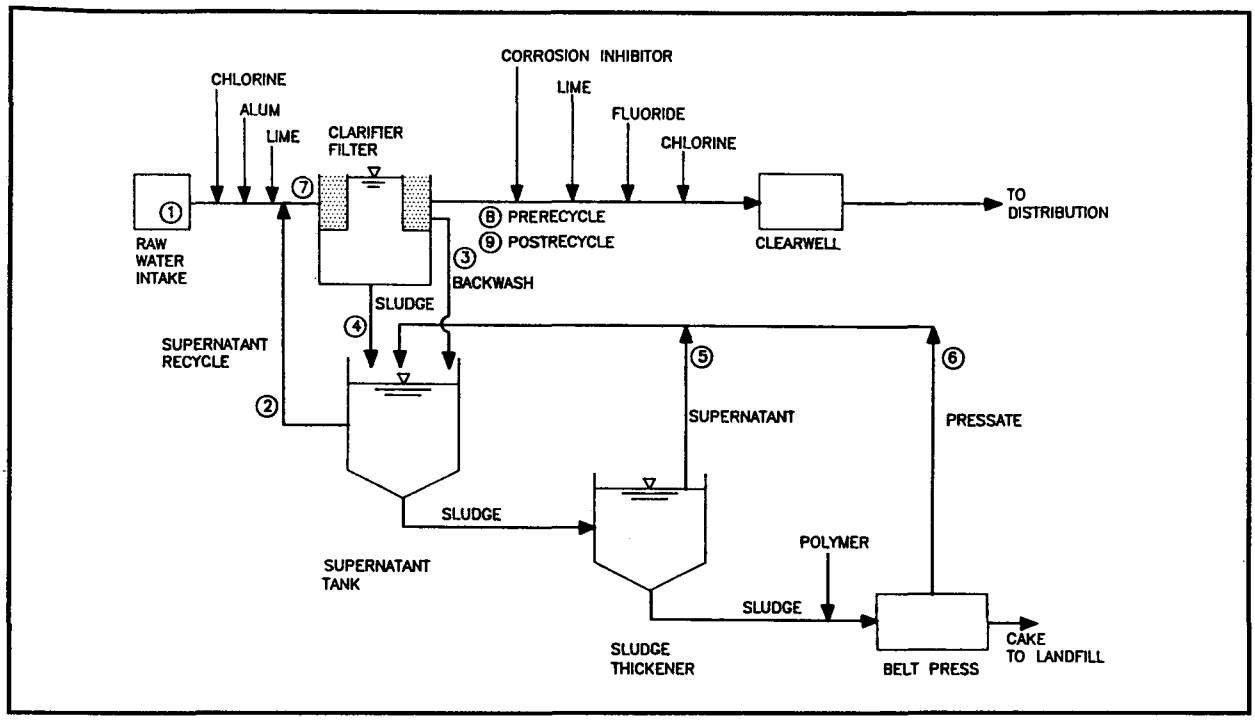


Figure 3.1 Process flow diagram and sampling point locations for Mianus Water Treatment Plant

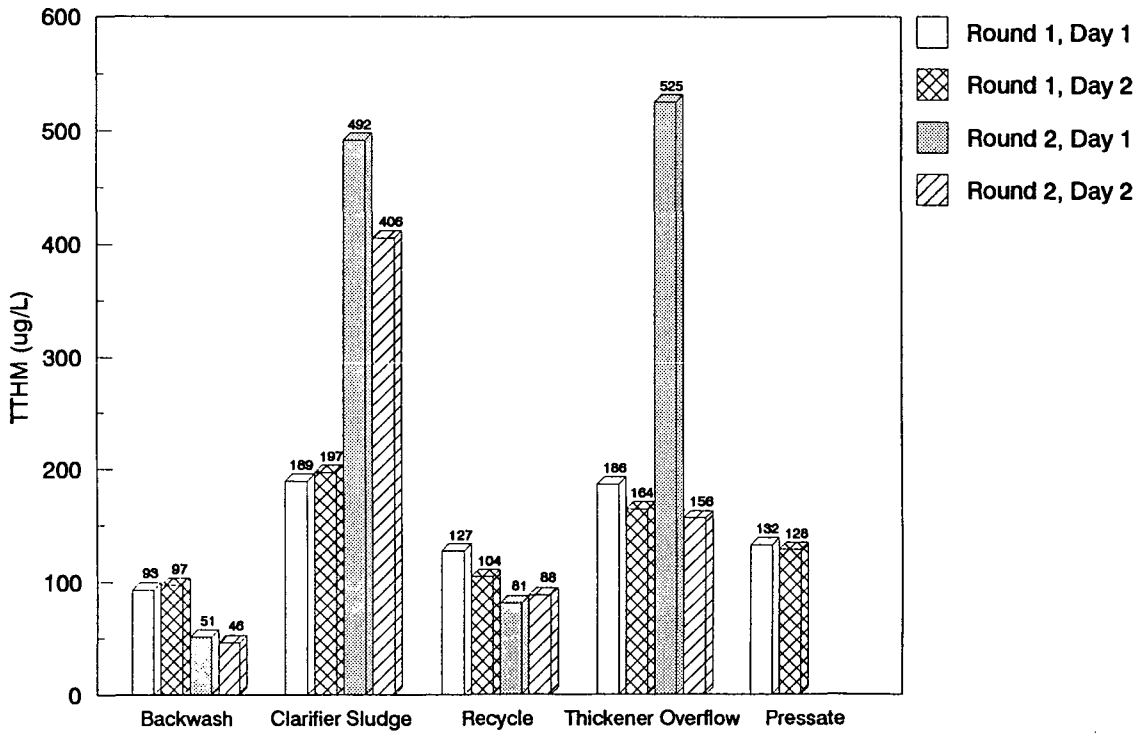


Figure 3.2 TTHM levels in waste streams for Mianus Water Treatment Plant

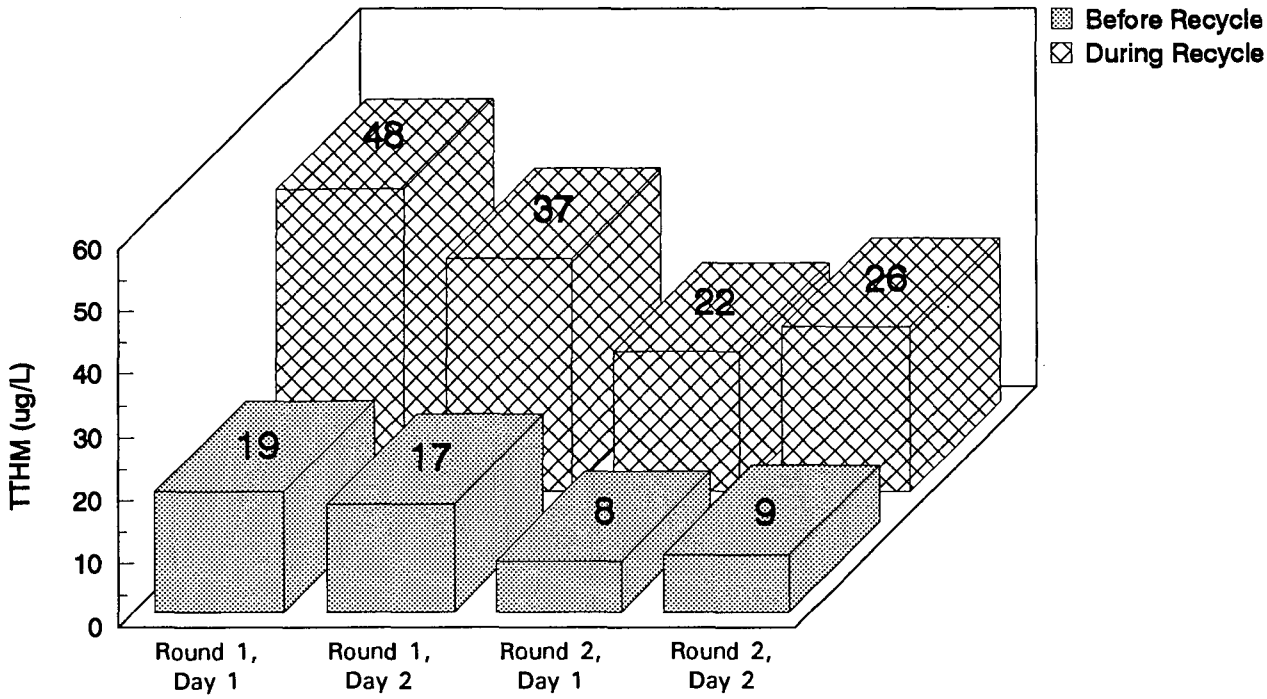


Figure 3.3 TTHM levels in mixed water for Mianus Water Treatment Plant

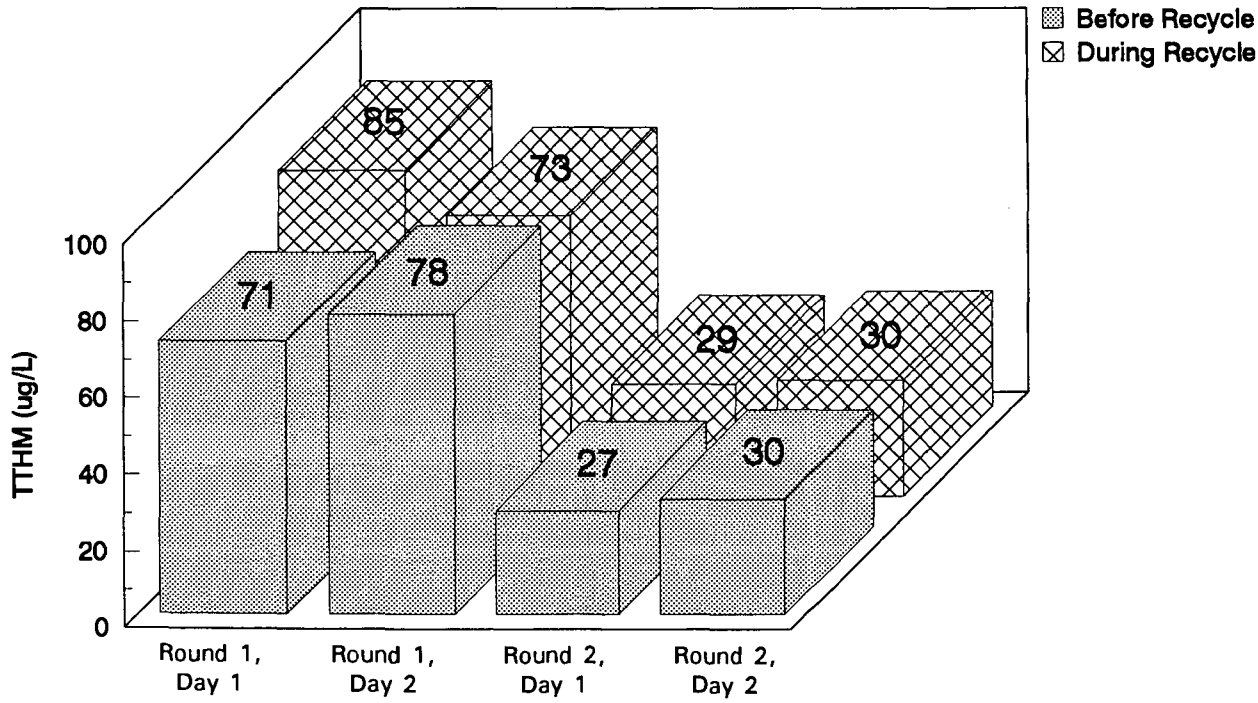


Figure 3.4 TTHM levels in filtered water for Mianus Water Treatment Plant

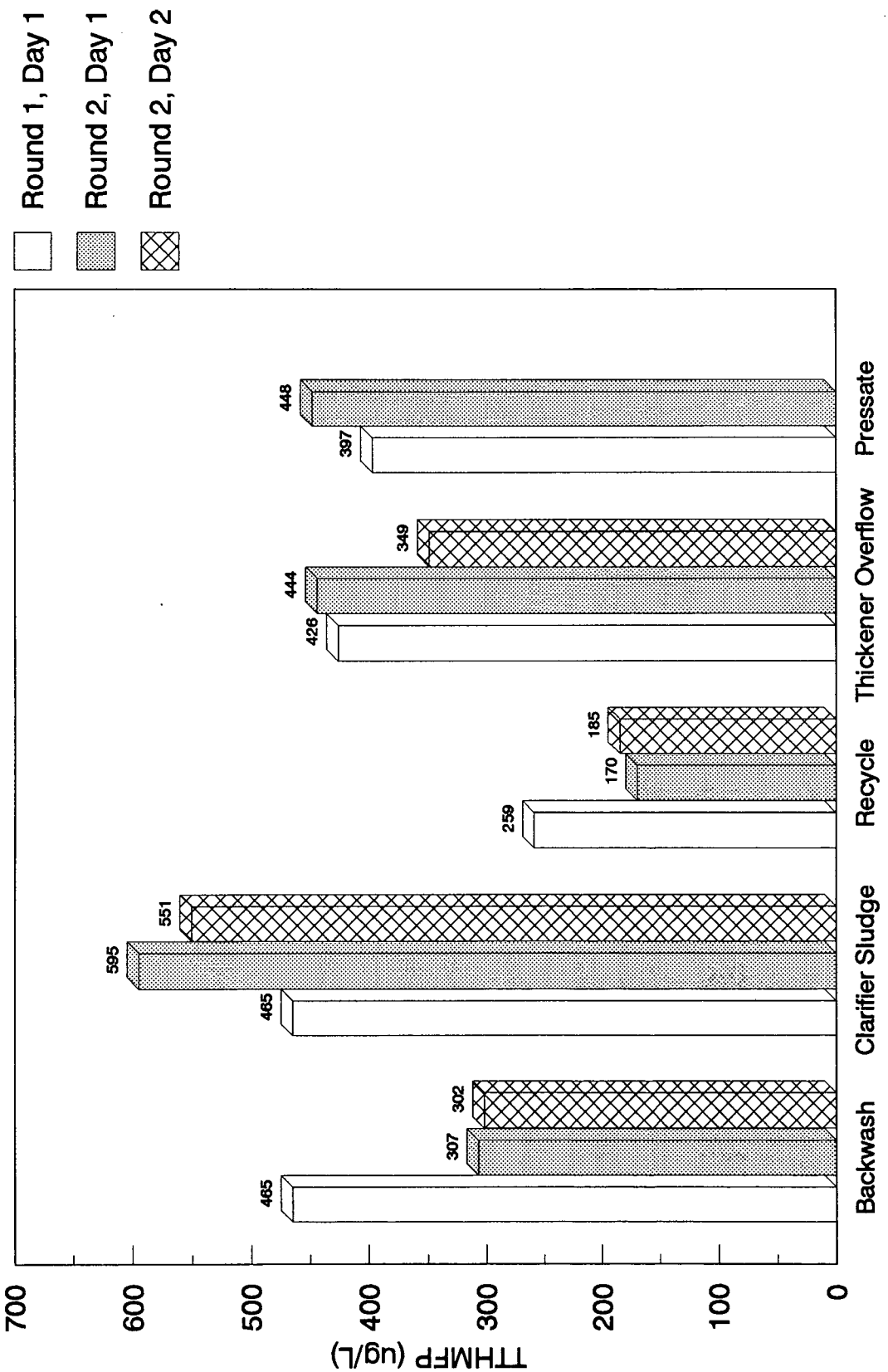


Figure 3.5 TTHMFP levels in waste streams for Mianus Water Treatment Plant

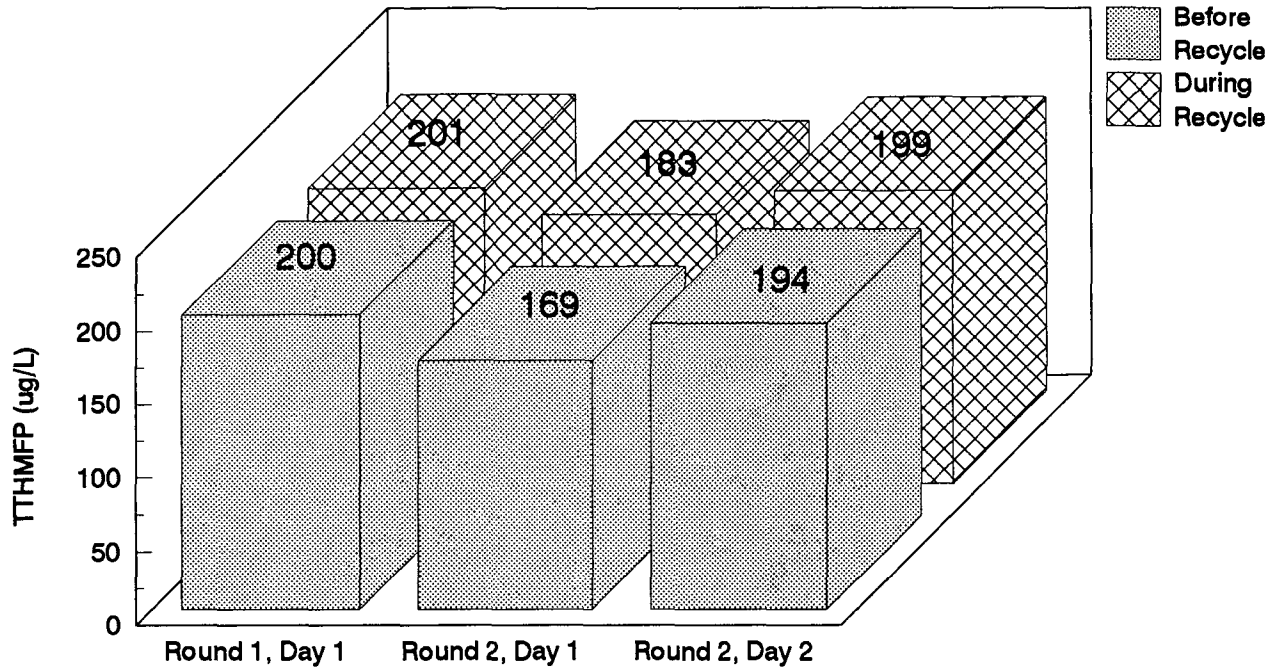


Figure 3.6 TTHMFP levels in influent water for Mianus Water Treatment Plant

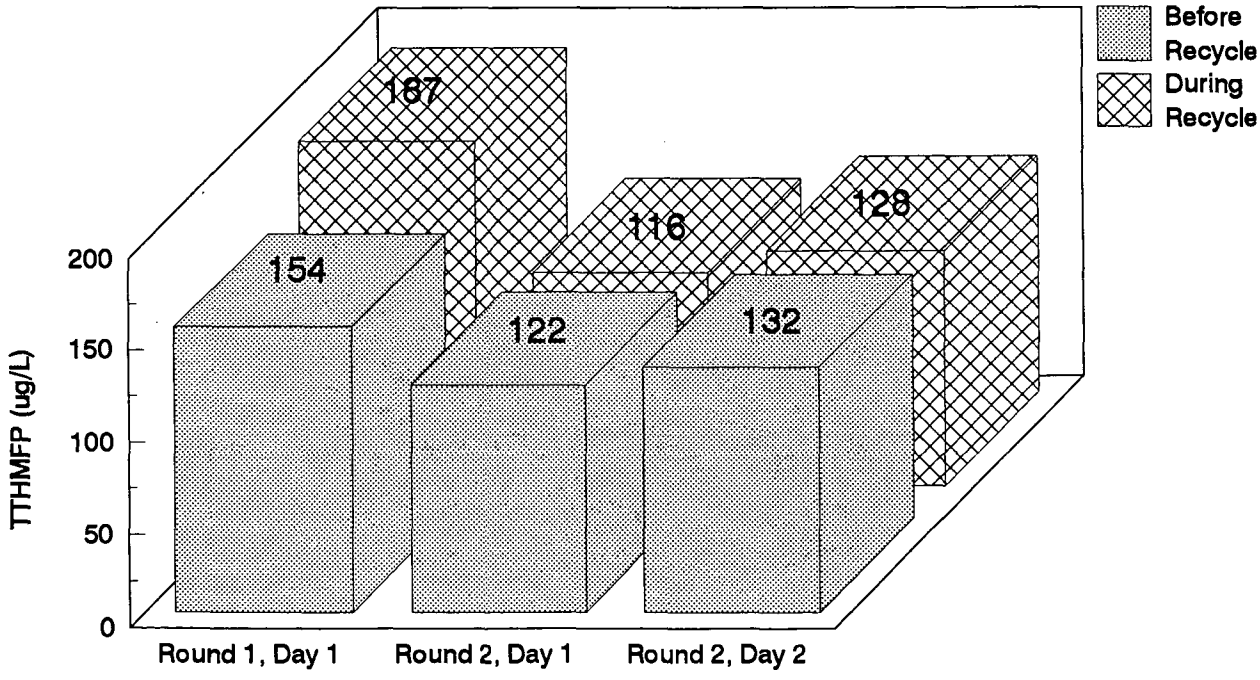


Figure 3.7 TTHMFP levels in filtered water for Mianus Water Treatment Plant

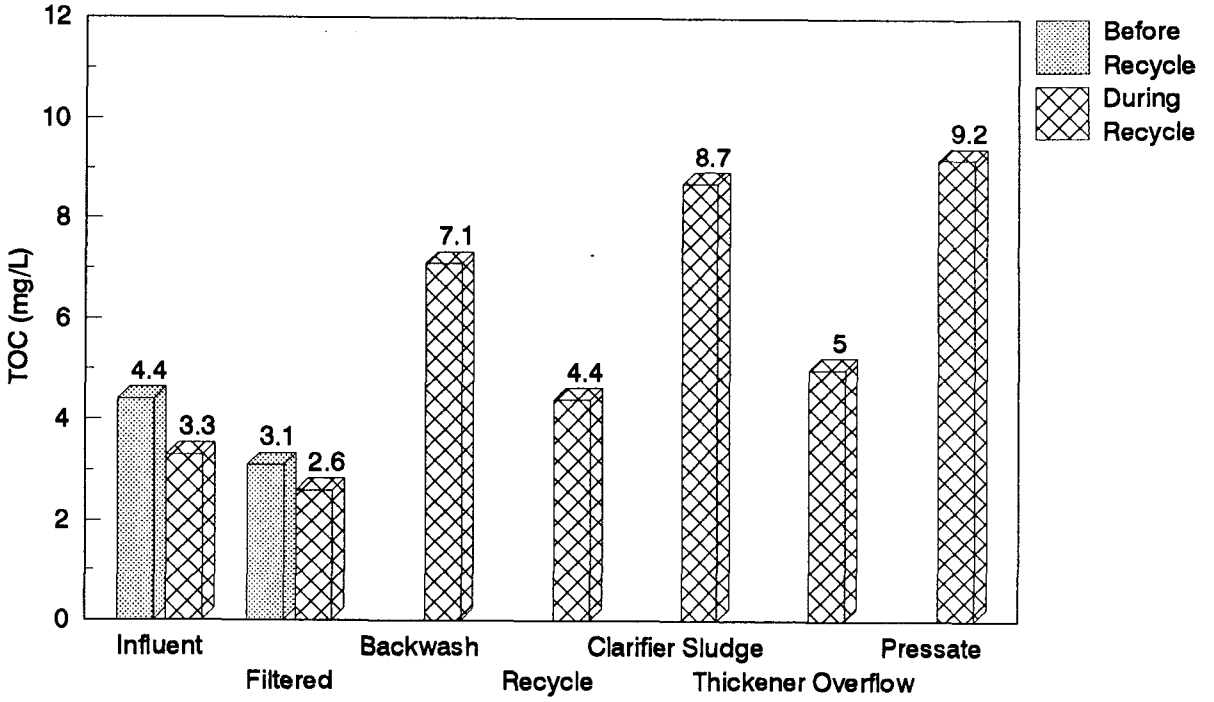


Figure 3.8 TOC levels in waste streams for Mianus Water Treatment Plant; round 1

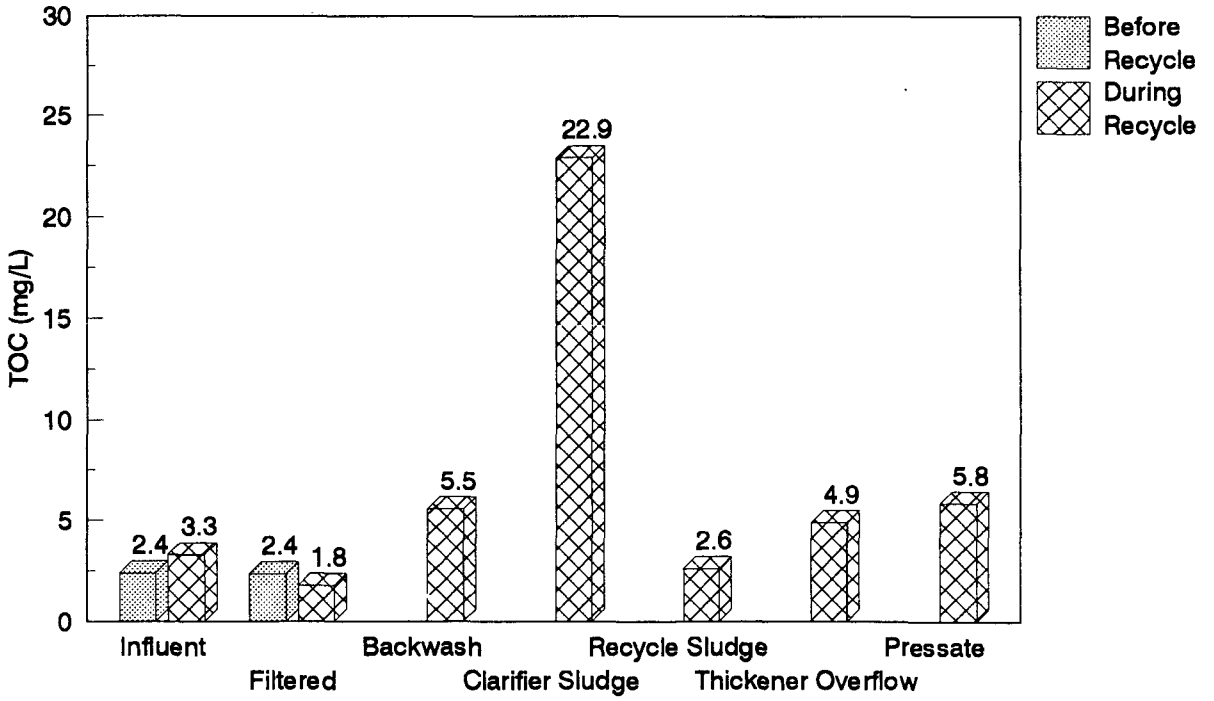
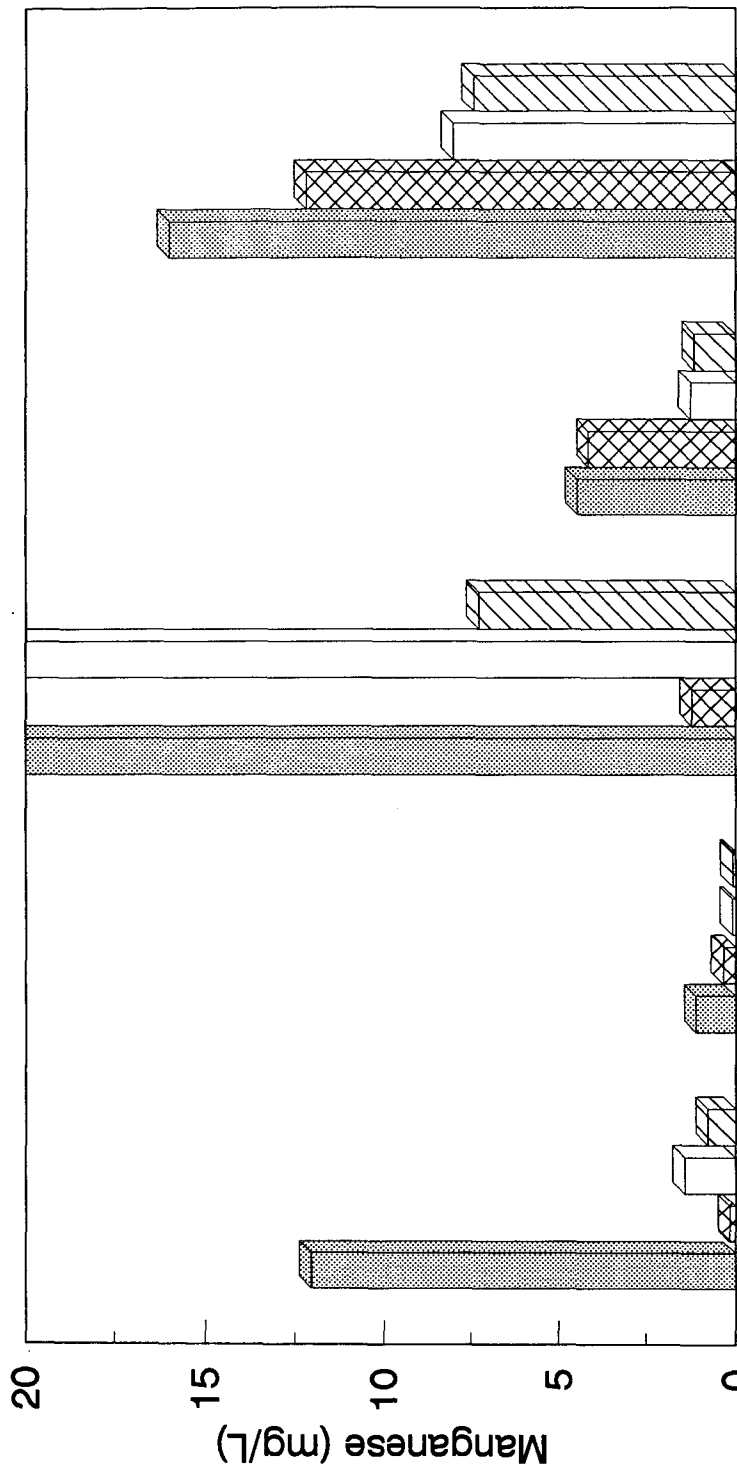


Figure 3.9 TOC levels in waste streams for Mianus Water Treatment Plant; round 2



	Backwash	Recycle	Clarifier Sludge	Thickener Overflow	Pressate
Round 1: Total Mn	12.03	1.09	180.20	4.46	15.99
Round 1: Dissolved Mn	0.15	0.32	1.21	4.13	12.19
Round 2: Total Mn	1.40	0.09	46.50	1.25	8.00
Round 2: Dissolved Mn	0.75	0.07	7.28	1.14	7.43

Figure 3.10 Manganese levels in waste streams for Mianus Water Treatment Plant

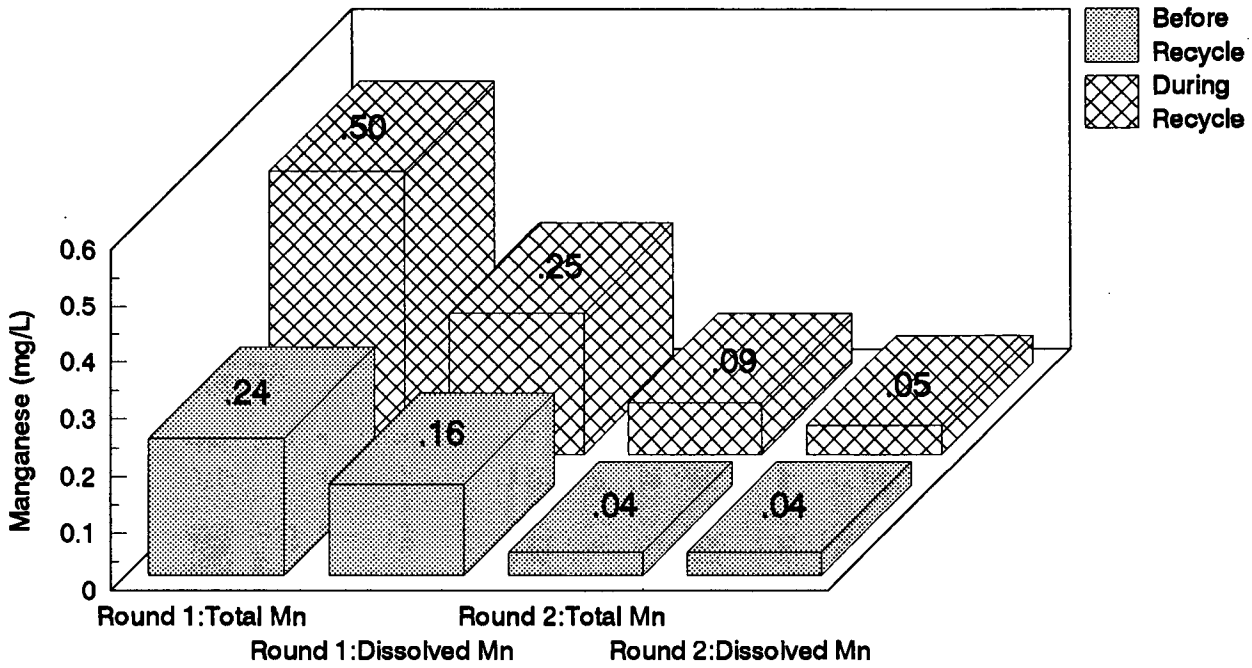


Figure 3.11 Manganese levels in influent water for Mianus Water Treatment Plant

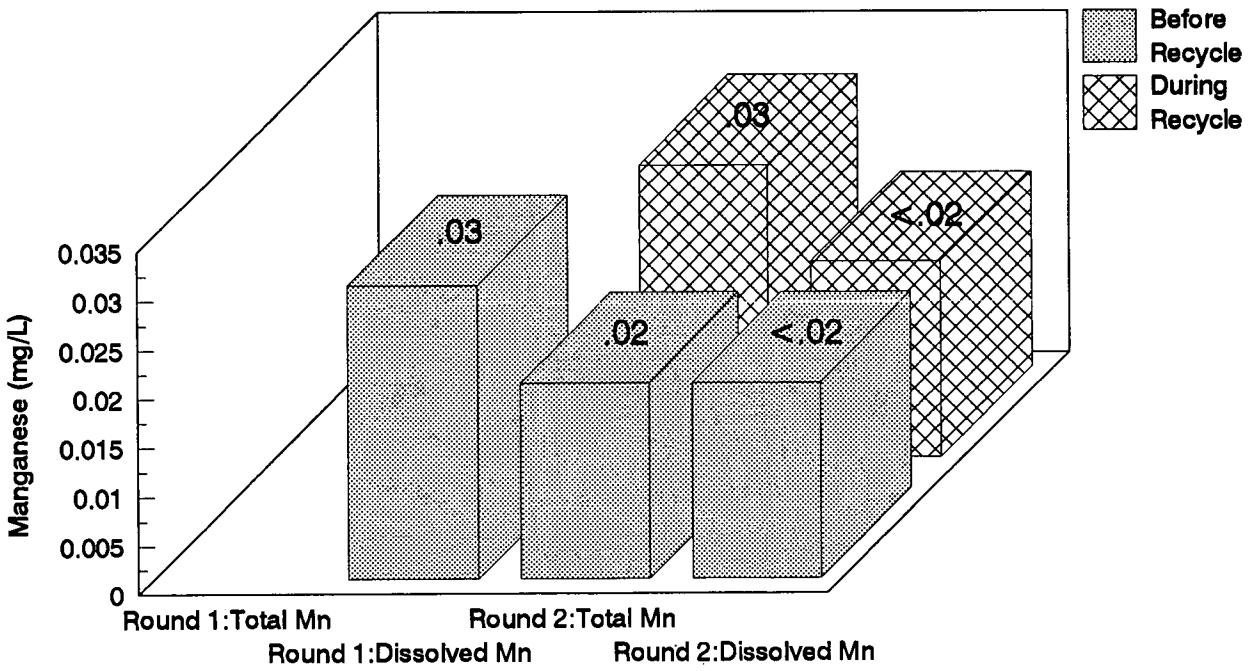


Figure 3.12 Manganese levels in filtered water for Mianus Water Treatment Plant

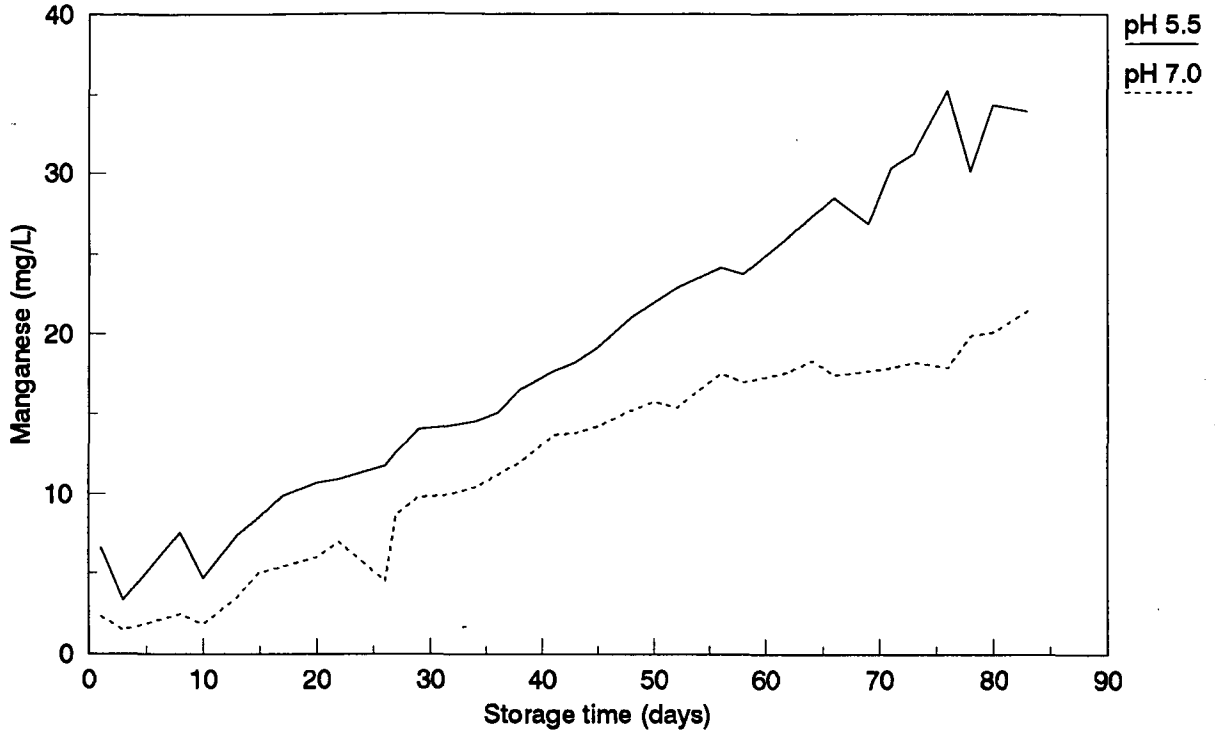


Figure 3.13 Manganese released with sludge storage time for Mianus Water Treatment Plant

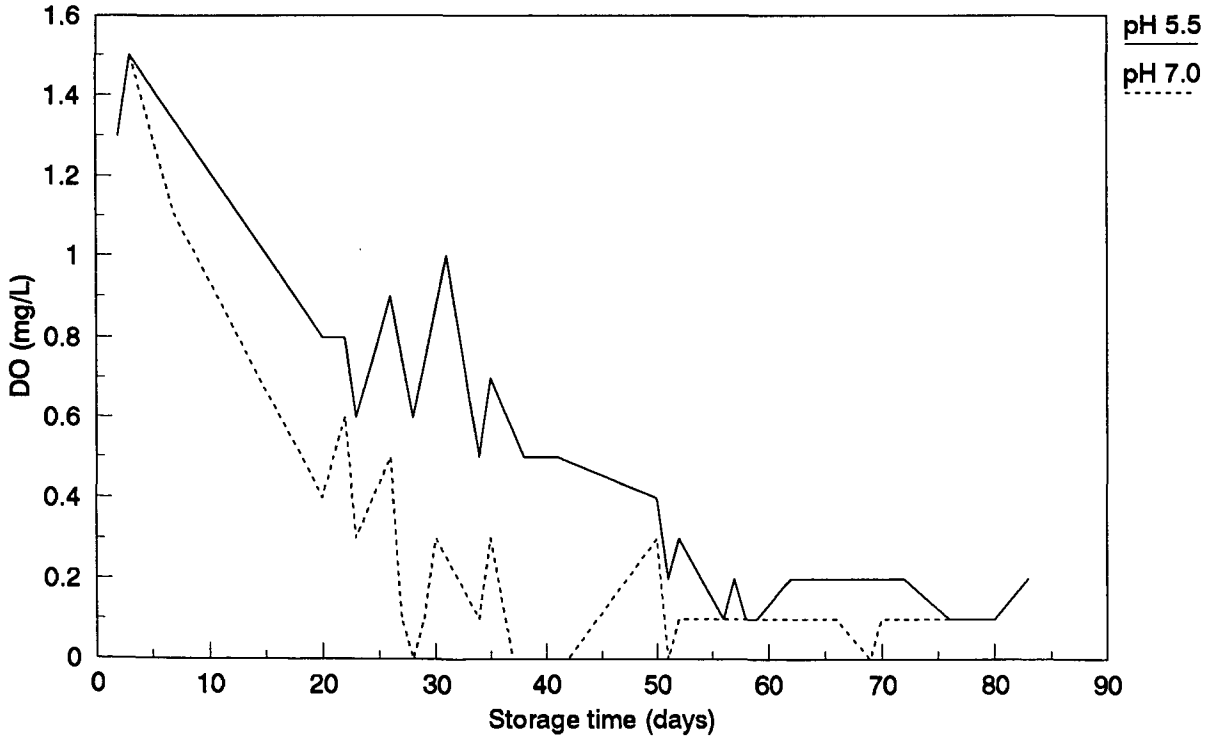
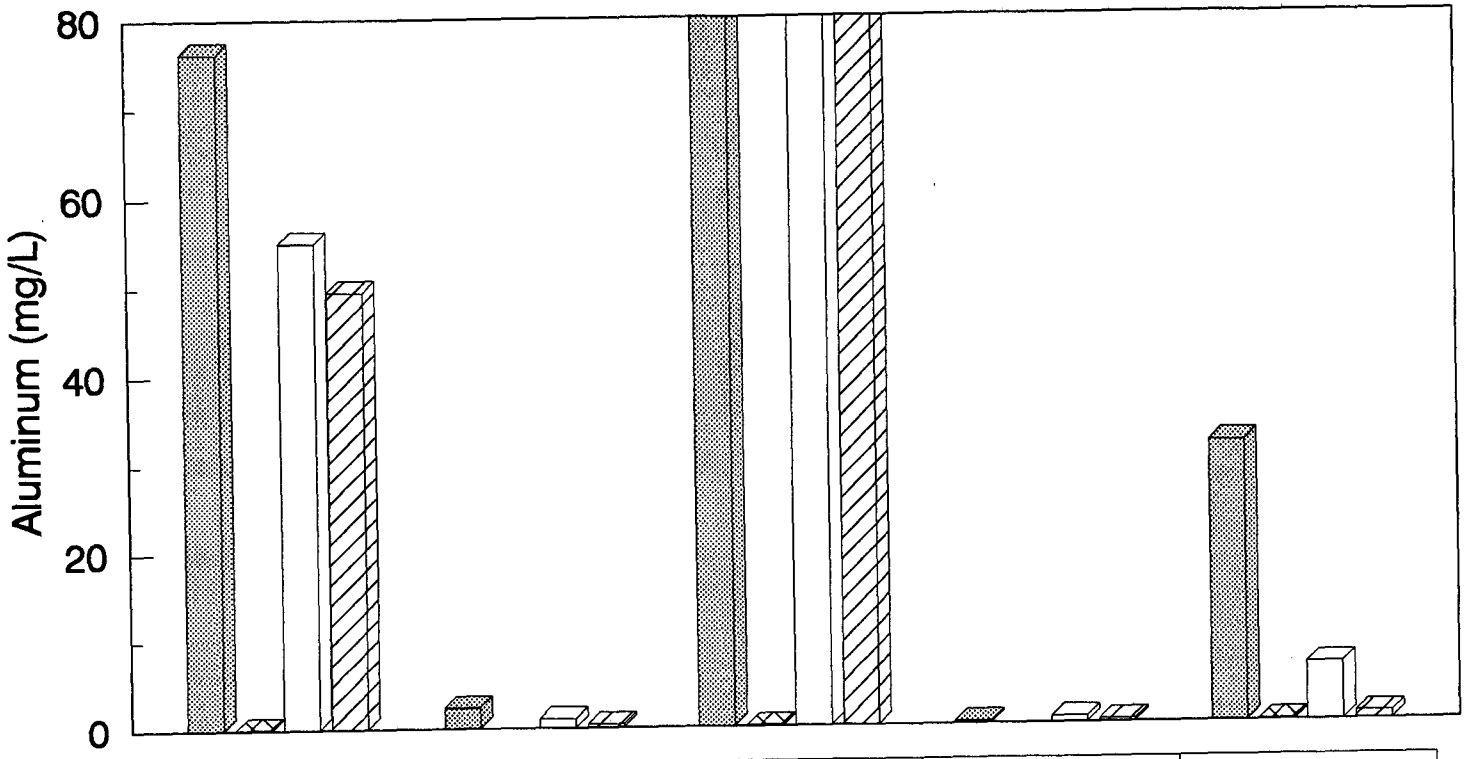


Figure 3.14 Dissolved oxygen concentrations over sludge storage time for Mianus Water Treatment Plant



	Backwash	Recycle	Clarifier Sludge	Thickener Overflow	Pressate
Round 1: Total Al	76.17	2.32	1,503.00	0.18	31.80
Round 1: Dissolved Al	0.03	No data	0.06	No data	0.02
Round 2: Total Al	55.00	1.00	2,567.00	0.62	6.40
Round 2: Dissolved Al	49.46	0.32	1,087.00	0.27	0.81

Figure 3.15 Aluminum levels in waste streams for Mianus Water Treatment Plant

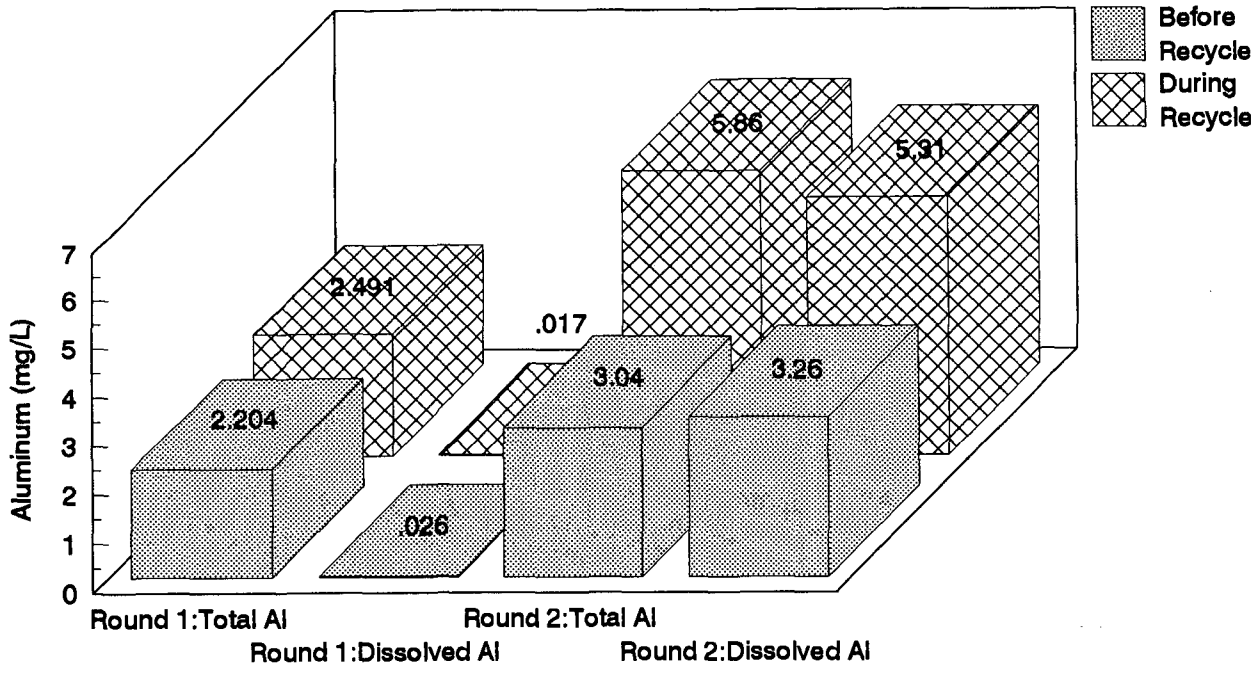


Figure 3.16 Aluminum levels in influent water for Mianus Water Treatment Plant

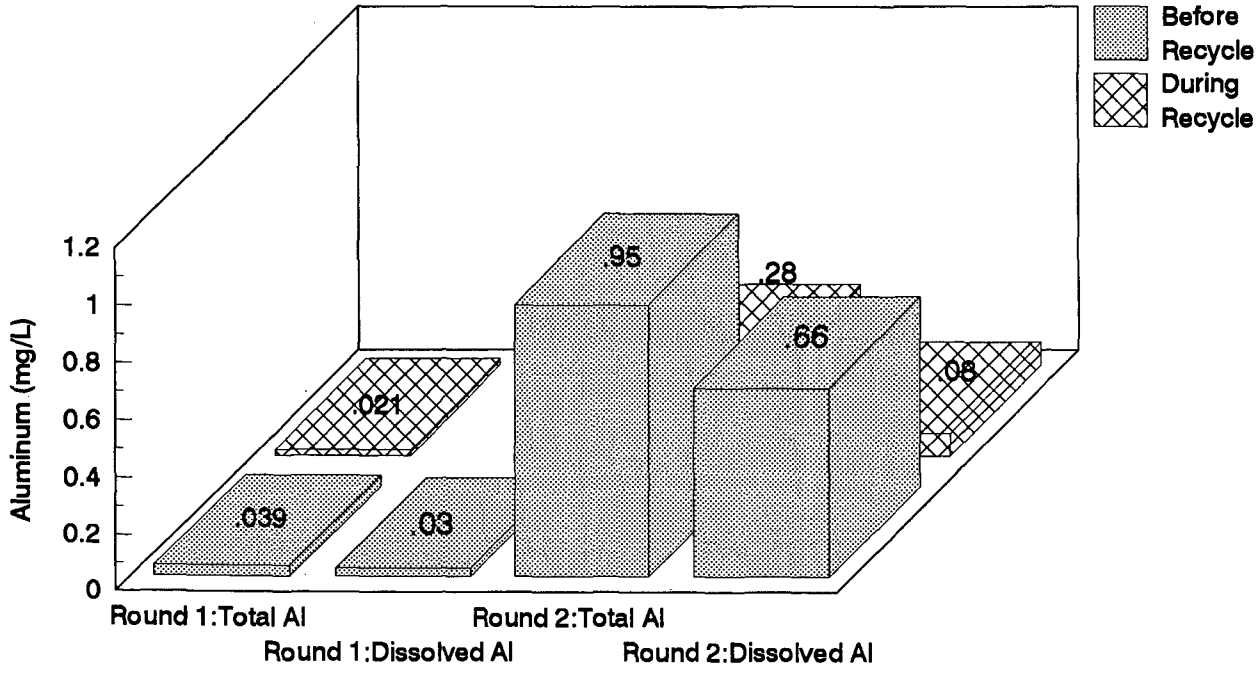


Figure 3.17 Aluminum levels in filtered water for Mianus Water Treatment Plant

Chapter 4

Kanawha Valley Water Treatment Plant

Plant Description

Treatment Process

The Kanawha Valley Water Treatment Plant is located in Charleston, W. Va. and draws water from the Elk River. Raw water quality is generally very good. Heavy rains create high turbidity, but this does not present a problem for treatment. There are four low-service pumps that draw from a wetwell. Pretreatment chemicals are fed into the raw water line. The plant was built to have two identical sides with independent operation if needed. Mixing is conducted in an over- and underbaffled chamber. From each mixing chamber the flow is diverted into upflow clarifiers. The settled water flows to 16 filters (8 per side) made up of sand and anthracite. Five high-service pumps are available for pumping from the 4-MG (15,000 m^3) clearwell. A process flow diagram is shown in Figure 4.1.

Plant Flow

The plant was designed to treat 40 mgd (6,300 m^3/h) at a 2-gpm/ft^2 (4.9-m/h) filtration rate. Average daily flow is 25 to 30 mgd (4,000 to 4,700 m^3/h); winter flow is 20 mgd (3,150 m^3/h), and in summer the flow approaches 40 mgd (6,300 m^3/h). The distribution system has 28 MG (0.11×10^6 m^3) of storage with tanks ranging in size from 0.1 to 5 MG (379 m^3 to 17,600 m^3).

Chemical Feed

The raw water chemicals used on a regular basis are polymer, lime, and chlorine; ClO_2 is used on a seasonal basis. Prefiltered water at the plant is treated by the addition of polymer and lime, and filtered water receives fluoride. Typical chemical doses are shown in Table 4.1.

Solids Handling

Sludge from the upflow clarifiers is sent to the sewer. Spent filter backwash water is recycled to the head of the plant.

Recycle

Spent filter backwash water is pumped from the holding tank into the raw water line upstream of the chemical application point. Some settling occurs in the holding tank prior to recycle. An initial slug of heavy solids is pumped at the beginning of the recycle operation. Recycle pumping periods last for 2 to 3 hours and occur one to three times a day. The recycle pumps are rated at 2,000 gpm (540 m^3/h) each, and normal operation is to operate one or two of the four pumps at one time. The recycle flow could therefore range from 10 to 20 percent of the raw water flow for conditions on an average day.

Water Quality

Raw and finished water quality data for the plant are summarized in Table 4.2. The main parameters of interest at this plant were turbidity, TTHM, and TTHMFP concentrations.

Preliminary sampling was conducted by taking a one-time grab sample of the recycle waste stream and the process stream. Clarified water was sampled before and during recycle in order to observe potential impacts of recycle. Table 4.3 summarizes the results of this initial investigation. These results showed elevated levels of TTHMFP and turbidity in the recycle water.

Comprehensive Sampling Program

Overview

Two rounds of field sampling and analysis were performed at the Kanawha Valley Water Treatment Plant. Because this plant recycles unsettled spent backwash water, the parameter of primary interest was turbidity.

Round 1 Sampling

Plant operation was normal during sampling. Plant flow was 30 mgd (4,730 m^3/h) and the recycle flow was 2,000 gpm (454 m^3/h), corresponding to 10 percent recycle. Settled turbidities were in the range of 1.0 to 2.0 ntu, and filtered turbidities were less than 0.20 ntu.

Sampling was conducted over a 2-day period, with one set of samples taken each day. The water quality parameters studied were

TTHM
TTHMFP
TOC
Turbidity
Chlorine residual
pH

The sample locations for these parameters are listed below. Numbers in parentheses indicate the sampling locations as shown in Figure 4.1.

Raw water (1)
Mixed water without recycle (2)

Settled water without recycle (3)
Filtered water without recycle (4)
Mixed water with recycle (2)
Settled water with recycle (3)
Filtered water with recycle (4)
Recycle water (unsettled spent backwash) (5)

The recycle of spent backwash water was halted 8 hours prior to sampling. This allowed residual recycle water from previous operations to be flushed from the plant. Samples were then collected on the raw, mixed, settled, and filtered water. The plant then backwashed the filters as needed. The spent backwash water soon filled the backwash holding tank, and recycle to the head of the plant began. A composite sample of the spent backwash water was taken as a recycle sample. Sampling times, determined using the theoretical detention times through each process, were as follows:

Mixing	33 minutes
Sedimentation	2.66 hours
Filtration	13 minutes

Two or three detention times were allowed for the recycle to be fully distributed through each process prior to sampling.

All samples were grab samples except the recycle sample, which was a composite sample. The results from round 1 sampling are contained in Table 4.4. The sampling locations are shown in Figure 4.1.

Round 2 Sampling

In addition to the same samples as collected in round 1, during round 2 unsettled backwash water was taken, allowed to settle for a predetermined amount of time, and sampled again. A chlorine die-off curve was also performed on the recycle water. The results from round 2 field sampling are shown in Table 4.5.

Trends

TTHM

The introduction of the recycle stream to the treatment process showed significant effects on TTHM levels throughout the treatment process. Figures 4.2 and 4.3 show the TTHM values at influent, settled, and filtered sampling points along with the TTHM concentration of the recycle streams from round 1 and round 2 sampling. These graphs show that TTHM values rose significantly at the plant sampling points during the recycle operation. Filtered water with TTHM increased from 73 to 95 µg/L in round 1 and from 25 to 38 µg/L in round 2.

TTHMFP

TTHMFP levels in the recycle water were generally twice those of the raw water. Figures 4.4 and 4.5 show TTHMFP values at the influent, settled, and filtered sampling points along with TTHMFP values of the recycle water. The results from this sampling show a slight increasing trend of TTHMFP levels throughout the

process during the recycle operation. The mixed, settled, and filtered water all increased by similar percentages. Round 2 sampling showed that settling the recycle water could significantly reduce the TTHMFP values.

Turbidity

Sampling from round 1 and round 2 showed that the recycle stream had substantial effects on the turbidity of the mixed water; however, there was no impact on clarified or filtered water. The treatment process was able to handle the increased turbidity loading without an impact on finished water. Figures 4.6 and 4.7 show the effects of the recycle stream on turbidity readings taken during round 1 and round 2 sampling.

Because the mixed water sampling point was the point most affected by the recycle stream, it was chosen as the appropriate location to perform an analysis of turbidity over time. Turbidity readings were taken at 10-minute intervals for 90 minutes after the start of recycle. Figure 4.8 shows the results of these readings, with a turbidity spike of 20 to 25 ntu taking place 30 to 40 minutes into the recycle process.

Chlorine

Two samples of the recycle stream were taken, and a chlorine die-off analysis was performed. The results of this analysis are shown in Figure 4.9. Both samples showed similar trends, with all chlorine being consumed between 30 and 40 minutes. However, because the backwash holding tank had very little residence time, all chlorine may not have been consumed before the introduction of the recycle stream back into the process. Therefore more TTHMs could be formed in the process stream.

Table 4.1 Chemical feed data for Kanawha Valley Water Treatment Plant

Location	Chemical	Dose (mg/L)
Raw	Polymer	1.5
	Lime	8.0
	Cl_2	1.5–3.0
	ClO_2 (summer)	6
Prefilter	Polymer	occasional
	Lime	occasional
Filtered	Fluoride	1.0
	Chlorine	1.0–2.0

Table 4.2 Average annual water quality data for Kanawha Valley Water Treatment Plant

Parameter	Raw	Finished
Turbidity, ntu	11	0.27
Color, cu	<5	<5
Iron, mg/L	<0.05	<0.05
Manganese, mg/L	<0.02	<0.02
pH	6.9	9.0
Alkalinity, mg/L $CaCO_3$	33	30
Ammonia, mg/L	<0.01	<0.01
Aluminum, mg/L	NA	0.01
Coliform, number/100 mL	285	<1
TOC, mg/L	2.0	1.8
TTHM, µg/L	NA	77
Free Cl_2, mg/L	NA	1.5

NA = no data available

Table 4.3 Preliminary sampling results for Kanawha Valley Water Treatment Plant

		Clarifier effluent	
Parameter	Recycle stream	Without recycle	With recycle
Turbidity, ntu	250	5	7
pH	9.1	6.9	6.9
Total chlorine, mg/L	1.5	1.5	1.5
Free chlorine, mg/L	1.5	1.5	1.5
Alkalinity, mg/L as $CaCO_3$	41	25	25
Coliform, number/100 mL	<1	<1	3
Heterotrophic plate colonies, colonies/mL	90	73	7
Aluminum, mg/L	0.23	0.04	0.05
Iron, mg/L	0.12	<0.05	<0.05
Manganese, mg/L	0.10	0.04	0.04
TSS, mg/L	1,000	10	8
TOC, mg/L	3.4	2.2	2.5
TTHM, µg/L	52	7	5
TTHMFP, µg/L	762	202	235

Table 4.4 Round 1 results for Kanawha Valley Water Treatment Plant

Sample	TTHM (µg/L)	TTHMFP (µg/L)	TOC (mg/L)	Turbidity (ntu)	pH	Free Cl_2 (mg/L)
Raw (1)*	NA	126	3.5	34	6.9	<0.1
Mixed B (2)	14	145	3.2	27	6.6	3.0
Mixed D (2)	29	162	3.0	30	6.7	2.9
Settled B (3)	65	159	2.9	1.7	6.6	0.2
Settled D (3)	97	169	3.8	1.9	6.7	0.2
Filtered B (4)	73	193	3.5	0.1	9.0	3.0
Filtered D (4)	95	198	NA	0.07	9.0	2.4
Recycle (5)	98	265	4.1	400	8.5	1.1

B = before recycle
D = during recycle
NA = no data available

* Numbers in parentheses indicate sample locations as shown in Figure 4.1.

Table 4.5 Round 2 results for Kanawha Valley Water Treatment Plant

Sample	TTHM (µg/L)	TTHMFP (µg/L)	TOC (mg/L)	Turbidity (ntu)	pH	Free Cl_2 (mg/L)
Raw (1)*	<0.5	128	1.57	3.0	6.9	<0.1
Mixed B (2)	4.0	82	1.85	6.2	7.0	0.5
Mixed D (2)	9.0	80	13.22	20	7.0	0.5
Settled B (3)	12.0	65	2.08	3.8	6.9	0.3
Settled D (3)	14.0	66	1.73	2.5	7.0	0.3
Filtered B (4)	25.0	73	1.75	0.1	9.0	1.3
Filtered D (4)	38.0	89	1.93	0.1	9.0	1.4
Recycle, unsettled (5)	28.0	160	2.96	78	9.6	<0.1
Recycle, settled (5)	29.0	84	3.93	2.5	9.6	<0.1

B = before recycle
D = during recycle

*Numbers in parentheses indicate sample locations as shown in Figure 4.1.

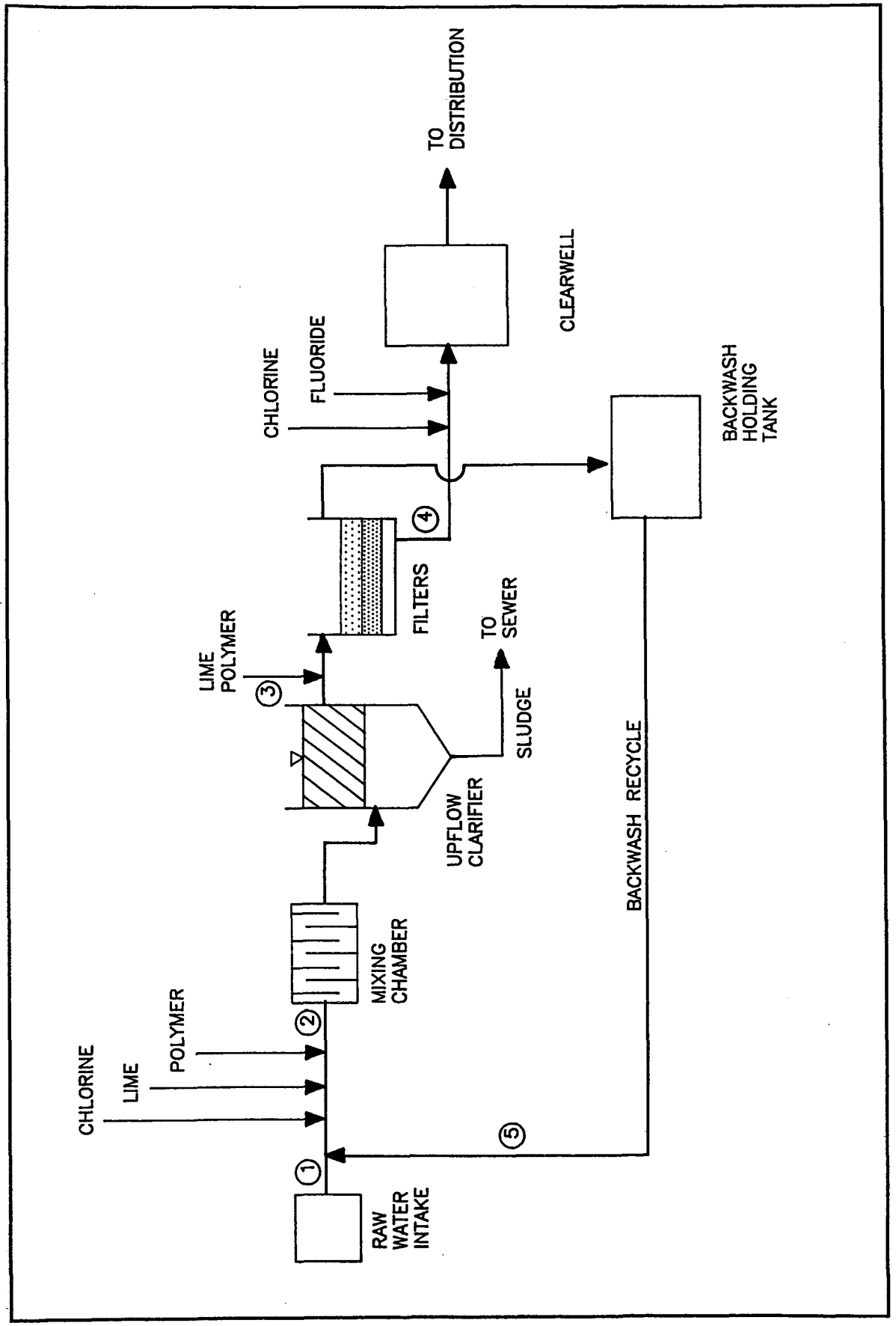


Figure 4.1 Process flow diagram and sampling point locations for Kanawha Valley Water Treatment Plant

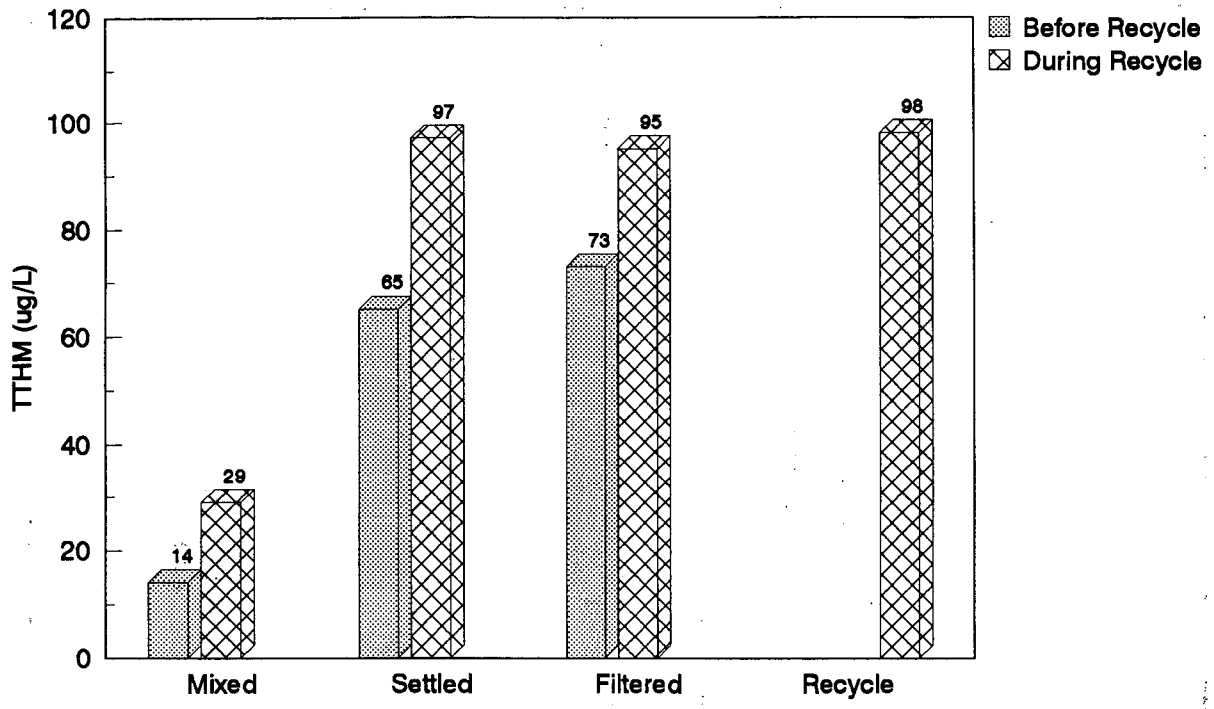


Figure 4.2 TTHM values for round 1 sampling at Kanawha Valley Water Treatment Plant

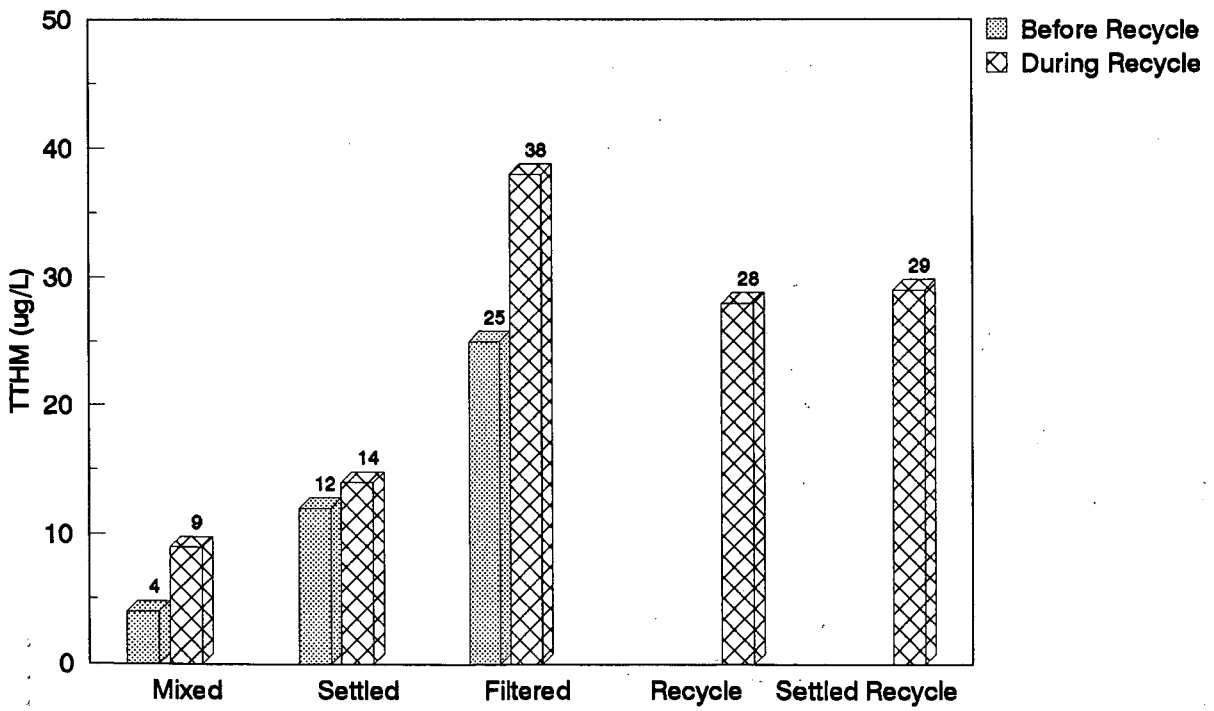


Figure 4.3 TTHM values for round 2 sampling at Kanawha Valley Water Treatment Plant

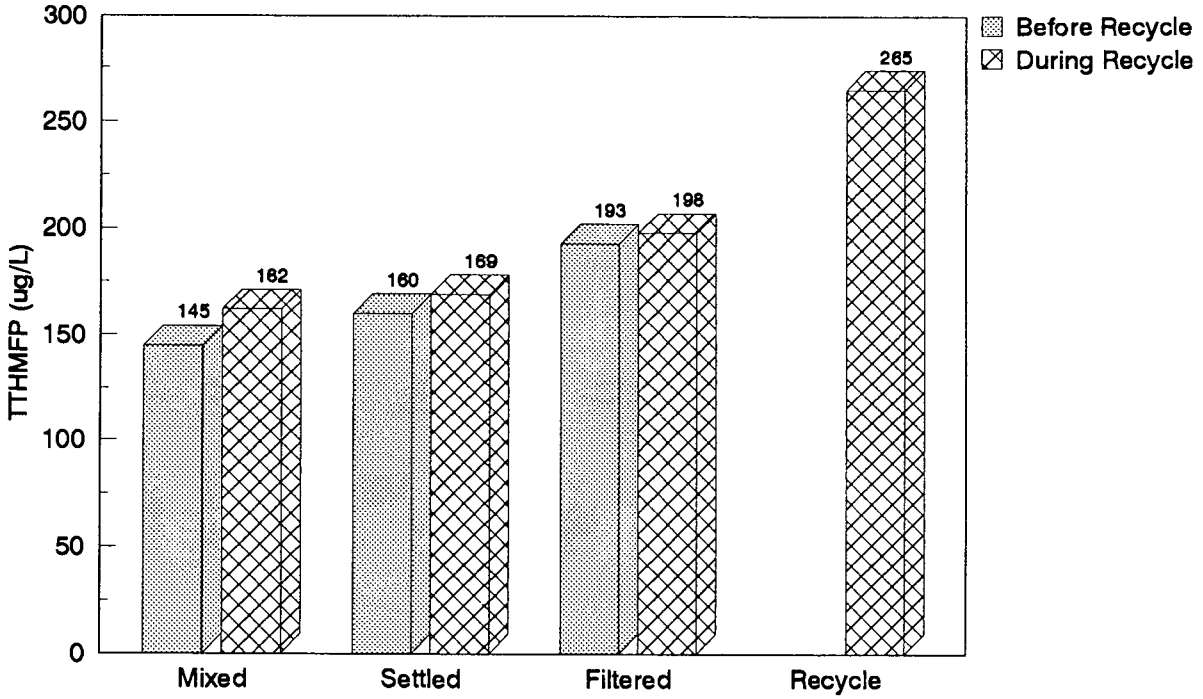


Figure 4.4 TTHMFP values for round 1 sampling at Kanawha Valley Water Treatment Plant

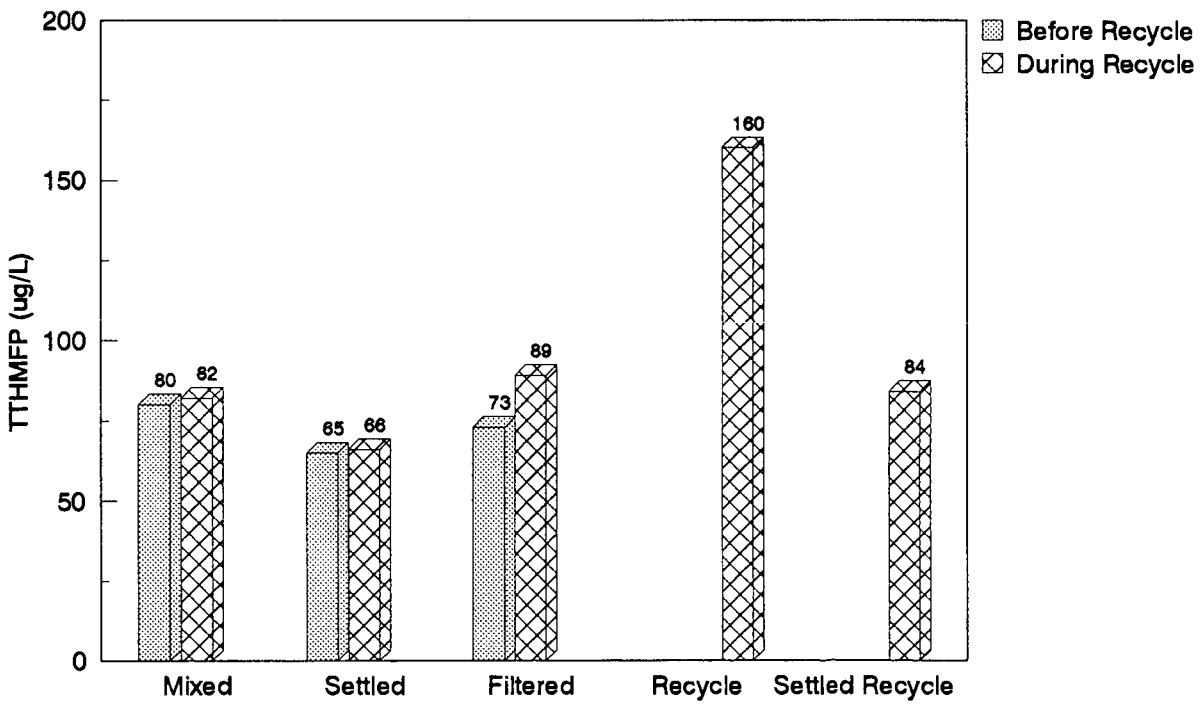


Figure 4.5 TTHMFP values for round 2 sampling at Kanawha Valley Water Treatment Plant

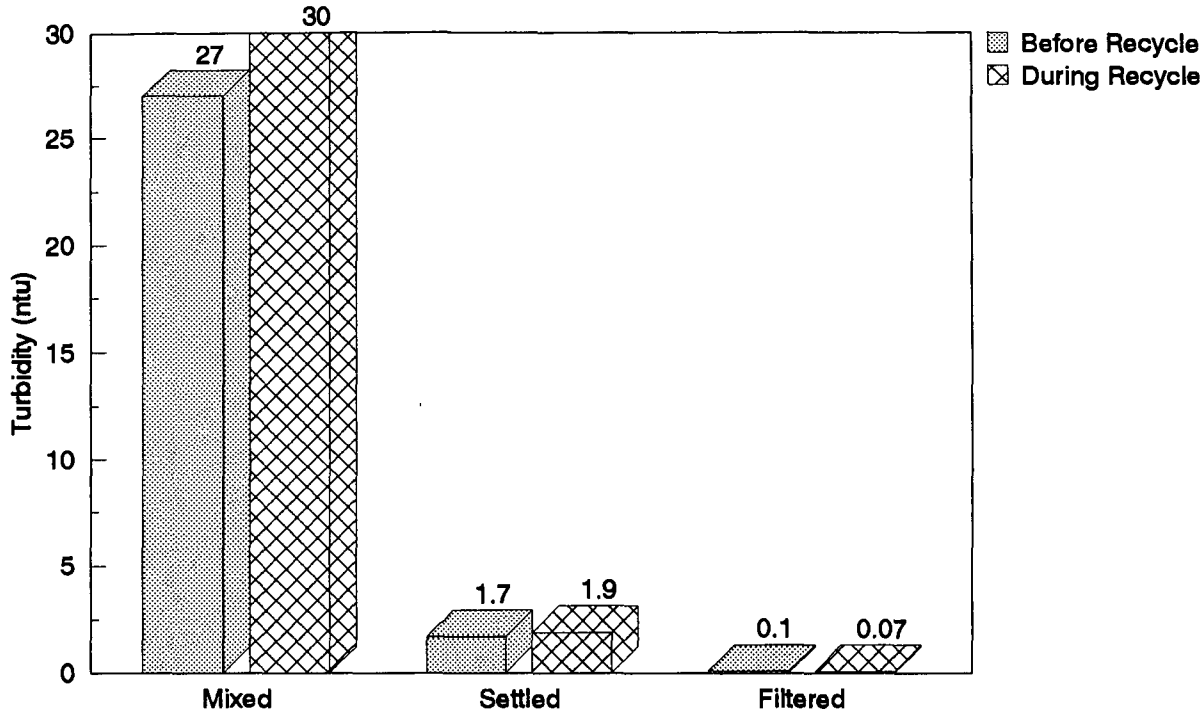


Figure 4.6 Turbidity values for round 1 sampling at Kanawha Valley Water Treatment Plant

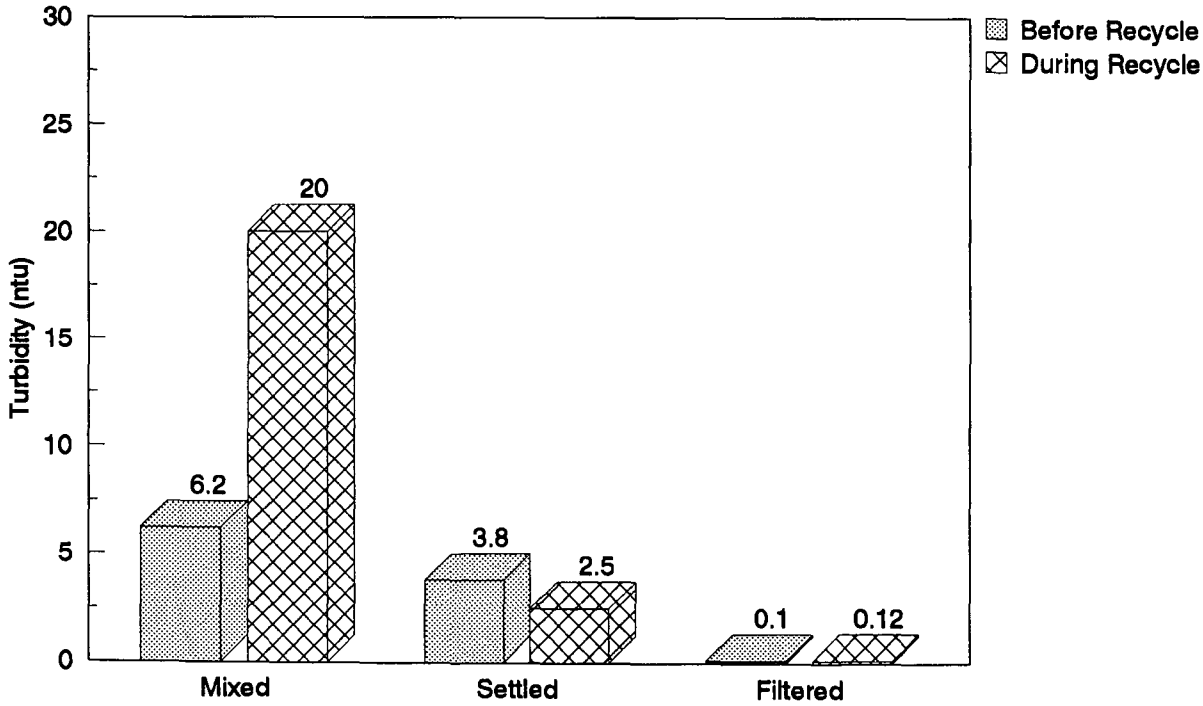


Figure 4.7 Turbidity values for round 2 sampling at Kanawha Valley Water Treatment Plant

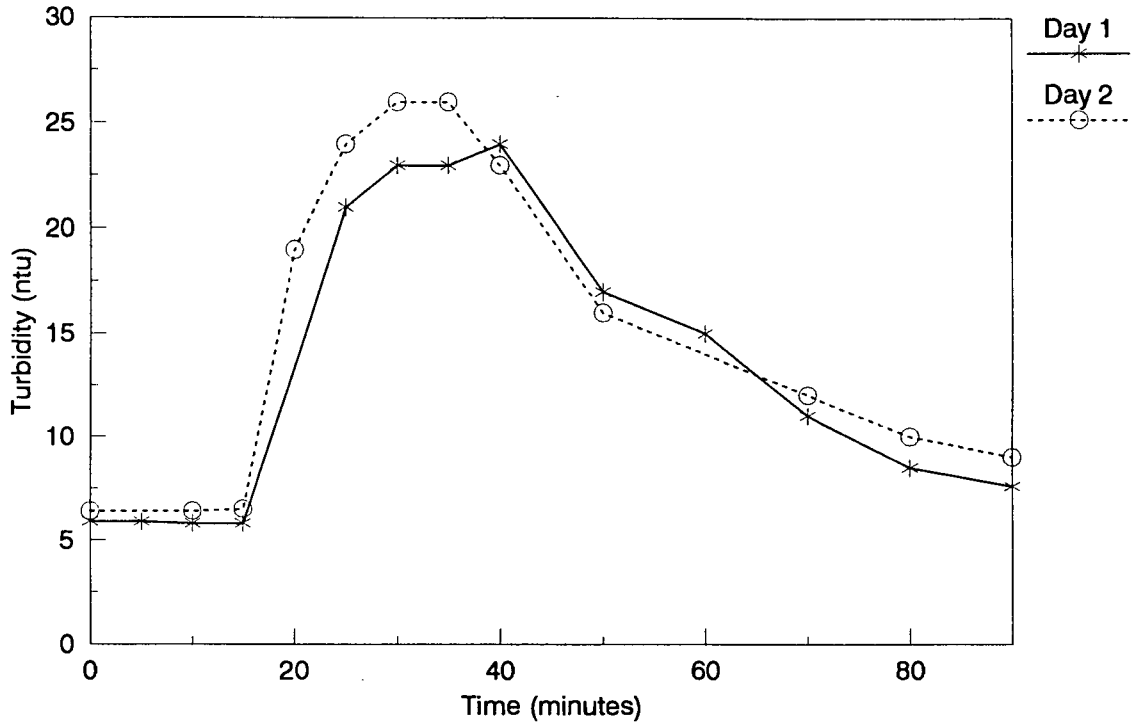


Figure 4.8 Mixed water turbidity during recycle at Kanawha Valley Water Treatment Plant

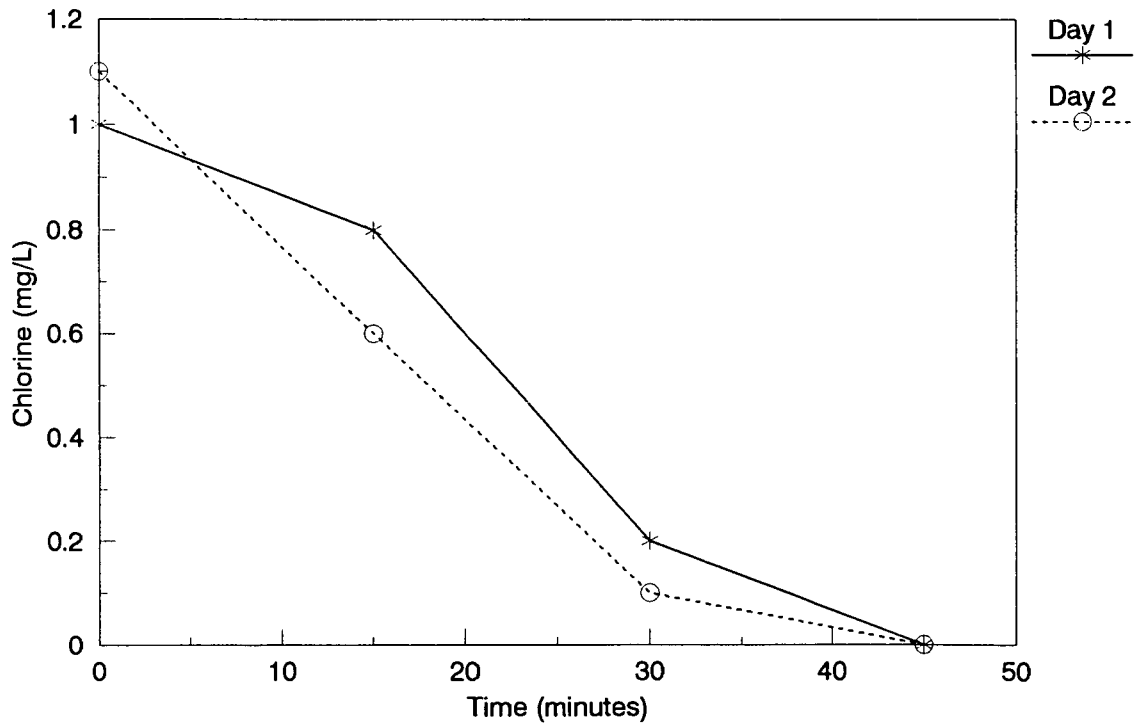


Figure 4.9 Chlorine residual in the recycle stream for Kanawha Valley Water Treatment Plant

Chapter 5

Swimming River Water Treatment Plant

Plant Description

Treatment Process

The Swimming River Water Treatment Plant is located in Strewsburg, N.J., and draws its water from the Swimming River Reservoir. Six Aldrich treatment units are used for combined mixing, settling, and filtration. The filtered water then goes into a clearwell before being pumped into the distribution system. Figure 5.1 shows the process flow schematic for the Swimming River Water Treatment Plant.

Plant Flow

The plant is rated at 36 mgd (5,700 m^3/h), with seasonal flows ranging from 18 mgd (2,850 m^3/h) in the winter to 40 mgd (6,300 m^3/h) in the summer. The daily plant flow is steady and does not vary more than 2 mgd (316 m^3/h) over a 24-hour period. The Aldrich units are rated at 6 mgd (950 m^3/h) each at a filtering rate of 4 gpm/ft^2 (9-9 m/h). The capacity of the finished water clearwell is 1.5 MG (5,700 m^3). There are seven high-service pumps rated at various capacities.

Chemical Feed

Typical raw water chemical feed consists of the addition of lime, chlorine, polymer, and alum. PAC was once added on a seasonal basis but now is added continuously in order to maintain a sludge blanket in the clarifier. Filtered water is treated with the addition of caustic, fluoride, and chlorine. Also, polymer is added to the settled sludge from the sludge thickener for conditioning purposes. Chemical feed doses are summarized in Table 5.1.

Solids Handling

Solids handling for Swimming River Water Treatment Plant consists of two backwash holding tanks, two small lagoons, and sludge dewatering by a proprietary belt press. Waste streams include

Settled solids from Aldrich units
Spent filter backwash
Backwash holding tank settled solids and supernatant

Lagoon overflow
Belt press pressate

The settled solids from the Aldrich units are withdrawn for 7 minutes every 4 hours. The washing period is determined by the percent solids in the reactor. The solids from the Aldrich units go to the sludge lagoons, and spent filter backwash flows to one of two 300,000-gal (1,000-m^3) holding tanks. The wastewater is allowed to settle for 2 hours before the supernatant is recycled. Sludge from the backwash holding tank goes to the lagoons. It takes 1 to 3 months to fill a lagoon to a sludge depth of 3 ft (1 m). Each lagoon has a capacity of 600,000 gal (2,200 m^3). Once the lagoon is full, the sludge is dewatered and removed by a private contractor.

Recycle

The two recycle streams at the Swimming River Water Plant are spent backwash holding tank supernatant and lagoon overflow. It takes two backwashes to fill one backwash holding tank. The spent backwash water is allowed to settle for 2 hours before the recycle pumps are turned on. Recycle pumps are rated at 1,400 gpm (378 m^3h) each (there are three pumps per tank, six total). Usually recycle is conducted with one pump, but all three can operate at one time. It takes 3 hours to empty a full backwash holding tank with one pump. The recycle stream enters the raw water line after carbon addition but before the remaining chemicals are added. With one pump on, the recycle flow is about 7 percent of the plant flow.

The lagoon overflow stream is recycled continuously. The recycle pumps are rated at 250 gpm (67 m^3/h) each. This recycle stream is therefore about 1 percent of the plant flow.

The effect of recycle comes primarily from the backwash stream. The SCD output becomes more negative during the 3-hour backwash recycle period. The SCD controls alum dose, increasing alum by between 2 and 5 mg/L during this period, from a normal alum dose of 10 to 15 mg/L. With this change in alum dose there is no change in settled water turbidity and no significant effect on treatment. There is no evidence of any effect on treatment from lagoon recycle. However, this recycle stream runs continuously, so it is not known what might happen if the stream were discontinued for an extended period of time.

Water Quality

Raw and finished water quality data for the Swimming River plant are summarized in Table 5.2. Raw water during summer months has a high algae content, and copper sulfate is applied in the reservoir for algae control. Raw water iron is approximately 1.0 mg/L but is not a problem for treatment. Raw water TOC is about 2.0 to 3.0 mg/L. Finished water TTHM is about 50 µg/L, with a free chlorine residual being carried through the entire plant.

Preliminary sampling consisted of collecting a one-time grab sample of the recycle waste streams and the clarified water. The clarified water was sampled before and during recycle in order to evaluate impacts of recycle. Table 5.3 summarizes the results of this initial investigation.

Round 1 Sampling

Sampling at this plant was conducted over 2 days. The primary parameters analyzed were

TTHM
TTHMFP
TOC
AOC
Aluminum
Manganese

The sample locations for these parameters are listed below. Numbers in parentheses indicate the sampling locations as shown in Figure 5.1.

Raw water (1)
Mixed water without recycle (2)
Filtered water without recycle (3)
Mixed water with recycle (2)
Filtered water with recycle (3)
Spent backwash supernatant (4)
Lagoon supernatant (5)
Spent backwash sludge (6)
Clarifier sludge (7)
Pressate (8)

Background data were collected on the treatment process before the recycle streams were introduced into the process. After these data were collected, two filters were backwashed and the spent backwash water was allowed to settle for 2 hours before the recycle pumps were started. The plant flow at the time of sampling was 26 mgd (4,100 m^3/h) and the recycle stream was 2.0 mgd (316 m^3/h) (7.5 percent). At a flow rate of 26 mgd (4,100 m^3/h) the theoretical detention times through each process were

Mixing	30 minutes
Settling	2.5 hours
Filtration	13 minutes

Grab samples were taken two to three detention times after recycle began in order to allow for adequate distribution of the recycle water in each process.

Figure 5.1 shows the sampling locations. Results from round 1 sampling are contained in Tables 5.4 and 5.5.

Trends

AOC

Figure 5.2 shows the AOC levels found at several sampling points in the Swimming River plant before and during recycle throughout the treatment process. The raw water had a total AOC of 228, whereas the waste sludge streams had levels of 900 to 1,100. The supernatant from the spent backwash water holding tank (one of the two recycle streams) had AOC levels of 800. However, AOC levels did not show increases at the mixed or filtered sampling points during recycle; in fact, levels decreased during recycle operations.

TTHM

TTHM levels in the spent backwash water recycle stream were essentially the same as those of the filtered water, both about 40 µg/L. A slight increase in TTHM and the mixing point occurred due to recycle, with the value rising from 4 to 11 µg/L. However, there was no measurable increase in filtered water TTHM. Figure 5.3 shows the TTHM results graphically

TTHMFP

Figure 5.4 shows the TTHMFP results for the Swimming River plant. TTHMFP levels were elevated in the waste streams (200 µg/L) as compared to the raw water (150 µg/L). The mixed water and filtered water sampling points showed slight increases in the TTHMFP levels during recycle. At a 7 to 8 percent recycle ratio, the increases were approximately as calculated based on a mass balance.

Manganese

The waste streams at the Swimming River plant had very high manganese levels. Figure 5.5 shows these levels along with the other measured manganese concentrations. The sludge from the Aldrich units had the highest manganese levels (48 mg/L total manganese and 1.6 mg/L dissolved manganese). The lagoon supernatant, which is the recycle stream resulting from the Aldrich unit's sludge, showed elevated manganese levels (0.7 mg/L total manganese and 0.6 mg/L dissolved manganese). Figure 5.5 shows that manganese levels at the filtered water sampling point were unaffected by recycle, indicating successful plant treatment. The lagoon supernatant only represented 1 percent of the raw water flow, and even though the manganese level was high, it represented a negligible increase to the plant influent.

Aluminum

Aluminum is another constituent that showed elevated levels within the waste streams. Figure 5.6 shows the aluminum results graphically. The sludge resulting from the Aldrich units showed the highest levels (808 mg/L). The supernatant recycled from the lagoon had about 1 mg/L of total aluminum but less than 0.1 mg/L of dissolved aluminum. It was observed that recycle had no effect on the aluminum levels throughout the treatment process. Both the mixed and filtered water sampling points actually showed decreased aluminum levels during the recycle operation.

TOC

The results of TOC testing are shown in Figure 5.7. Elevated levels of TOC occurred in the waste streams, with the highest level appearing in the sludge from the Aldrich units (245 mg/L). Both recycle streams, the lagoon supernatant and the backwash holding tank supernatant, had TOC concentrations in the same range as those of the raw water. As a result, recycle appeared to have had little effect on TOC concentrations at the mixed and filtered water sampling points. As with the plants studied, settling of the waste streams reduced the excess TOC levels.

Table 5.1 Chemical feed data for Swimming River Water Treatment Plant

Location	Chemical	Dose mg/L
Raw	Alum	10–15
	Polymer	1.0
	Cl_2	6–15
	ClO_2	2.0
	Lime	7.0
	PAC	8–15
Filtered	Chlorine	1.0–2.0
	Fluoride	1.0
	Caustic	12.0

Table 5.2 Average annual water quality data for Swimming River Water Treatment Plant

Parameter	Raw	Finished
Turbidity, ntu	10.3	0.03
Color, cu	<5	<5
Iron, mg/L	0.96	0.01
Manganese, mg/L	0.09	0.04
pH	7.2	8.4
Alkalinity, mg/L $CaCO_3$	37	45
Aluminum, mg/L	NA	0.05
Coliform, number/100 mL	29	<1
TOC, mg/L	3.1	2.6
TTHM, µg/L	NA	50
Free Cl_2, mg/L	NA	1.3

NA = no data available

Table 5.3 Preliminary sampling results for Swimming River Water Treatment Plant

Parameter	Backwash recycle stream	Clarifier effluent	
		Without recycle	With recycle
Turbidity, ntu	1.25	0.87	1.0
pH	6.6	6.6	6.5
Free chlorine, mg/L	0.15	0.90	1.0
Total chlorine, mg/L	0.3	1.0	1.2
Alkalinity, mg/L as $CaCO_3$	24.5	27.5	26
Coliform, number/100 mL	<1	<1	<1
Heterotrophic plate count, colonies/mL	2920	369	2
Aluminum, mg/L	0.18	0.15	0.14
Iron, mg/L	<0.05	<0.05	<0.05
Manganese, mg/L	0.02	<0.02	<0.02
TSS, mg/L	13	10	1
TOC, mg/L	2.8	2.3	3.5
TTHM, µg/L	59	32	46
TTHMFP, µg/L	312	321	270

Table 5.4 Round 1 sampling results for Swimming River Water Treatment Plant

Sample site	TTHM (µg/L)	TTHMFP (µg/L)	TOC (mg/L)	Aluminum Dissolved (mg/L)	Aluminum Total (mg/L)	Manganese Dissolved (mg/L)	Manganese Total (mg/L)	Turbidity (ntu)	pH	Free Cl_2 (mg/L)
Raw (1)*	<0.5	150	3.1	<0.001	0.107	<0.02	<0.02	2.6	7.1	<0.1
Mixed B (2)	4	153	2.4	0.039	2.904	0.04	0.16	12.0	6.4	5.5
Mixed D (2)	11	157	2.8	0.010	2.481	<0.02	0.16	12.1	6.5	5.0
Filtered B (3)	42	112	1.7	0.004	0.073	<0.02	<0.02	0.08	6.4	0.4
Filtered D (3)	35	129	1.8	0.007	0.033	<0.02	<0.02	0.08	6.4	0.3
Backwash supernatant (4)	40	126	2.1	0.051	0.252	<0.02	<0.02	1.2	6.8	0.2
Lagoon supernatant (5)	19	192	3.6	0.003	0.976	0.62	0.70	4.5	6.8	<0.1
Clarifier sludge (7)	25	209	245	0.024	808.3	1.66	48.61	NA	6.3	0.5
Backwash sludge (6)	36	190	75	0.013	110.2	0.47	6.22	NA	6.3	<0.1
Clarified B	NA	NA	NA	<0.001	<0.001	<0.02	<0.02	0.45	6.4	0.2
Clarified D	NA	NA	NA	<0.001	<0.001	<0.02	<0.02	0.4	6.3	0.3

B = before recycle
D = during recycle
NA = no data available

*Numbers in parentheses indicate the sampling location as shown in Figure 5.1.

Table 5.5 Round 1 AOC levels for Swimming River Water Treatment Plant

Sample Site	P17 (µg/L) Sample 1	P17 (µg/L) Sample 2	P17 (µg/L) Average	NOX (µg/L) Sample 1	NOX (µg/L) Sample 2	NOX (µg/L) Average
Raw (1)*	202	121	152	115	36	76
Mixed B (2)	40	36	38	103	73	88
Mixed D (2)	0.2	0.2	0	129	143	141
Filtered B (3)	124	101	113	125	94	110
Filtered D (3)	60	29	45	100	95	98
Backwash supernatant (4)	471	584	528	279	264	272
Lagoon overflow (5)	307	245	276	55	58	57
Clarifier sludge (7)	493	275	384	378	660	519
Backwash sludge (6)	638	334	486	762	716	739

B = before recycle
D = during recycle

*Numbers in parentheses indicate the sampling locations as shown in Figure 5.1.

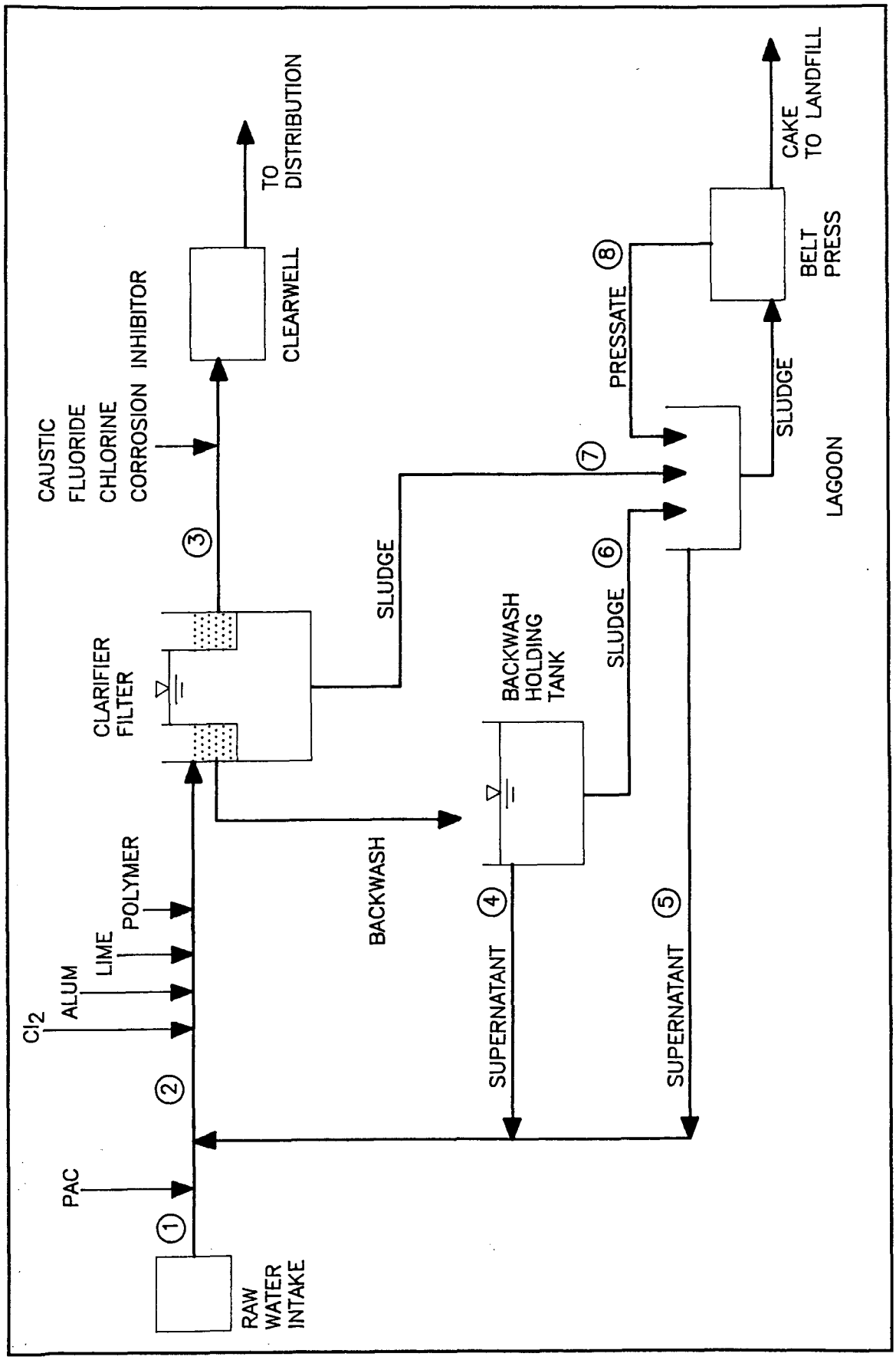


Figure 5.1 Process flow diagram and sample point locations for Swimming River Water Treatment Plant

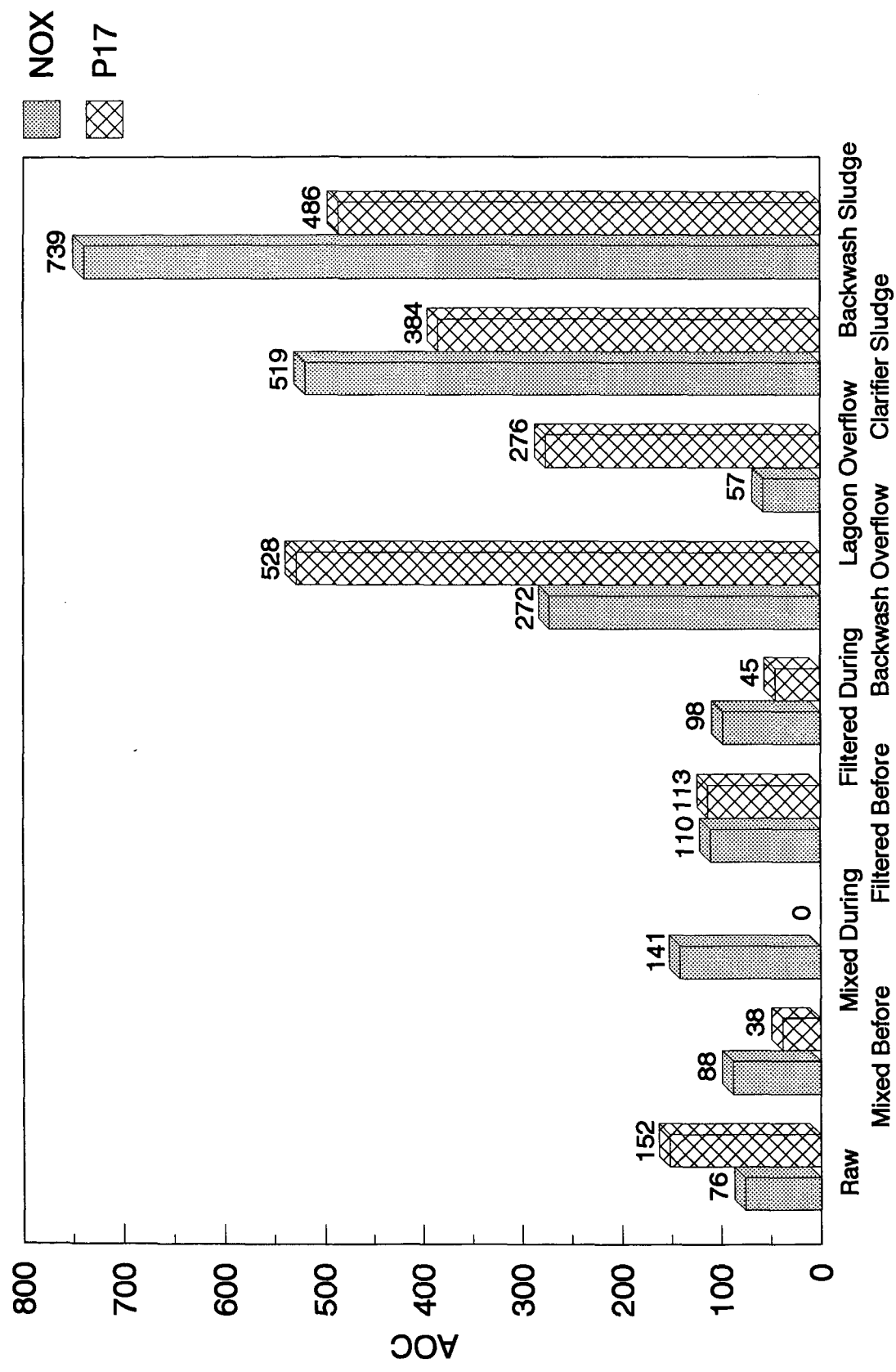


Figure 5.2 AOC levels at Swimming River Water Treatment Plant

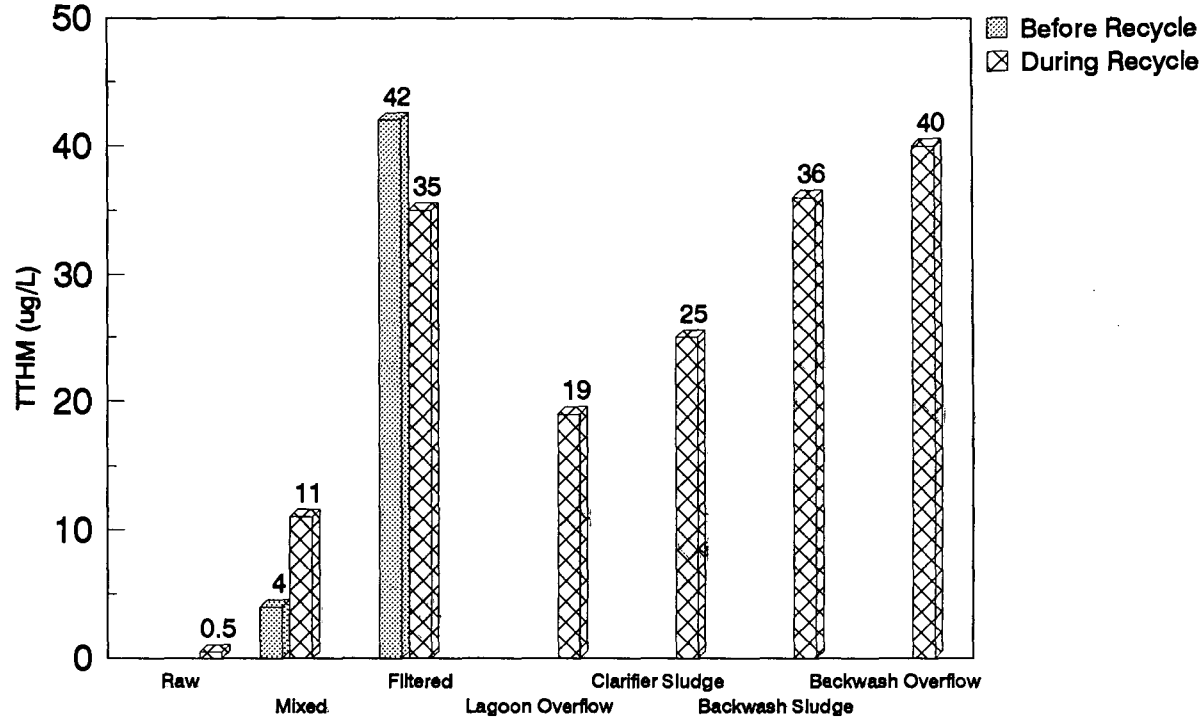


Figure 5.3 TTHM levels at Swimming River Water Treatment Plant

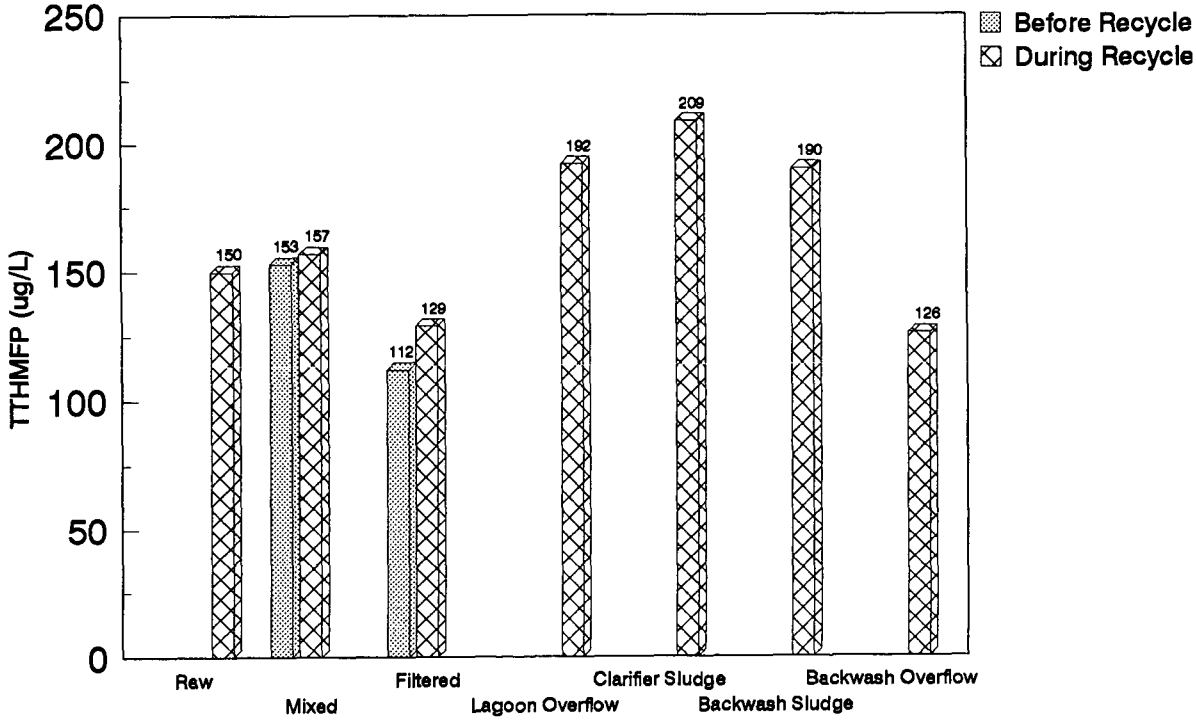


Figure 5.4 TTHMFP levels at Swimming River Water Treatment Plant

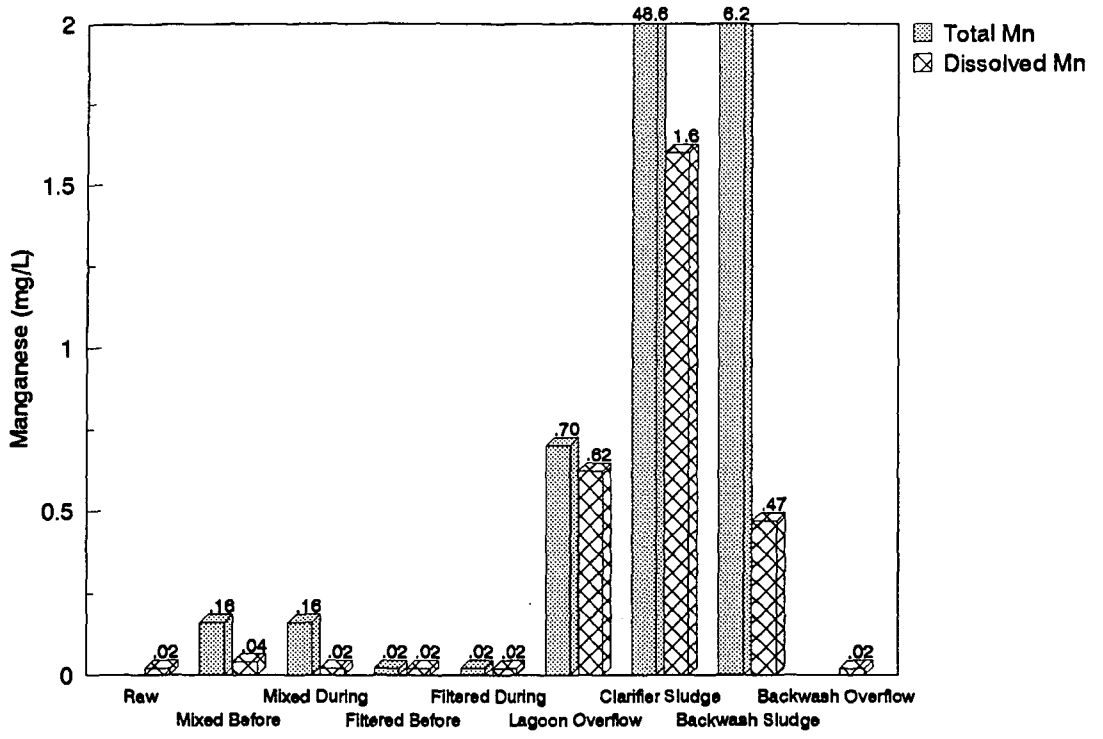


Figure 5.5 Manganese levels at Swimming River Water Treatment Plant

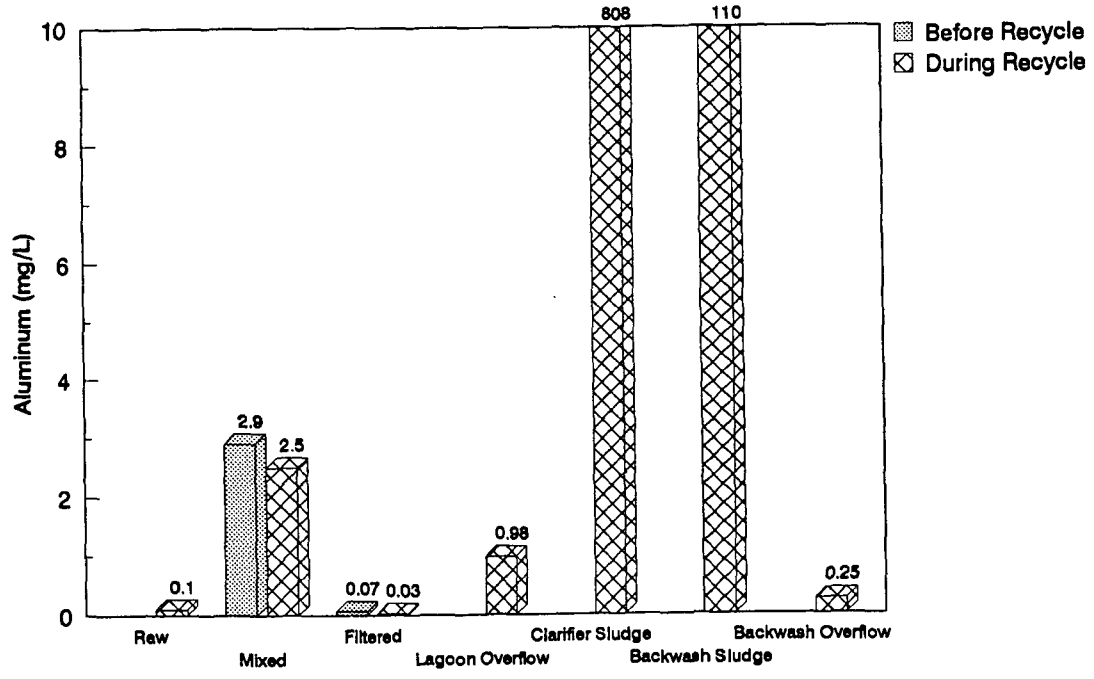


Figure 5.6 Total aluminum concentrations at Swimming River Water Treatment Plant

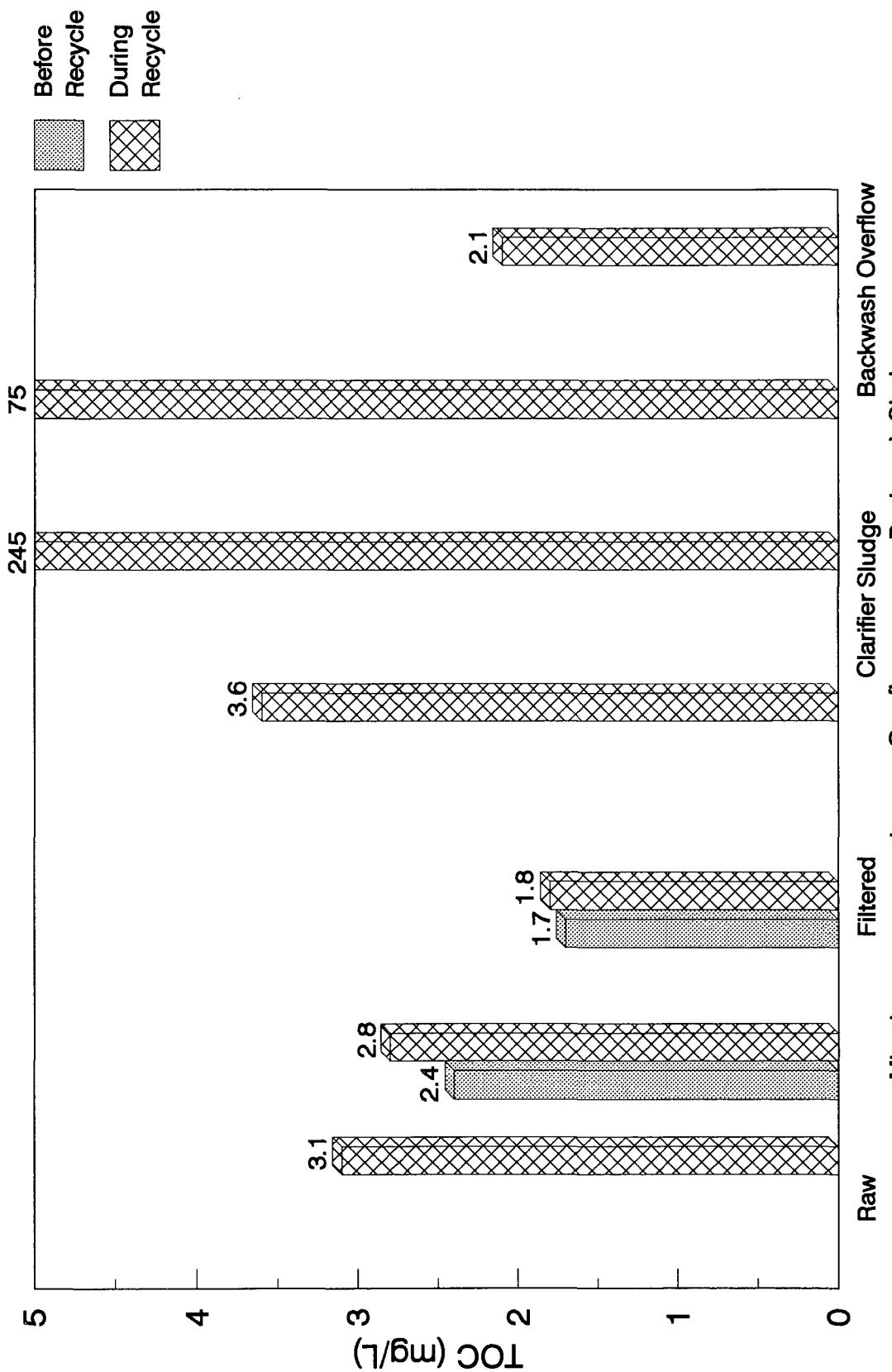


Figure 5.7 TOC values at Swimming River Water Treatment Plant

Chapter 6

New Castle Water Treatment Plant

Plant Description

Treatment Process

The source of supply for the New Castle Water Treatment Plant, located in New Castle, Pa., is the Shenango River. The river can be characterized as industrialized with low to moderate turbidity. Iron, manganese, and bacteria levels can fluctuate widely over a short period of time. Three low-service pumps are used to pump raw water to the plant. The New Castle Water Treatment Plant utilizes conventional treatment with a rated capacity of 8.4 mgd (1,300 m^3/h) based on a filtration rate of 4 gpm/ft^2 (9.7 m/h).

Raw water from the low-service pumps is delivered to a two-chamber concrete mixing tank that is equipped with two variable-speed rapid mixers. Pretreatment chemicals are applied at the mix tank.

After mixing, the treated water flows into two open concrete flocculation and sedimentation basins. Water enters the flocculation section of basin no. 1, which is equipped with eight turbine flocculators. Flow continues in series through no. 1 and no. 2 sedimentation basins. Total detention time in the two basins is 4.4 hours at the 8.4-mgd (1,300 m^3/h) plant rating.

Settled water flows to four concrete-housed filters. Each filter is equipped with automatic electrically operated influent, effluent, wash, and drain valves, as well as automatic rate-of-flow controllers and loss-of-head gauges. Surface wash and air wash are provided for all filters. Filter media consists of 54 in. (1.4 m) of granulated activated carbon (GAC), 5 in. (12.7 cm) of sand, and 3 in. (7.6 cm) of garnet on a gravel base.

Due to the high levels of naturally occurring organic matter and bacteria within the source of supply, the GAC filter media is changed every 9 months to achieve taste-and-odor removal.

Filtered water flows to a two-compartment concrete clearwater basin that is covered and is below grade. The clearwell provides a total capacity of 0.404 MG (1,530 m^3), corresponding to 1.15 hours of theoretical detention time at the rated plant capacity.

Six distribution pumps draw finished water from the clearwell and deliver it to the distribution system. Figure 6.1 shows a process schematic of the New Castle Water Treatment Plant.

Plant seasonal flow ranges from 6 to 8.4 mgd (950 to 1,300 m^3/h), with an annual average of about 8 mgd (1,260 m^3/h). The flow generally varies between 7 and 8.5 mgd (1,100 and 1,300 m^3/h) throughout the day.

Chemical Feed

Chemicals are fed at the rapid mix basin and postfilter. Chlorine, alum, polymer, and lime are all added at the rapid mix basin on a regular basis, whereas PAC and potassium permanganate are added on a seasonal basis. Postfilter chemical addition consists of chlorine, fluoride, and corrosion inhibitor. Chemical feed data are shown in Table 6.1.

Solids Handling

Solids-handling equipment at New Castle Water Treatment Plant consists of a backwash water holding tank, a gravity thickener, and a belt filter press. Waste streams include

Settled sludge from both sedimentation basins
Spent filter backwash water
Belt press pressate

The no. 1 sedimentation basin is equipped with a pneumatically operated vacuum-type collection system that continuously cleans residual solids from the basin. The no. 2 sedimentation basin is not equipped for automatic sludge removal and is manually cleaned.

Filter backwash water is fed by gravity from a 75,000-gal (284-m^3) elevated washwater storage tank. Two 2,250-gpm (600-m^3/h) washwater pumps fill the tank from the plant clearwell. Filters also can be directly washed from the washwater pumps or from distribution system pressure. Spent filter backwash water is collected in a 40-ft-diameter (12 m) concrete holding tank and is then recycled to the raw water pump suction well. Sludge from the sedimentation basin is collected in a thickening tank. Supernatant from the thickener is decanted to the raw water pump suction well for recycling through the plant process. The thickened solids are dewatered on a belt filter press. The belt filter pressate is returned to the thickener.

The backwash recycle rate is usually about 10 percent of plant flow. The belt press pressate flow rate to the thickener is usually 40 to 60 gpm (11 to 16 m^3/h). The no. 1 sedimentation basin pneumatic vacuum operates at approximately 130 gpm (35 m^3/h).

Water Quality

Typical raw and finished water quality data are summarized in Table 6.2.

Preliminary sampling conducted at the plant consisted of collecting a one-time grab sample of the recycle waste stream and the applied water. The applied water was sampled before and during recycle in order to observe impacts of recycle. Table 6.3 summarizes the results of the initial investigation. These results showed a high level of TTHMFP present in the recycle stream and the treatment process. Aluminum, TSS, manganese, iron, and TTHM values were also elevated in the recycle stream.

Comprehensive Sampling Program

Overview

Three rounds of field sampling and analysis were performed for the New Castle Water Treatment Plant. The parameters for which the water was analyzed and the sampling points were derived from a review of the water quality information supplied by the operators of the New Castle facility and from the results of the preliminary sampling. The parameters of primary interest at this plant were TTHM, TTHMFP, AOC, and manganese.

Round 1 Sampling

The plant was operating under normal conditions at the time of sampling, with the exception that the no. 2 sedimentation basin was out of service. Plant flow averaged 8.1 mgd (1,279 m^3/h) and settled water turbidities were 1.0 to 2.0 ntu. Filtered water turbidities were less than 0.3 ntu.

The water quality parameters evaluated were

AOC
TTHM
TTHMFP
TOC
Manganese
Aluminum
Turbidity

The sample locations for these parameters are listed below. Numbers in parentheses indicate the sampling locations as shown in Figure 6.1.

Raw water (1)
Mixed water before recycle (2)
Mixed water during recycle (2)
Filtered water before recycle (3)
Filtered water during recycle (3)
Spent backwash recycle (5)
Thickener supernatant recycle (6)
Settled sludge (4)
Belt press pressate (7)

Prior to sampling, all backwashing and sludge collection was suspended for an 8-hour period. This allowed sampling of the system without recycle. Filters were then washed and the solids-handling equipment placed in service. The recycle stream started almost immediately when a filter was being backwashed, and the thickener overflow stream began when sludge was being fed to the thickener. Samples of the recycle streams (unsettled backwash water and thickener overflow) were taken immediately following the first backwash. The process samples containing recycle water were taken accordingly, timed from the theoretical detention time as with the other facilities. All samples were grab samples. The results from round 1 sampling are summarized in Table 6.4. This sampling was conducted in July.

Round 2 Sampling

The plant was operating normally, with all basins in service and an average plant flow of 8.9 mgd (1,400 m^3/h). Round 2 sampling consisted of analyzing the same parameters as in round 1 and at the same sample locations.

Prior to sampling, all backwashing and sludge collection was suspended for an 8-hour period to obtain background samples. Two sets of samples were taken for round 2 testing. The first set of data was taken to measure the effects of recycling supernatant from the gravity thickener and the backwash holding tank. The second set of data was taken to measure the effects of recycling supernatant from the gravity thickener only. The belt filter press and the sludge collection system were running during these measurements, and thus in the supernatant from the gravity thickener was a composite of the two input streams. The results from round 2 sampling are summarized in Table 6.5. This sampling was conducted in January.

Round 3 Sampling

Round 3 sampling consisted of sampling the same parameters as in round 1 and round 2 and at the same locations. Round 3 sampling was conducted to further evaluate AOC.

Prior to sampling, all backwashing and sludge collection was suspended for an 8-hour period to obtain background samples. Round 3 sampling was performed to verify the effects of recycling supernatant from the gravity thickener and the backwash holding tank. The results from round 3 sampling are shown in Table 6.6. This round was conducted in May.

Laboratory-Scale Analysis

Sludge from the New Castle plant was one of three sludges that were studied at a bench-scale level. Sludge from the plant was put into two 4-L beakers and was tested for pH and DO levels once a week and for manganese levels three times a week. DO was measured in both the supernatant and the settled sludge, whereas dissolved manganese and pH were measured in the supernatant only. One beaker was maintained at a pH of approximately 5.5 and one at a pH of approximately 7.0. All manganese determinations were for dissolved manganese.

Trends

TTHM

Figure 6.2 graphically shows TTHM values for the waste and recycle streams for each of the sampling events at the New Castle Water Tratment Plant. The TTHM values were very high in the sludge from the sedimentation basins. The overflow from the thickener, which is one of the recycle streams, generally showed high TTHM levels (100 to 200 µg/L) compared to the filtered water (40 to 120 µg/L). The spent backwash water, which is also recycled, had TTHM concentrations of 60 to 100 µg/L.

The addition of the recycle stream to the treatment process did show an increase of TTHM levels in the mixed water. Due to the practice of raw water chlorination and TTHM formation kinetics, the filtered water TTHM levels were not affected by the recycle. Figures 6.3 and 6.4 show the results of recycle on the mixed and filtered water, respectively.

TTHMFP

TTHMFP levels for the raw water and various waste streams are shown in Figure 6.5. The sludge from the sedimentation basins showed the highest TTHMFP values (500 to 2,000 µg/L). The recycle streams themselves had TTHMFP levels of 250 to 600 µg/L. Except for round 1 sampling, the TTHMFP levels in the recycle streams were no higher than the raw water levels. The addition of the recycle stream to the head of the plant had little effect on the TTHMFP levels of the water in the rapid mix basin or after filtration, as is shown in Figures 6.6 and 6.7.

Manganese

Manganese levels were significant in all of the waste streams. Figure 6.8 shows the manganese results from rounds 1, 2, and 3 sampling in the recycle and waste streams. Figures 6.9 and 6.10 show the effects of recycle on manganese levels of the mixed and filtered water sampling points. The recycle streams had dissolved manganese levels between 0.1 and 3 mg/L; however, no impact on filtered water was found. Note that $KMnO_4$ was added prior to the mixed water sampling point, and manganese data collected from this sampling point reflected raw water manganese levels and chemical addition.

Bench-scale tests were conducted to evaluate manganese release from the sludge due to storage. The manganese levels in the supernatant showed steady increases over time for both samples (pH of 5.5 and 7.0). Figure 6.11 shows these increases. Figure 6.12 shows a downward trend over time for DO levels in the settled sludge for the New Castle sample. The amount of manganese released was higher in the lower pH sample.

Aluminum

Figure 6.13 shows the aluminum concentrations in the waste and recycle streams. Most of the aluminum is associated with the solids, but elevated dissolved aluminum concentrations were observed. Figures 6.14 and 6.15 show the aluminum concentrations at the rapid mix and filtered water sampling points before and during the recycle operation. Increases in aluminum levels at the rapid mix point were found, but no increases in filtered water aluminum levels occurred.

AOC

Round 1 sampling showed that AOC levels were higher in all the waste streams than in the raw water. The backwash recycle stream had an AOC of 1,053 compared to the raw water level of 219. The pressate had an AOC of 2,224. Round 2 results showed a significant increase of filtered water AOC levels during recycle; the AOC values in the filtered water increased from about 60 without recycle to 400

with recycle. Round 3 sampling again showed that the filtered water AOC levels were higher during recycle. Without recycle the filtered water AOC was 24, and with recycle the AOC level increased to 107. These results are also shown in Figure 6.16.

TOC

TOC levels were high in several of the waste streams. Sedimentation basin sludge TOC ranged from 15 to 60 mg/L. However, TOC levels in the recycle streams were generally in the same range as those in the raw water (4 to 6 mg/L). The thickener supernatant had some elevated TOC values (11 to 15 mg/L). The pressate and the sludge showed the highest levels of TOC. Recycle resulted in no increase in TOC concentrations in either the rapid mix or filter sampling points. TOC concentrations resulting from round 1, round 2, and round 3 testing are shown in Figure 6.17.

Table 6.1 Chemical feed data for New Castle Water Treatment Plant

Location	Chemical	Dose (mg/L)
Raw	Alum	15–25
	Polymer	1.5
	Chlorine	5.0–7.0
	ClO_2 (seasonal)	1.5–3.0
	$KMnO_4$ (seasonal)	0.5
	Lime	9–15
	Carbon (seasonal)	5–10
Filtered	Chlorine	3.5
	Corrosion inhibitor, ZOP	2.0–4.0
	Fluoride	1.0

ZOP = zinc orthophosphate

Table 6.2 Average annual water quality data for New Castle Water Treatment Plant

Parameter	Raw	Finished
Turbidity, ntu	15	0.30
Color, cu	5	<5
Iron, mg/L	0.6	<0.05
Manganese, mg/L	0.2	<0.02
pH	7.5	7.2
Alkalinity, mg/L $CaCO_3$	70	50
Ammonia, mg/L	<0.01	<0.01
Aluminum, mg/L	NA	0.10
Coliform, number/100 mL	200	<1
TOC, mg/L	5.6	3.5
TTHM, µg/L	NA	95
Free Cl_2, mg/L	NA	1.5

NA = no data available

Table 6.3 Preliminary sampling results for New Castle Water Treatment Plant

		Clarifier effluent	
Parameter	Recycle stream	Without recycle	With recycle
Turbidity, ntu	28	2.3	2.1
pH	7.2	7.2	7.1
Free chlorine, mg/L	0.1	1.6	1.4
Total chlorine, mg/L	0.4	1.9	1.7
Alkalinity, mg/L as $CaCO_3$	140	72	62
Coliform, number/100 mL	<1	<1	<1
Heterotrophic plate count, colonies/mL	24	<1	1
Aluminum, mg/L	67.7	0.41	0.39
Iron, mg/L	7.0	<0.05	<0.05
Manganese, mg/L	2.6	<0.02	<0.02
TSS, mg/L	2,552	1	12
TOC, mg/L	7.1	6.0	6.1
TTHM, µg/L	90	47	42
TTHMFP, µg/L	834	518	481

Table 6.4 Round 1 sampling results for New Castle Water Treatment Plant

	TOC (mg/L)	TTHM (µg/L)	TTHMFP (µg/L)	Turbidity (ntu)	Total Mn (mg/L)	Total Al (mg/L)	AOC		
							P17	NOX	Total
Raw (1)*	6.76	<0.5	364	20	0.14	0.76	102	117	219
Mixed B (2)	5.64	14	400	17	<0.02	0.70	NA	NA	NA
Mixed D (2)	5.47	36	460	28	<0.02	0.49	319	369	888
Filtered B (3)	4.94	119	421	0.08	<0.02	0.30	NA	NA	NA
Filtered D (3)	4.76	119	419	0.09	<0.02	0.22	NA	NA	NA
Sedimentation sludge (4)	59.4	674	2,032	NA	63.3	903	1,186	2,441	3,626
Backwash recycle (5)	7.4	118	658	75	1.85	25.65	517	536	1,053
Thickener supernatant (6)	15.1	197	686	10	3.69	0.66	NA	NA	NA
Pressate (7)	18.2	150	616	NA	20.3	186	1,161	1,063	2,224

B = before recycle
D = during recycle
NA = no data available

*Numbers in parentheses indicate sampling locations as shown in Figure 6.1.

Table 6.5 Round 2 sampling results for New Castle Water Treatment Plant

Sample location	pH	Turbidity (ntu)	Cl_2 (mg/L)	TTHM (µg/L)	TTHMFP (µg/L)	TOC (mg/L)	Manganese		Aluminum		AOC		
							Total (mg/L)	Dissolved (mg/L)	Total (mg/L)	Dissolved (mg/L)	P17	NOX	Total (mg/L)
Set 1: settled sludge and backwash recycle stream													
Raw (1)*	7.4	9.3	<0.1	10	402	4.62	<0.02	0.04	0.11	0.04	309.8	38.8	348.6
Mixed B (2)	6.6	23	3.9	24	352	4.51	NA	NA	NA	NA	NA	NA	NA
Mixed D (2)	6.6	23	3.7	30	274	4.48	0.18	0.16	5.85	4.79	NA	NA	NA
Filtered B (3)	7.3	0.19	0.6	NA	350	2.78	<0.02	<0.02	0.35	0.11	26.2	32.5	58.7
Filtered D (3)	7.3	0.21	0.5	43	218	2.76	<0.02	<0.02	0.23	0.05	106.5	288.8	395.3
Thickener supernatant (6)	7.5	4	<0.1	113	270	5.06	0.26	0.26	0.92	0.66	248.8	1.0	249.8
Backwash recycle (5)	7.2	62	<0.1	60	259	5.63	0.89	0.92	18.98	18.78	654.9	14.1	669.0
Pressate (7)	7.3	55	<0.1	114	366	15.5	1.49	1.50	7.60	3.94	NA	NA	NA
Sedimentation Sludge (4)	NA	NA	NA	NA	468	14.0	5.24	5.22	300	300	NA	NA	NA
Set 2: settled sludge and pressate recycle stream													
Raw (1)	7.4	8.7	<0.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mixed B (2)	6.5	14	4.0	25	214	NA	<0.02	0.04	4.26	3.77	NA	NA	NA
Mixed D (2)	6.6	15	3.8	23	212	3.72	0.12	0.06	4.00	2.96	NA	NA	NA
Filtered B (3)	7.4	0.19	3.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Filtered D (3)	7.4	0.25	3.0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Thickener supernatant (6)	7.5	5.5	<0.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Backwash recycle (5)	7.4	NA	<0.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Pressate (7)	7.3	75	<0.1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

B = before recycle
D = during recycle
NA = no data available

*Numbers in parentheses indicate the sampling locations as shown in Figure 6.1.

Table 6.6 Round 3 sampling results for New Castle Water Treatment Plant

Sample location	pH	Turbidity (ntu)	Cl_2 (mg/L)	TTHM (µg/L)	TTHMFP (µg/L)	TOC (mg/L)	Manganese Total (mg/L)	Manganese Dissolved (mg/L)	Aluminum Total (mg/L)	Aluminum Dissolved (mg/L)	AOC P17	AOC NOX	AOC Total (mg/L)
Settled sludge and backwash recycle													
Raw (1)*	7.0	8.3	<0.1	<0.5	420	5.66	0.22	0.14	0.14	0.015	75	8	83
Mixed B (2)	6.8	10	3.5	15	308	5.15	2.51	<0.02	4.7	0.090	62	126	188
Mixed D (2)	6.8	15	3.4	35	385	5.76	1.11	<0.02	5.61	0.100	85	141	226
Filtered B (3)	7.2	0.1	0.2	80	358	3.39	<0.02	<0.02	0.050	0.050	12	12	24
Filtered D (3)	7.2	0.1	<0.1	87	376	3.76	<0.02	<0.02	0.050	0.050	68	39	107
Thickener supernatant (6)	7.0	1	<0.1	NA	547	11.33	3.51	3.08	0.215	0.040	118	50	168
Backwash secycle (5)	7.5	50	<0.1	71	299	5.11	21.7	0.15	29.4	0.230	156	96	252
Pressate (7)	7.3	50	<0.1	151	499	14.34	6.71	5.21	9.9	0.120	256	80	336
Sedimentation sludge (4)	NA	NA	NA	321	1,373	27.80	73.9	2.40	1,021	0.450	NA	NA	NA

B = before recycle
D = during recycle
NA = no data available

*Numbers in parentheses indicate sampling locations as shown in Figure 6.1.

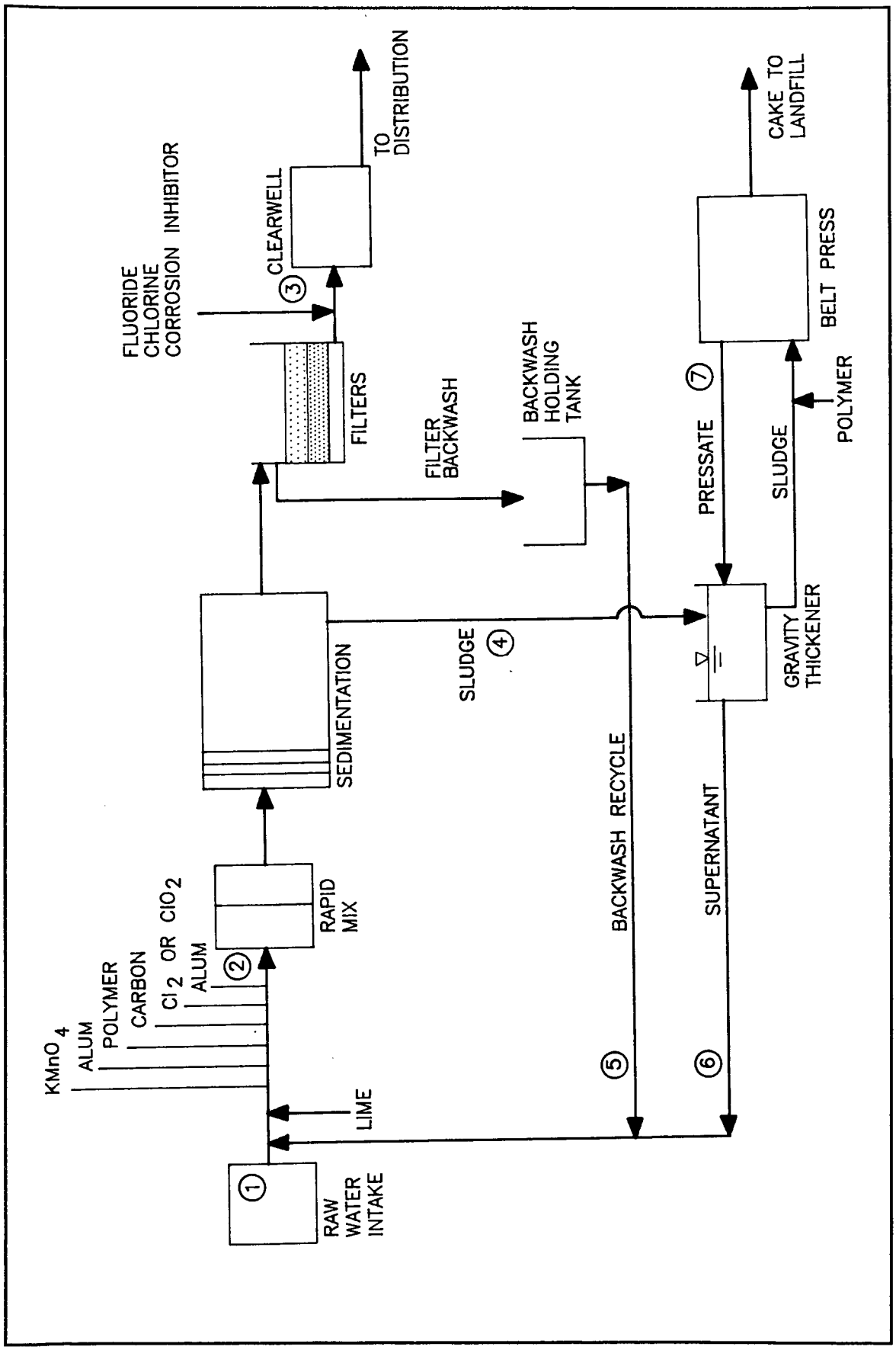


Figure 6.1 Process flow diagram and sample point locations for New Castle Water Treatment Plant

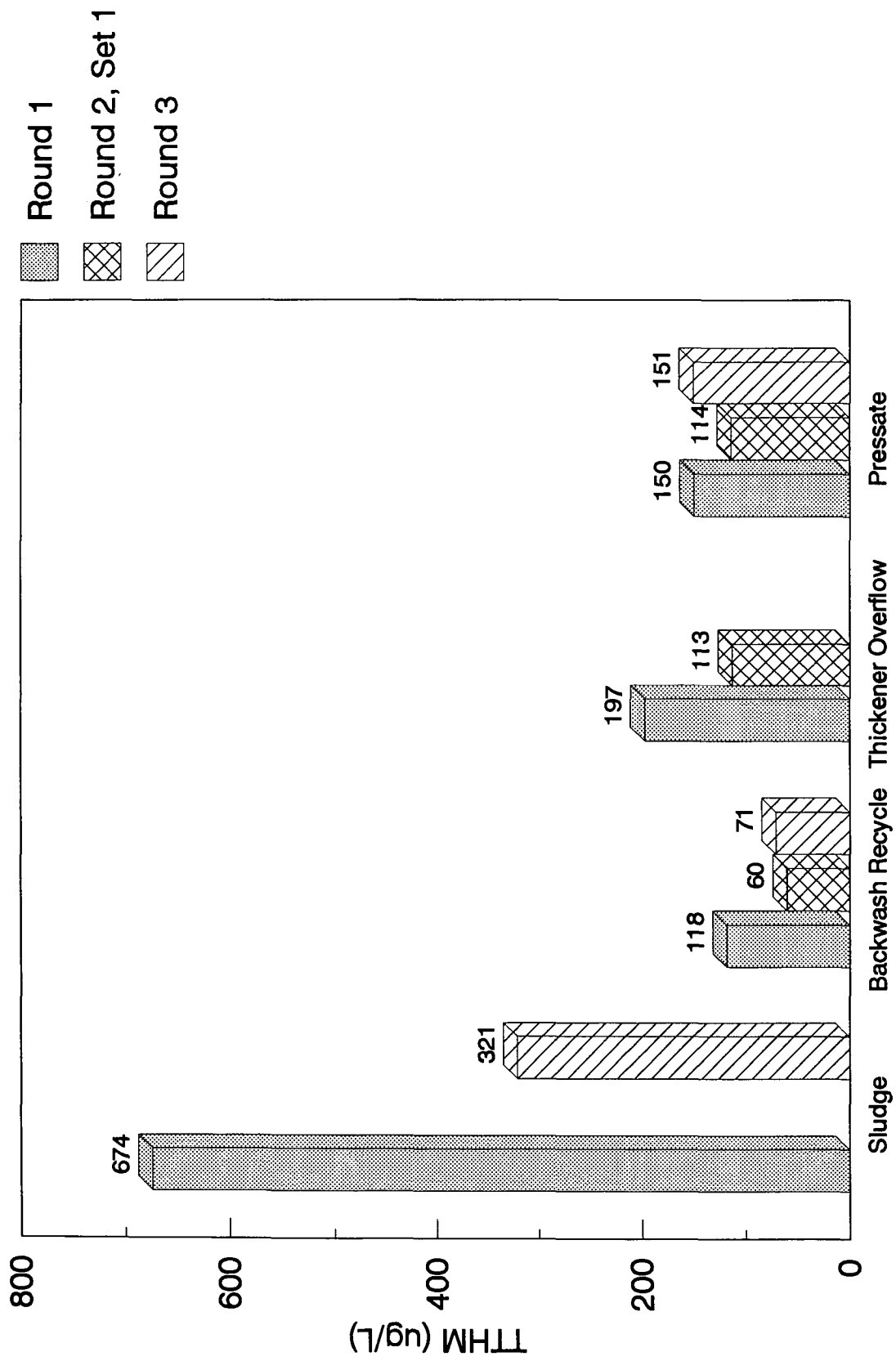


Figure 6.2 TTHM levels in waste streams for New Castle Water Treatment Plant

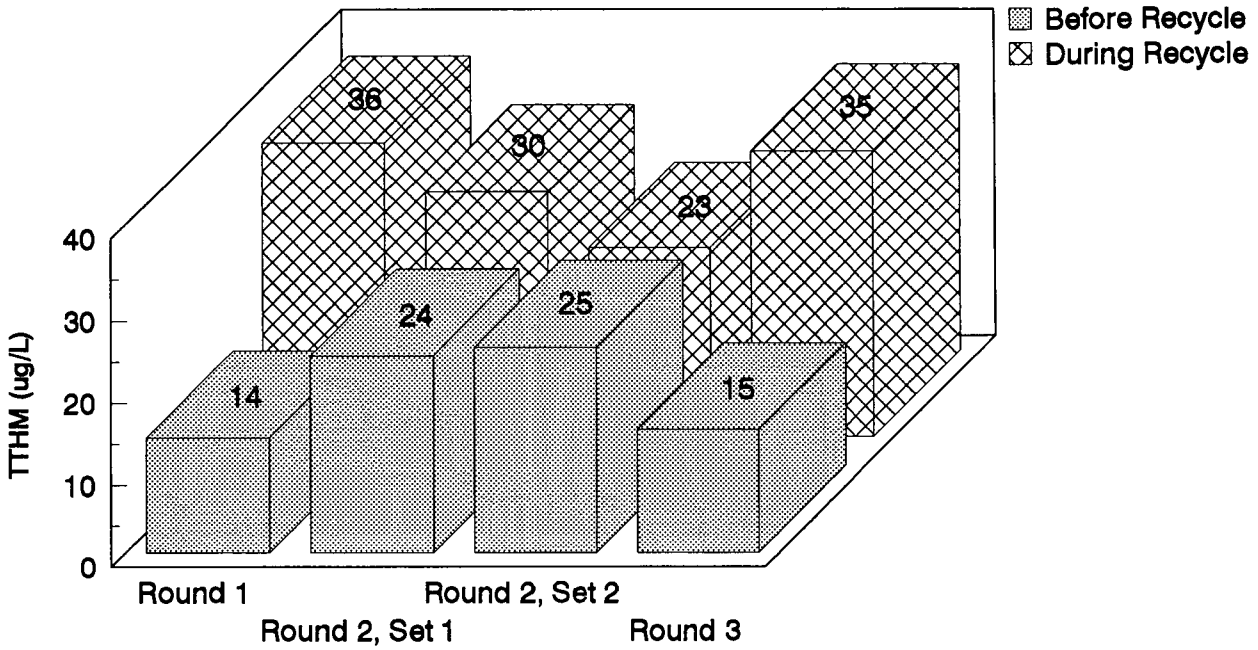


Figure 6.3 TTHM levels in influent water for New Castle Water Treatment Plant

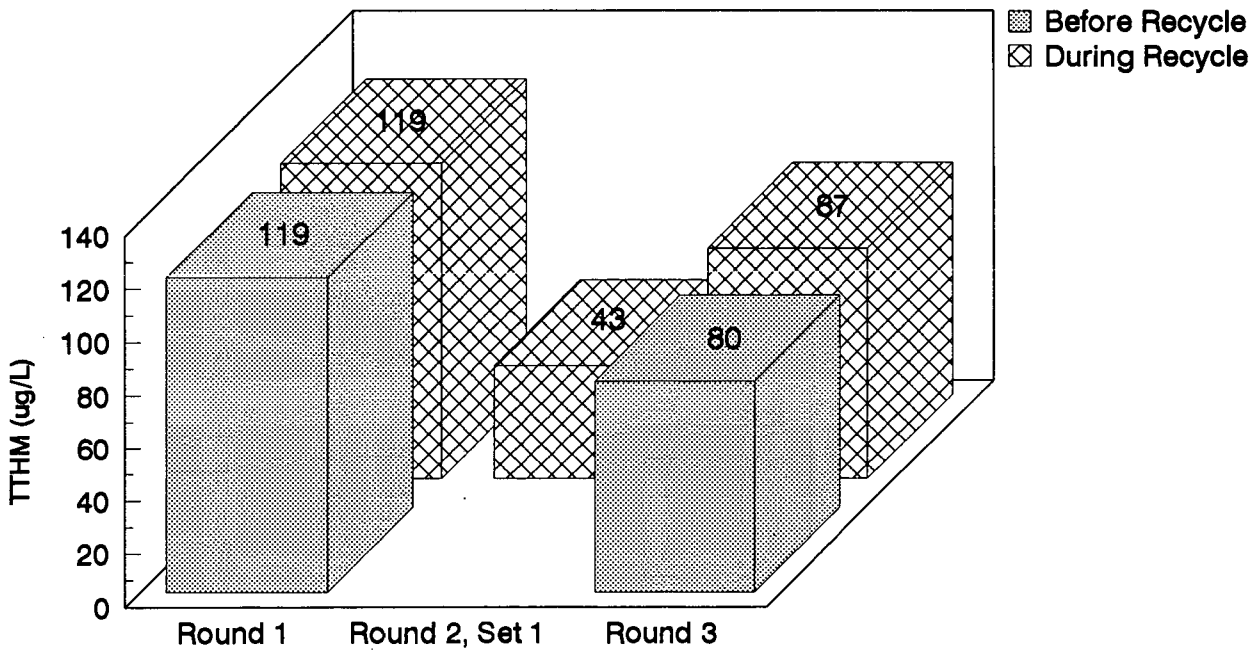


Figure 6.4 TTHM levels in filtered water for New Castle Water Treatment Plant

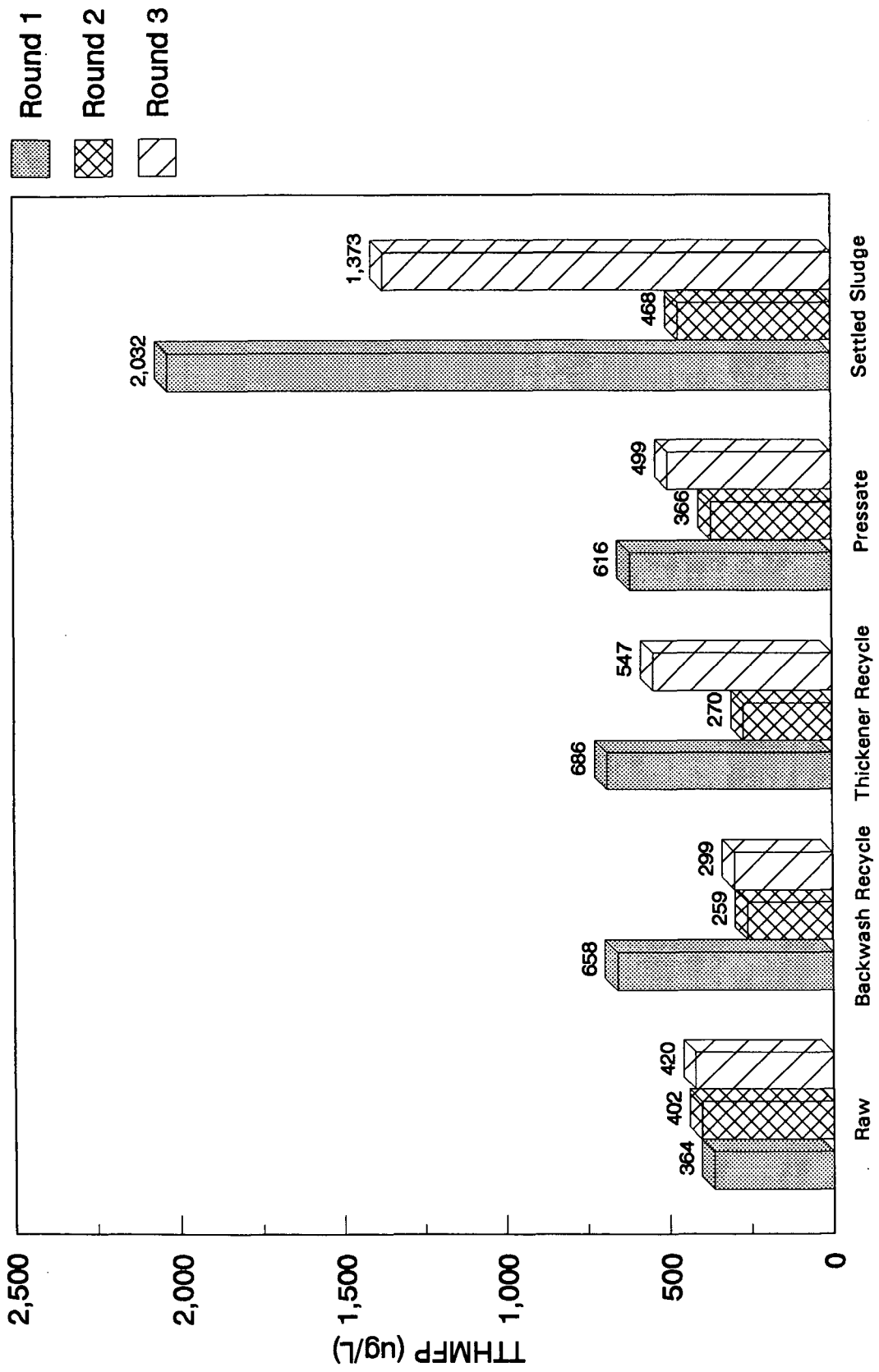


Figure 6.5 TTHMFP levels in waste streams for New Castle Water Treatment Plant

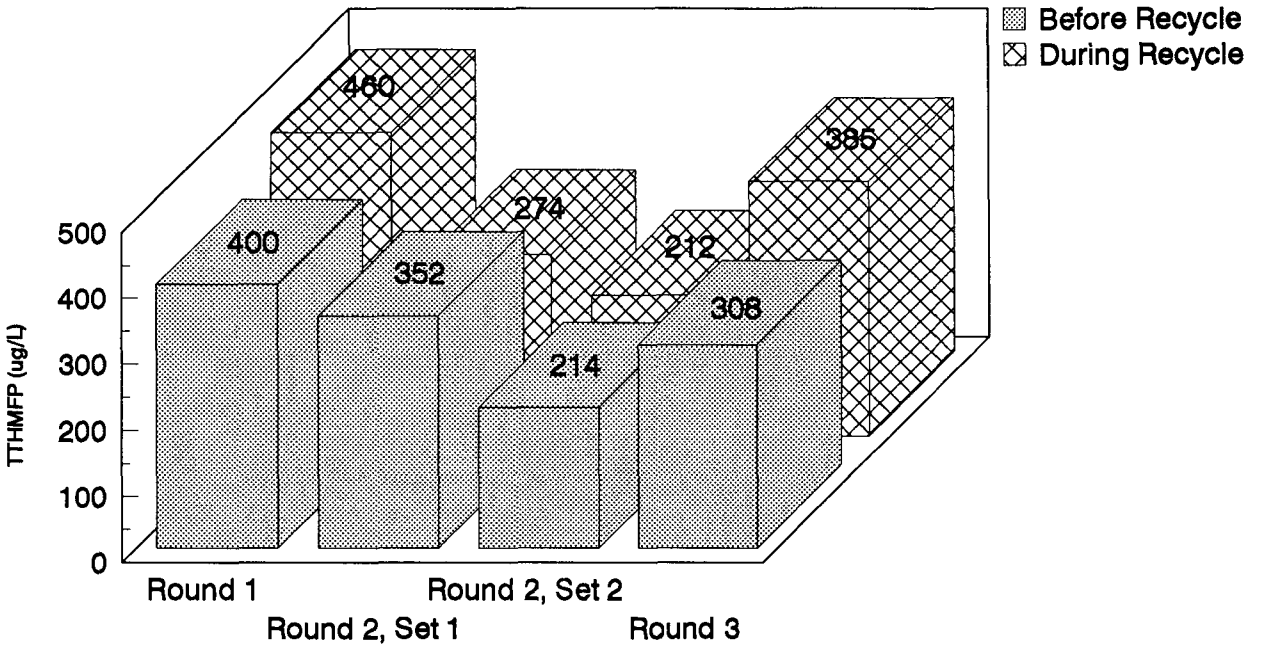


Figure 6.6 TTHMFP levels in influent water for New Castle Water Treatment Plant

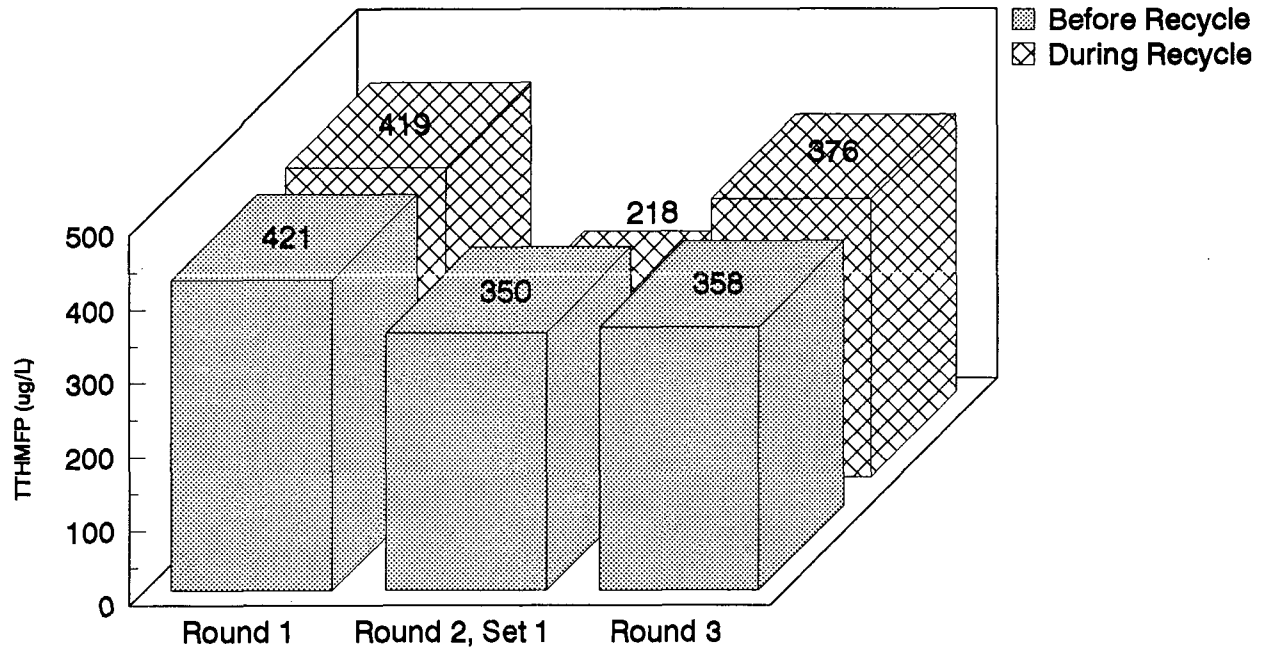
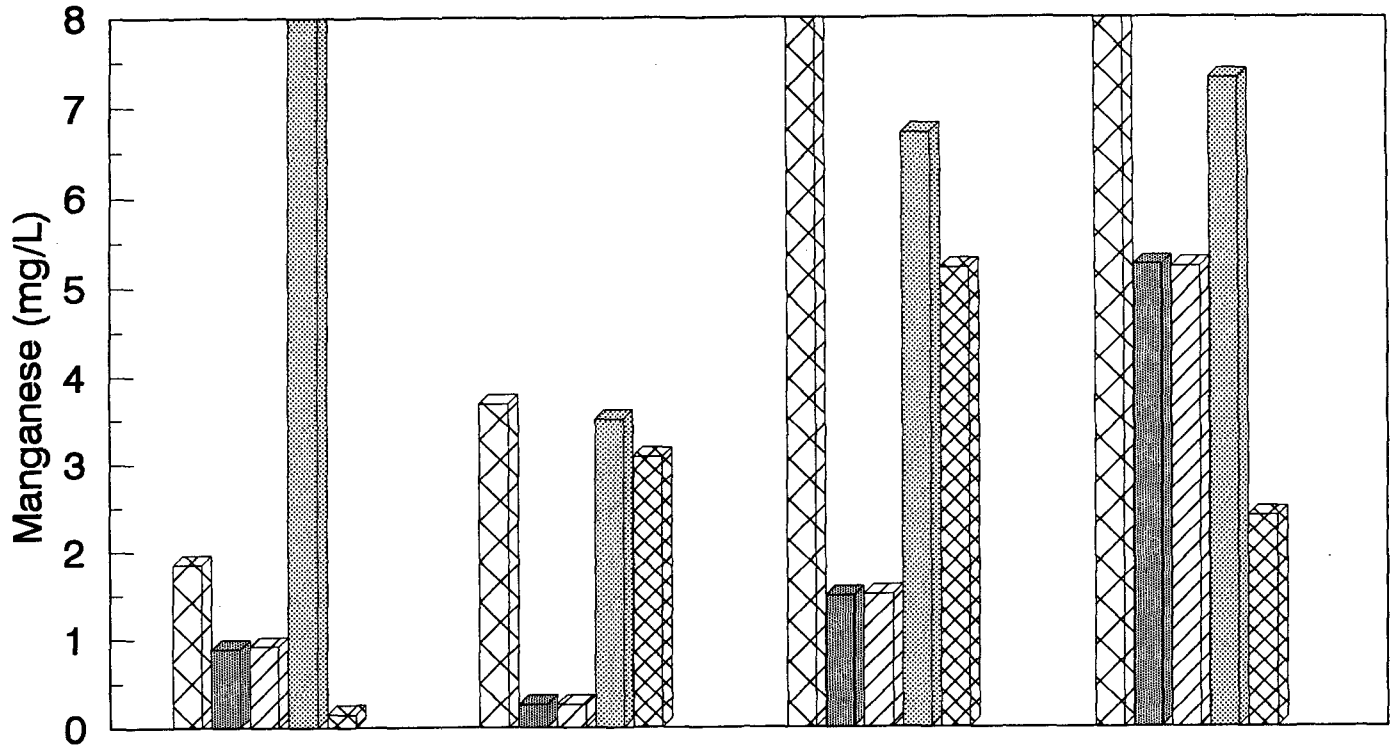


Figure 6.7 TTHMFP levels in filtered water for New Castle Water Treatment Plant



	Backwash Recycle	Thickener Recycle	Pressate	Settled Sludge
Round 1: Total Mn	1.85	3.69	20.30	63.30
Round 2: Total Mn	0.89	0.26	1.49	5.24
Round 2: Dissolved Mn	0.92	0.26	1.50	5.22
Round 3: Total Mn	21.70	3.51	6.71	7.31
Round 3: Dissolved Mn	0.15	3.08	5.21	2.40

Figure 6.8 Manganese levels in waste streams for New Castle Water Treatment Plant

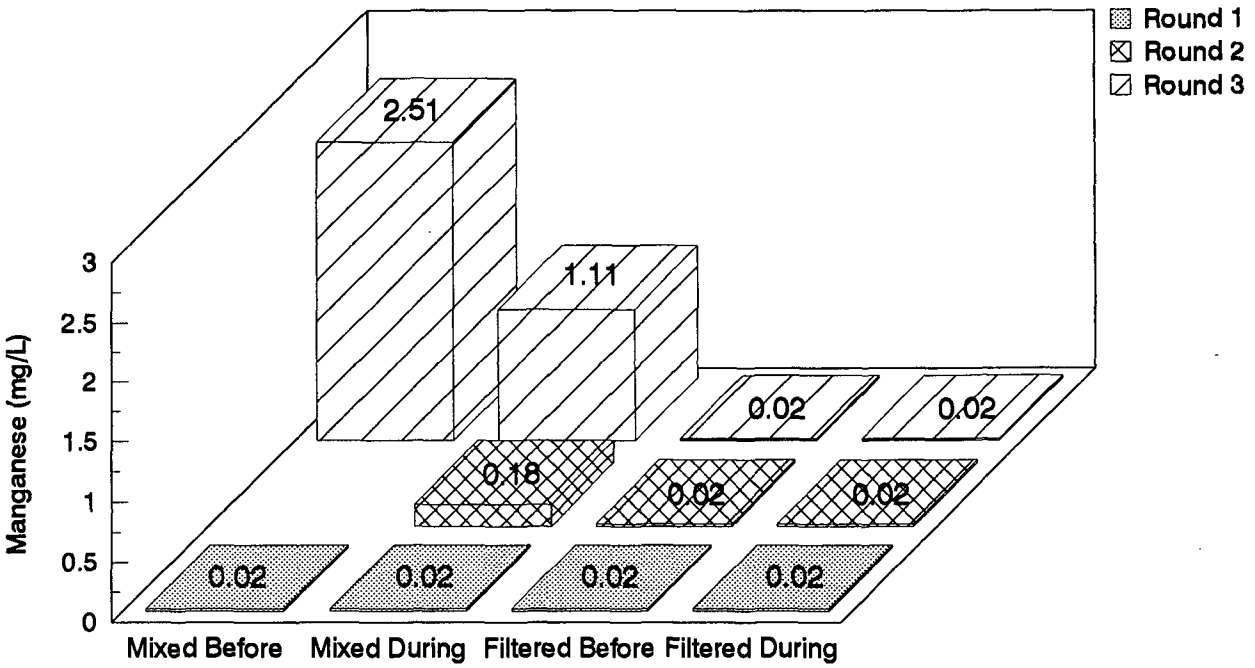


Figure 6.9 Total manganese concentrations in mixed and filtered water for New Castle Water Treatment Plant

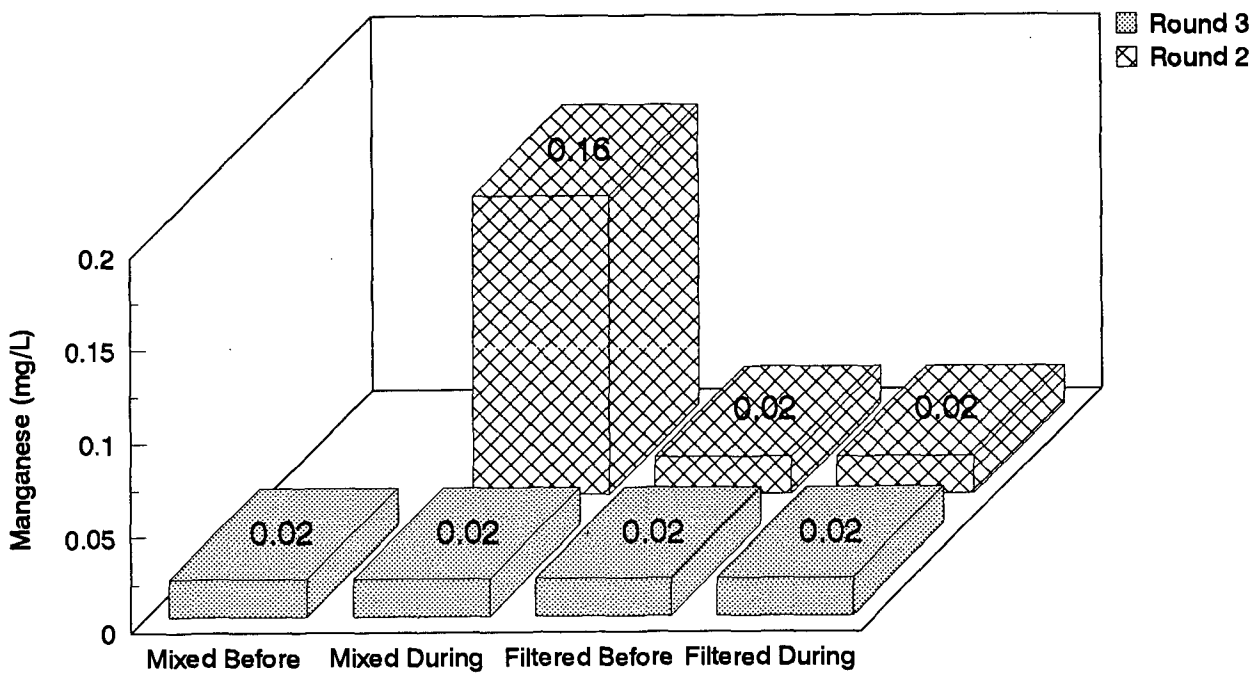


Figure 6.10 Dissolved manganese concentrations in mixed and filtered water for New Castle Water Treatment Plant

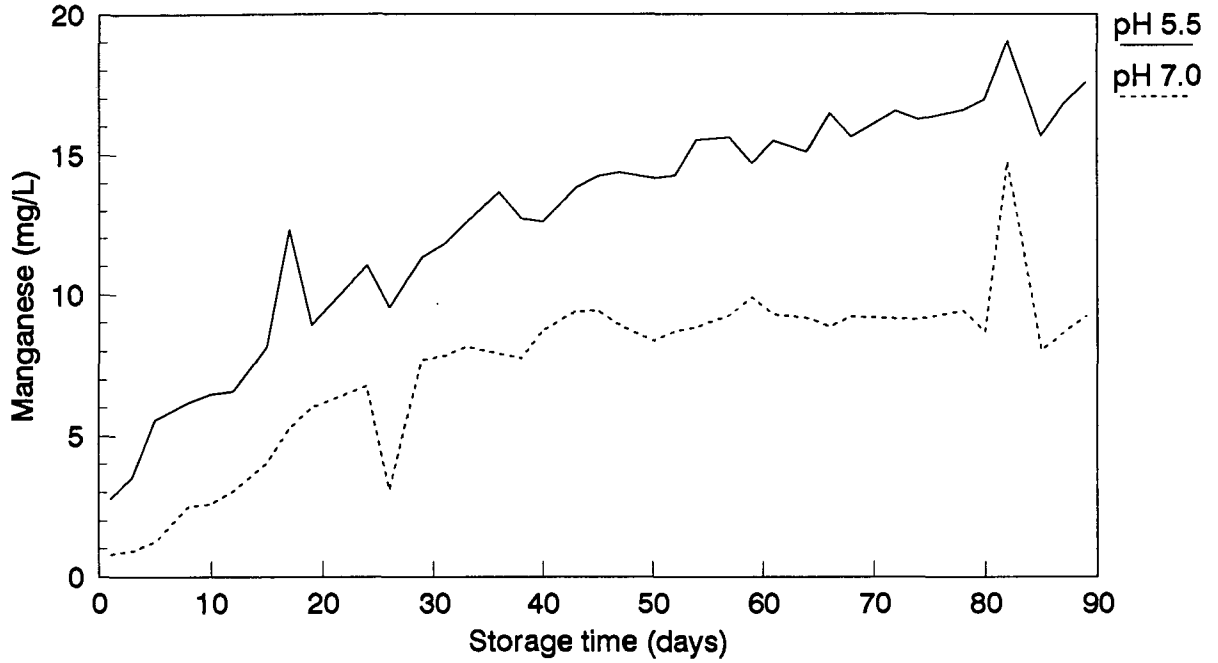


Figure 6.11 Manganese released with sludge storage time for New Castle Water Treatment Plant

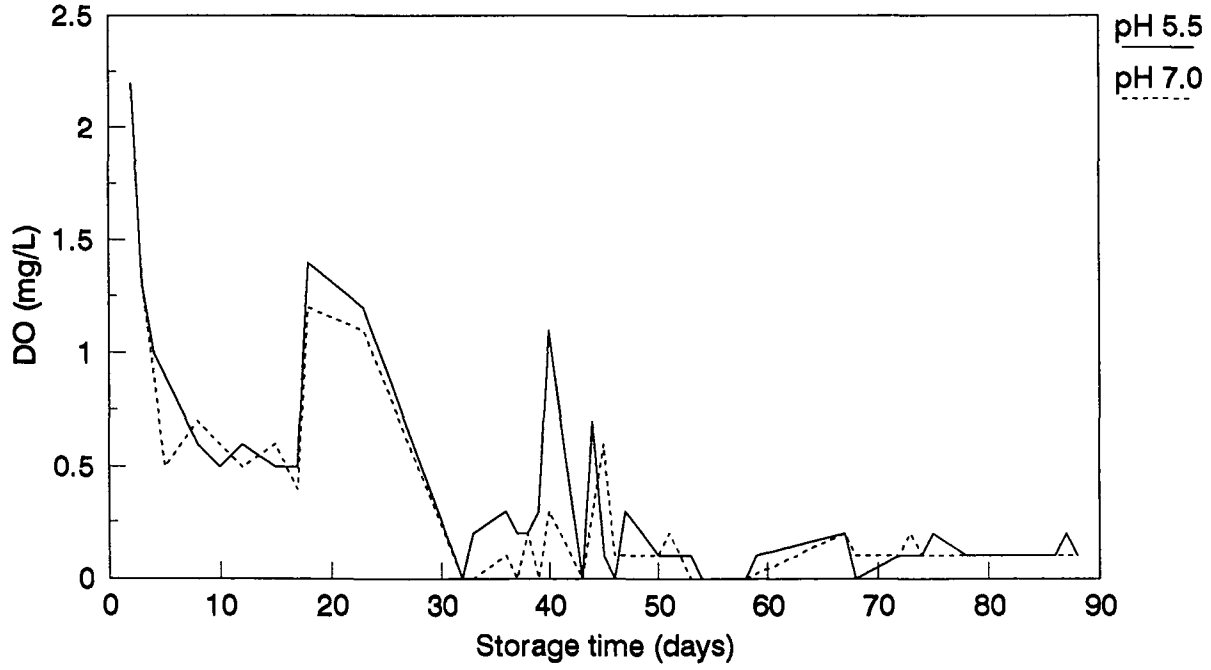
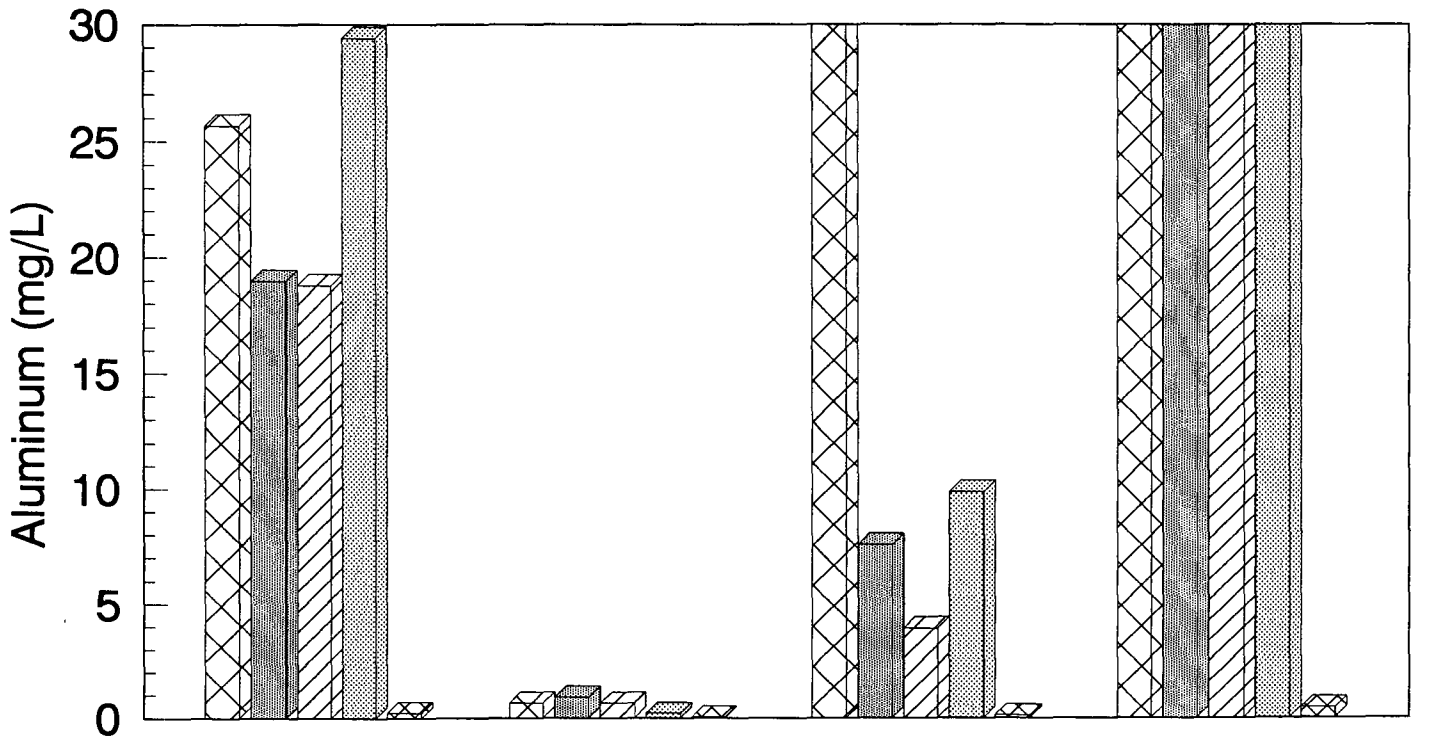


Figure 6.12 Dissolved oxygen concentrations for New Castle Water Treatment Plant



	Backwash Recycle	Thickener Recycle	Pressate	Settled Sludge
Round 1: Total Al	25.65	0.66	186.00	903.00
Round 2: Total Al	18.98	0.92	7.60	300.00
Round 2: Dissolved Al	18.78	0.66	3.94	300.00
Round 3: Total Al	29.400	0.215	9.900	1,021.000
Round 3: Dissolved Al	0.23	0.04	0.12	0.45

Figure 6.13 Aluminum levels in waste and recycle streams for New Castle Water Treatment Plant

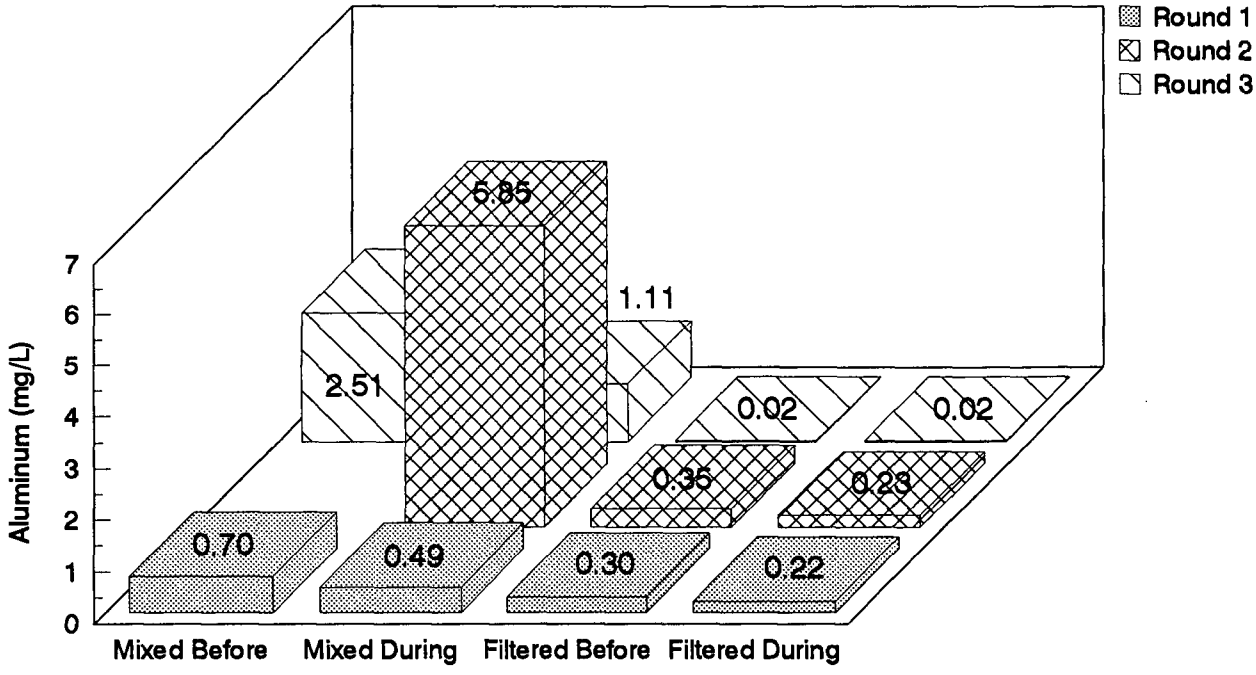


Figure 6.14 Total aluminum levels in mixed and filtered water before and during recycle for New Castle Water Treatment Plant

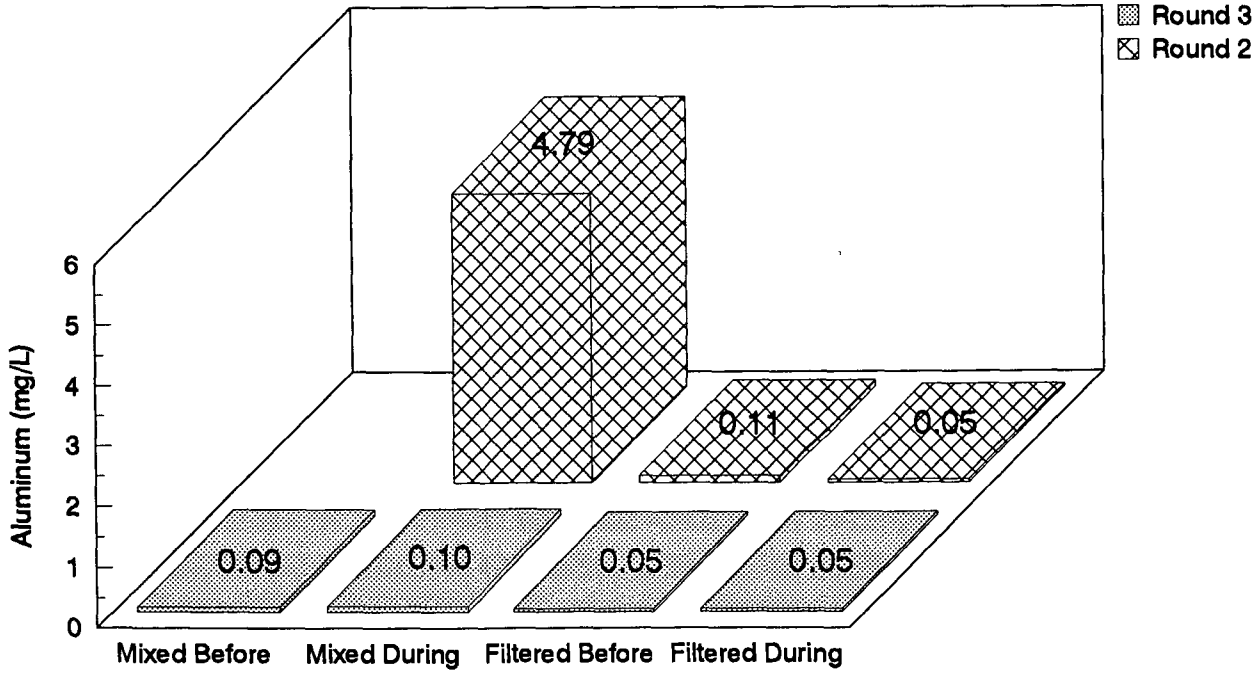


Figure 6.15 Dissolved aluminum levels in mixed and filtered water before and during recycle for New Castle Water Treatment Plant

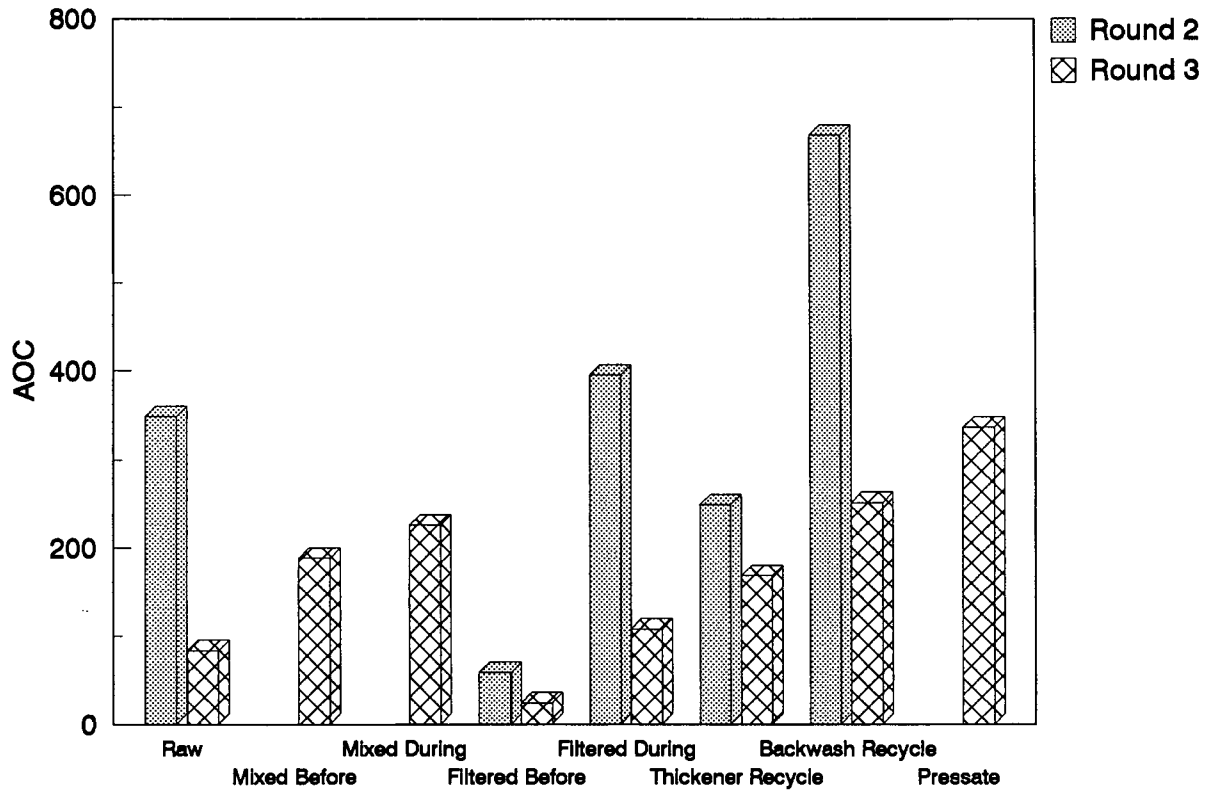


Figure 6.16 Total AOC levels for New Castle Water Treatment Plant; rounds 2 and 3

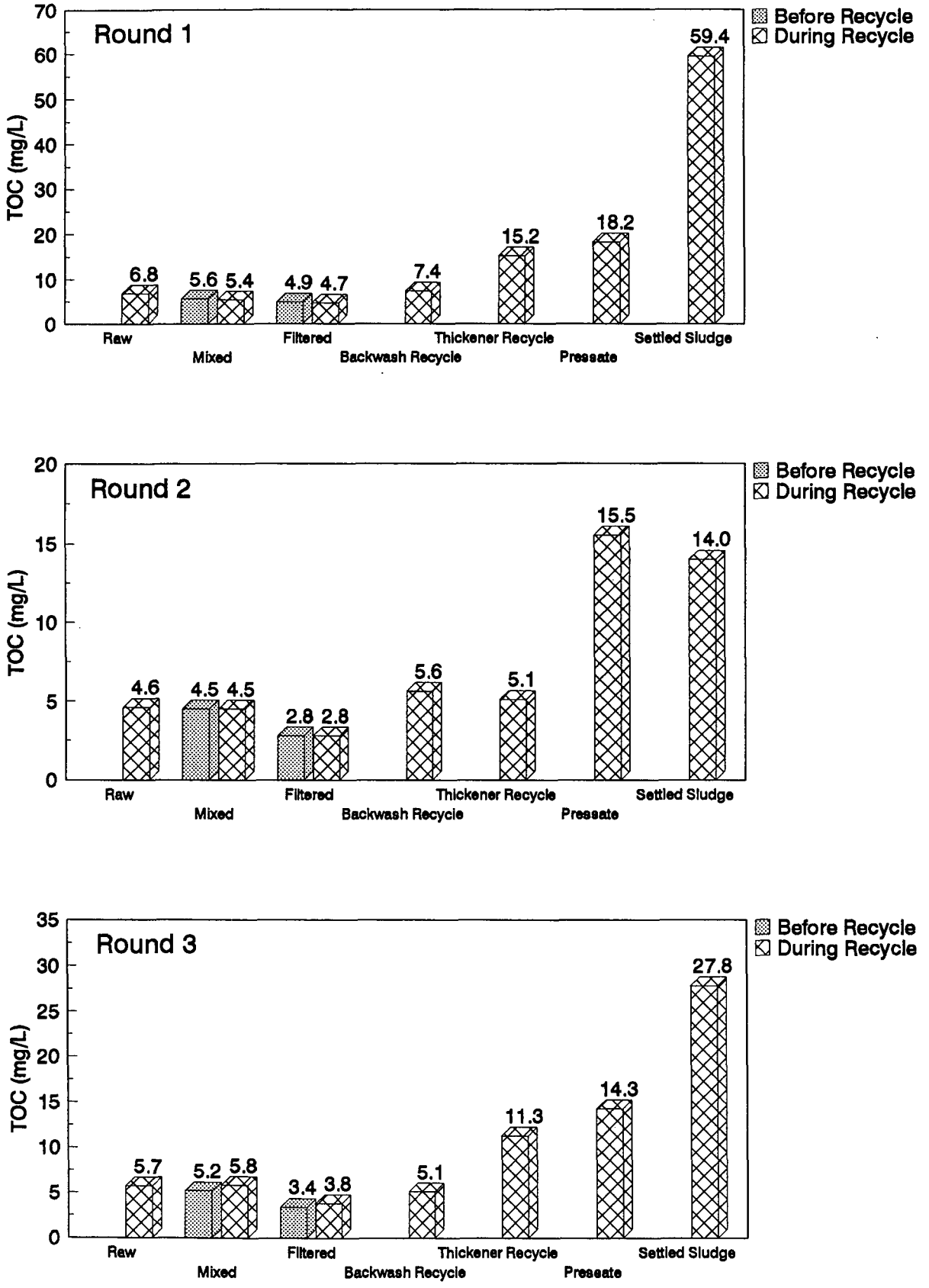


Figure 6.17 TOC levels for New Castle Water Treatment Plant

Chapter 7

Bangor Water Treatment Plant

Plant Description

Treatment Process

The Bangor Water Treatment Plant is a direct filtration plant located in Bangor, Pa. The raw water sources consist of surface water, deep and artisian wells, and springs. The source waters are collected in a small open reservoir above grade from the plant. The filters consist of three mixed media filters rated at 8 gpm/ft^2 (19.5 m/h). Filtered water goes to a clearwell before being pumped to the distribution system.

Raw water quality is excellent with an average turbidity of 0.5 ntu. Filtered water turbidity is about 0.10 ntu. Occasional high raw water turbidity of 5.0 ntu causes shortened filter runs but does not decrease finished water quality. The process flow schematic is shown in Figure 7.1.

Plant Flow

This plant is rated at 3.5 mgd (550 m^3/h) and is normally operated at the design rate of 3.5 mgd (550 m^3/h) for 6 to 8 hours a day, 7 days a week.

Chemical Feed

Chlorine is added to the intake line at the raw water reservoir, and alum is added in the raw water line at the plant. Filtered water is treated by the addition of caustic soda, corrosion inhibitor, and chlorine. Chemical feed data are shown in Table 7.1.

Solids Handling

The waste streams are spent backwash water and filter-to-waste. Both go to a backwash clarifier. The clarifier tank has a capacity of 160,000 gal (19 m^3/h). The supernatant is recycled to the head of the plant, and the solids go to drying beds. In one year of operation there has been very little solids buildup on the drying beds, and they have never been cleaned.

Recycle

The backwash clarifier is allowed to settle 1 to 2 hours after a backwash before the recycle is started. There are three recycling pumps rated at 70 gpm each (19 m^3/h).

During recycle the SCD changes from zero to negative. The increase in applied turbidity is several times the normal turbidity applied to the filters. There is no apparent effect on filtered turbidity during recycle.

Water Quality

Raw and finished water quality data for the plant are summarized in Table 7.2.

Preliminary sampling consisted of collecting a one-time grab sample of the recycle stream and the filtered water. The filtered water was sampled before and during recycle. These sampling points are shown in Figure 7.1. Table 7.3 summarizes the results of this initial investigation. Turbidity and suspended solids were very high in the recycle stream compared to the source water.

Comprehensive Sampling Program

Overview

The main parameters evaluated at the Bangor Water Treatment Plant were turbidity, *Giardia* and *Cryptosporidium* cysts, and particle counts. Two rounds of field sampling and analysis were performed at the plant. In addition to the field sampling and analysis performed, spent backwash water from the plant was also collected for bench-scale testing. Bench-scale testing evaluated the addition of polymer and flocculation for the enhancement of solids removal from the spent backwash water. *Giardia* and *Cryptosporidium* were analyzed according to the procedures of LeChevallier et al. (1991).

Round 1 Sampling

The plant was operating under normal conditions at the time of field sampling. The plant flow was 2.4 mgd (380 m^3/h) and the recycle flow was 0.12 mgd (19 m^3/h) (5 percent). Raw turbidity was typical at 0.34 ntu, and filtered turbidity was less than 0.10 ntu.

Sampling was conducted over an 8-hour period. A composite sample was collected and analyzed for the following parameters:

Turbidity
Particle counts
Giardia
Cryptosporidium

The sample locations for these parameters are listed below. Numbers in parentheses indicate the sampling locations as shown in Figure 7.1.

Raw (1)
Raw with recycle (3)
Spent filter backwash water (4)
Supernatant recycle (2)
Filtered (5)

The plant was first operated for 2 hours without recycling any supernatant in order to collect background samples. The recycle stream was then started to collect samples on the effects of recycle. Parasite samples were collected over the entire recycle period. Grab samples were taken for particle counts. Turbidity was monitored continuously during the recycle period. *Giardia* and *Cryptosporidium* data are contained in Table 7.4.

Round 2 Sampling

The plant flow was approximately 2.8 mgd (442 m^3/h). Raw water turbidities ranged between 0.23 and 0.36 ntu during the test period.

Particle counts and *Giardia* and *Cryptosporidium* were the parameters tested in round 2. All sample locations from round 1 testing were resampled. In addition, samples of mixed backwash and settled backwash were tested to determine the efficiency of the wastewater clarifier. Parasite samples were continuously collected as before. Composite samples were taken in round 2 for particle counting to better simulate the parasite data.

Laboratory-Scale Analysis

Removal of *Giardia*- and *Cryptosporidium*-size particles from the spent filter backwash water was investigated with polymers, flocculation, and filtration. In the first test, filter backwash water was placed in six 2-L Gator jars. A nonionic polymer (POL-E-Z 652, Calgon Corp., Ellwood City, Pa.) was added to these jars with dosages of 0.0, 0.1, 0.2, 0.5, 0.8, and 1.0 mg/L. After all the jars were mixed for 10 seconds, samples were collected corresponding to settling velocities of 4, 0.8, 0.4, 0.13, and 0.07 cm/min. Each sample was then tested for particle counts. In the second test, different times of flocculation ($G = 25\ s^{-1}$) were evaluated.

In the third test, water from the recycle stream was filtered through a laboratory sand filter to estimate the removal efficiency for *Giardia*- and *Cryptosporidium*-size particles. This filter achieved 1.66-log removal of *Giardia*-size particles and 0.72-log removal of *Cryptosporidium*-size particles.

Trends

Turbidity

The turbidity of the applied water increased with the addition of the recycle water. Figure 7.2 shows the applied water turbidity increase during recycle. The filtered water turbidity showed no increase in turbidity, indicating effective treatment. This result is shown in Figure 7.3.

Particle Counts

Figures 7.4 and 7.5 show the particle counts by size range for round 1 (grab sample) and round 2 (composite sample). The recycle greatly increased the applied particle counts, particularly in the 2-to-15-μm size range. During both rounds of sampling the raw water particle counts were about 2,200/mL between 2 and 15 μm, and with recycle the levels increased to almost 10,000/mL. However, the number of particles in the filtered water was essentially the same with or without recycle.

Table 7.5 summarizes the filter removal efficiencies for round 1 grab samples and the round 2 composite sample. Because applied particle counts increased and filtered particle counts remained about the same, removal efficiency of course was higher during recycle. During round 2 sampling, composite samples were taken throughout the run from the effluent of the individual filters 1, 2, and 3. These data are shown graphically in Figure 7.6. There was no adverse impact on filtered water particle counts due to recycle for any of the filters evaluated.

During round 1, the spent backwash water clarifier supernatant was sampled immediately after a filter backwash and after 2 and 20 hours of settling time. These results are shown graphically in Figure 7.7. The results showed that sedimentation substantially reduced the number of particles in the supernatant. Little reduction in particle numbers resulted from increasing the sedimentation time from 2 to 20 hours.

Laboratory results for the removal of particles from spent filter backwash water are shown in Figures 7.8 through 7.11. Each is presented in a format of percent removal versus particle settling velocity. Particle settling velocity in this case is equivalent to the spent backwash water clarifier overflow rates required to achieve the desired percent removal. Equivalent overflow values are also shown. Figure 7.8 is a plot of *Giardia*-size particle removal (5-to-15-μm-size particles) for different polymer doses. For example, if a spent backwash clarifier was designed for the Bangor plant at a hydraulic overflow rate of 0.5 gpm/ft^2 (1.2 m/h), Figure 7.8 shows that only 6 percent of the *Giardia*-size particles would be removed without the use of a polymer. However, more than 90 percent removal could be achieved with a polymer dose of 0.8 to 1 mg/L. Figure 7.9 shows that essentially no removal (less than 3 percent) of *Cryptosporidium*-size particles was achieved without polymer use. Polymer was again successful in increasing removal efficiency.

Results of using flocculation to further enhance removal are shown in Figures 7.10 and 7.11. Although the results show that flocculation may have slightly enhanced the removal, polymer use alone may be sufficient for practical applications.

Bangor recycle water (spent backwash water after sedimentation in the holding tank) was passed through a bench scale filter that consisted of 2 ft (0.6 m) of filter-grade sand (ES = 0.5) and 6 in. (15 cm) of gravel at a loading rate of 2 gpm/ft^2 (4.9 m/h). Filtration of this water resulted in removal of 97.8 percent (1.66 log) and 81 percent (0.72 log) of *Giardia*- and *Cryptosporidium*-size particles, respectively. One could combine the sedimentation efficiency data with the filtration efficiency data to estimate the overall removal of the cyst-size particles that could be achieved with sedimentation and filtration of the spent filter backwash water.

Parasite Data

In addition to estimates of *Giardia* and *Cryptosporidium* presence by particle count analysis, actual parasite counting was also performed in accordance with the procedure in LeChevallier et al. (1991). Figures 7.12 and 7.13 summarize these

results for round 1 and round 2 testing. In round 1 testing, the clarifier removed about 94 percent of the *Giardia* cysts and about 87 percent of the *Cryptosporidium* particles from the spent backwash water. In round 2, no *Giardia* cysts were detected in any of the analyses. Only 12 percent of the *Cryptosporidium* cysts were removed in the spent backwash clarifier tank. The spent backwash water was also allowed to settle for 2 hours, which again resulted in poor *Cryptosporidium* cyst removal. The *Cryptosporidium* cysts were only reduced from 8.47/L to 6.26/L after the 2 hours. The round 2 sampling of actual cysts showed removal similar to that obtained from the laboratory particle count analyses. In the lab particle count experiments, fewer than 10 percent of the *Cryptosporidium*-size particles were removed by simple sedimentation of the spent backwash water.

Table 7.1 Chemical feed data for Bangor Water Treatment Plant

Location	Chemical	Dose (mg/L)
Raw	Alum	1–4
	Chlorine	1–3
Filtered	Chlorine	0.5–1.0
	Corrosion inhibitor, ZOP	3.0
	Caustic	10.0

ZOP = zinc orthophosphate

Table 7.2 Average annual water quality data for Bangor Water Treatment Plant

Parameter	Raw	Finished
Turbidity, ntu	0.3	0.13
Color, cu	0	0
Iron, mg/L	<0.05	<0.05
Manganese, mg/L	<0.02	<0.02
pH	6.3	7.2
Alkalinity, mg/L $CaCO_3$	6	20
Ammonia, mg/L	<0.01	<0.01
Aluminum, mg/L	NA	<.001
Coliform, number/100 mL	<1	<1
TTHM, µg/L	NA	15
Free Cl_2, mg/L	NA	1.7

NA = no data available

Table 7.3 Preliminary sampling results for Bangor Water Treatment Plant

Parameter	Backwash recycle	Filtered	
		Without recycle	With recycle
Turbidity, ntu	16	0.07	0.09
pH	6.7	6.4	6.3
Total chlorine, mg/L	<0.1	1.6	1.3
Free chlorine, mg/L	<0.1	1.5	1.2
Alkalinity, mg/L as $CaCO_3$	12	2	8
Coliform, number/100 mL	<1	<1	<1
Heterotrophic plate count, colonies/mL	40	2	29
Aluminum, mg/L	1.4	0.06	0.07
Iron, mg/L	0.18	<0.05	<0.05
Manganese, mg/L	0.04	<0.02	<0.02
TSS, mg/L	23	1	6
TOC, mg/L	5.7	1.0	1.1
TTHM, µg/L	61	2	5
TTHMFP, µg/L	550	58	40

Table 7.4 Round 1 parasite data for Bangor Water Treatment Plant

Sample site	*Giardia* (cysts/L)	*Cryptosporidium* (cysts/L)
Raw (1)*	0.03	0.06
Mixed raw and recycle (3)	0.07	0.40
Backwash (4)	13.52	9.02
Supernatant recycle (2)	0.86	1.41

*Numbers in parentheses indicate sampling locations as shown in Figure 7.1.

Table 7.5 Particle removal efficiency for Bangor Water Treatment Plant filters

	Percent removal	Log removal
Round 1 - grab sample		
Combined filter effluent (without recycle)		
All particles (1–100 µm)	99.3	2.15
Giardia size (5–15 µm)	99.4	2.22
Cryptosporidium size (2–9 µm)	99.4	2.22
Combined filter effluent (with recycle)		
All particles (1–100 µm)	99.4	2.22
Giardia size (5–15 µm)	99.6	2.40
Cryptosporidium size (2–9 µm)	99.3	2.15
Round 2 – composite sample		
Filter 2 effluent (without recycle)		
All particles (1–100 µm)	94.1	1.23
Giardia size (5–15 µm)	92.8	1.14
Cryptosporidium size (2–9 µm)	94.3	1.24
Filter 2 effluent (with recycle)		
All particles (1–100 µm)	96.4	1.44
Giardia size (5–15 µm)	96.3	1.43
Cryptosporidium size (2–9 µm)	96.5	1.46

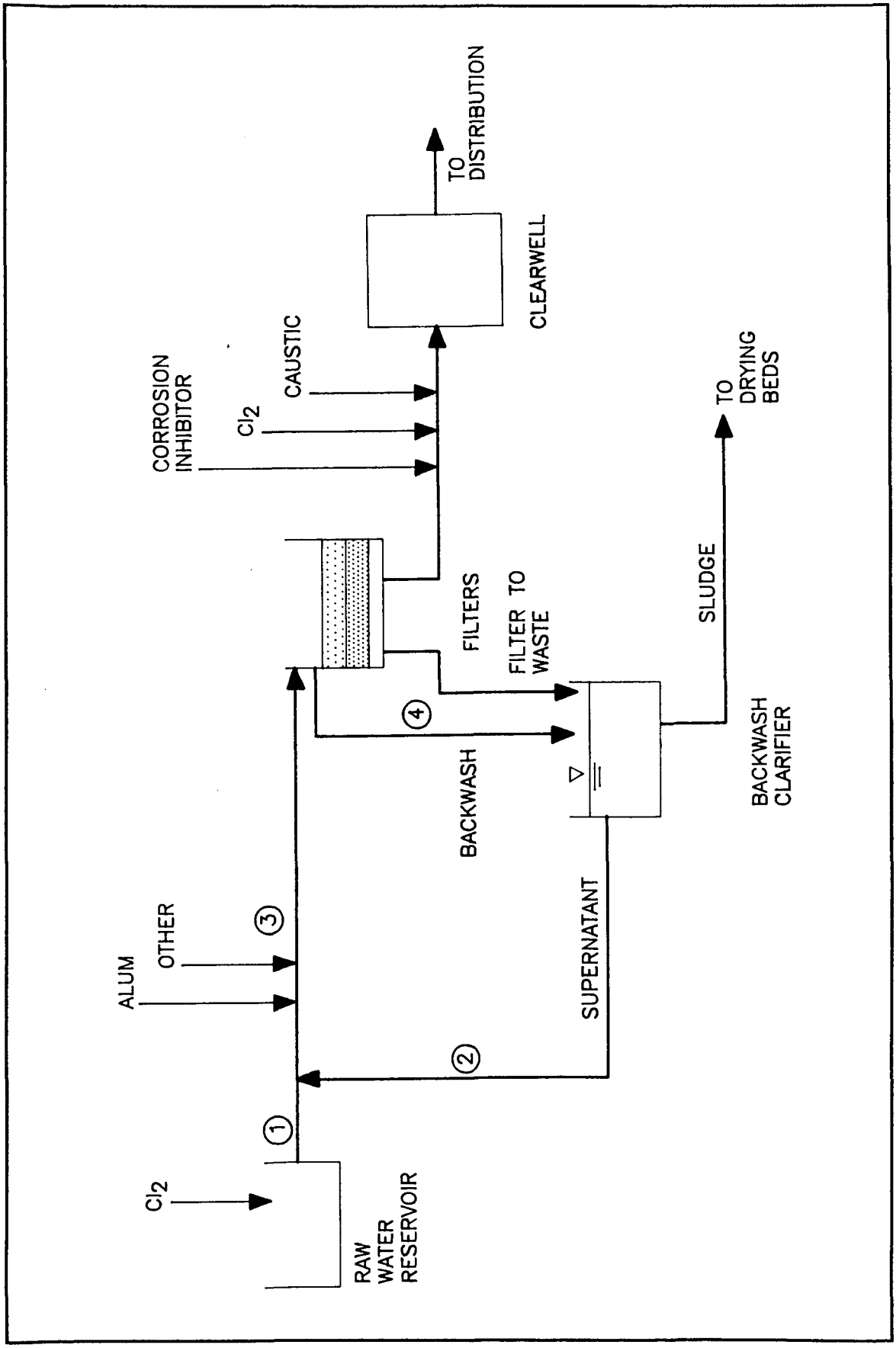
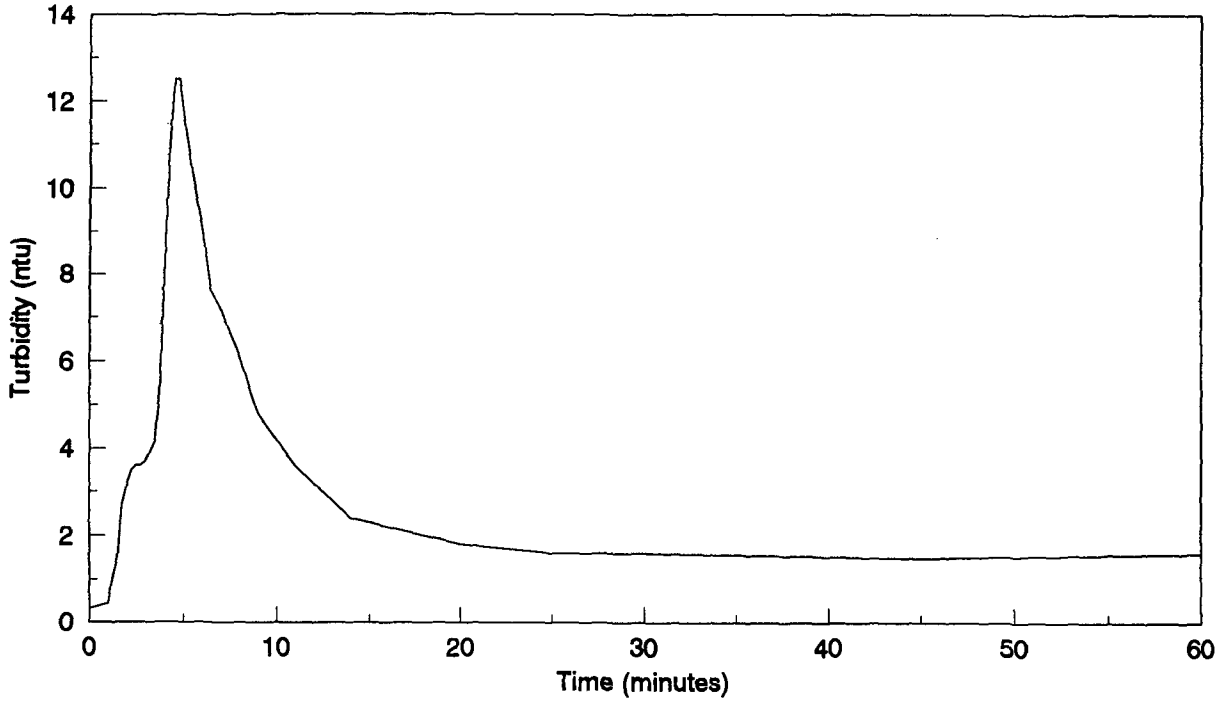
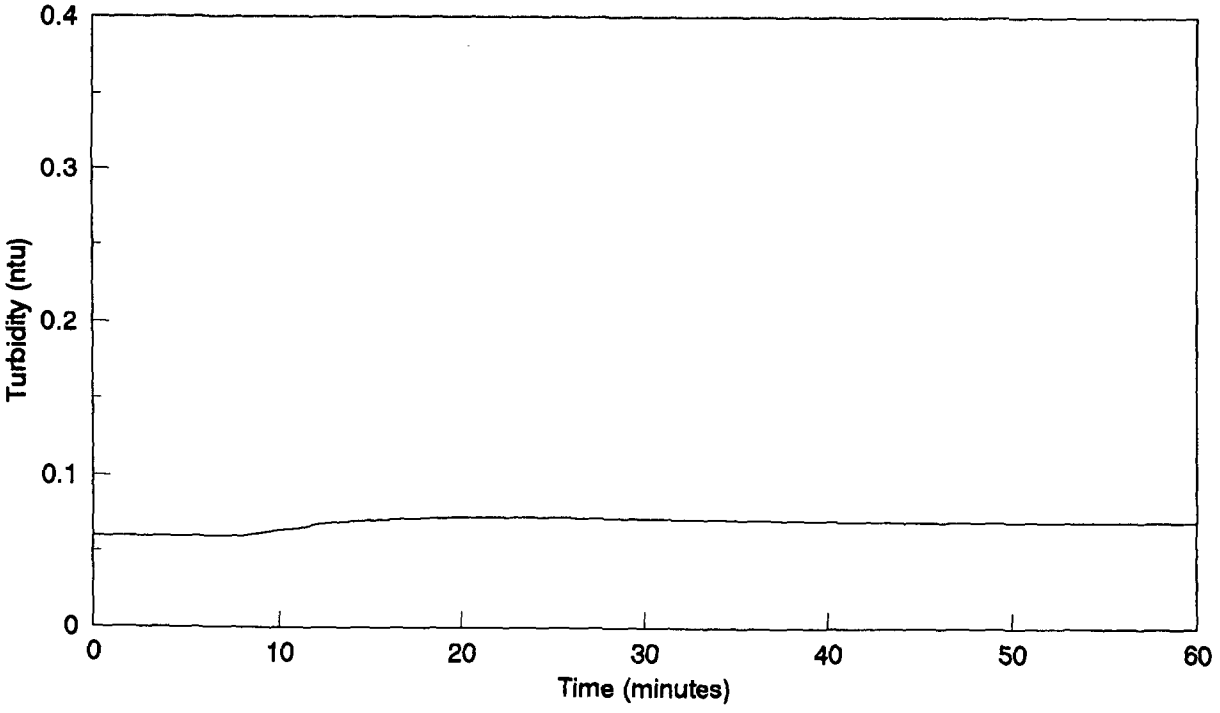


Figure 7.1 Process flow diagram and sample point locations for Bangor Water Treatment Plant



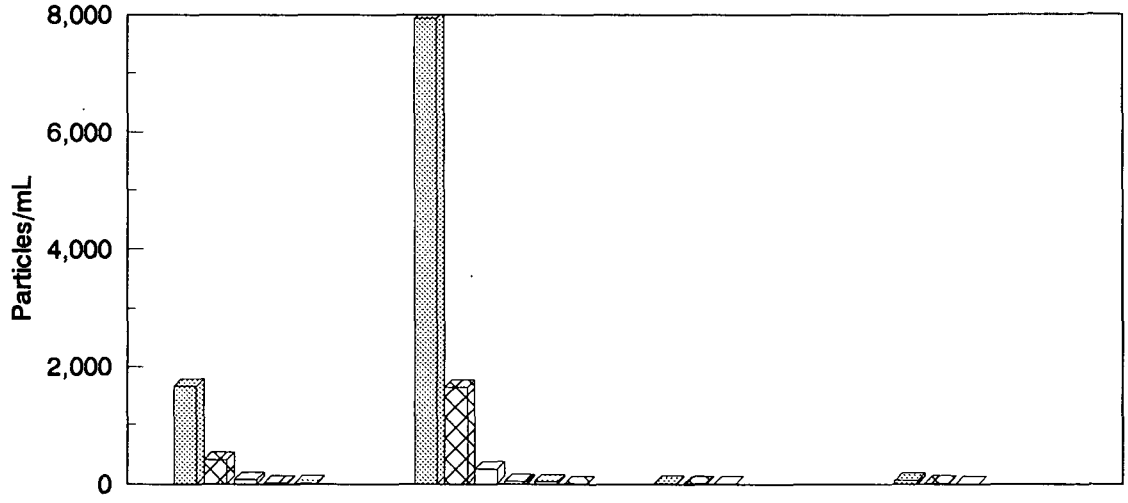
Note: Recycle began at time 0.

Figure 7.2 Applied water turbidity during recycle for Bangor Water Treatment Plant; round 1



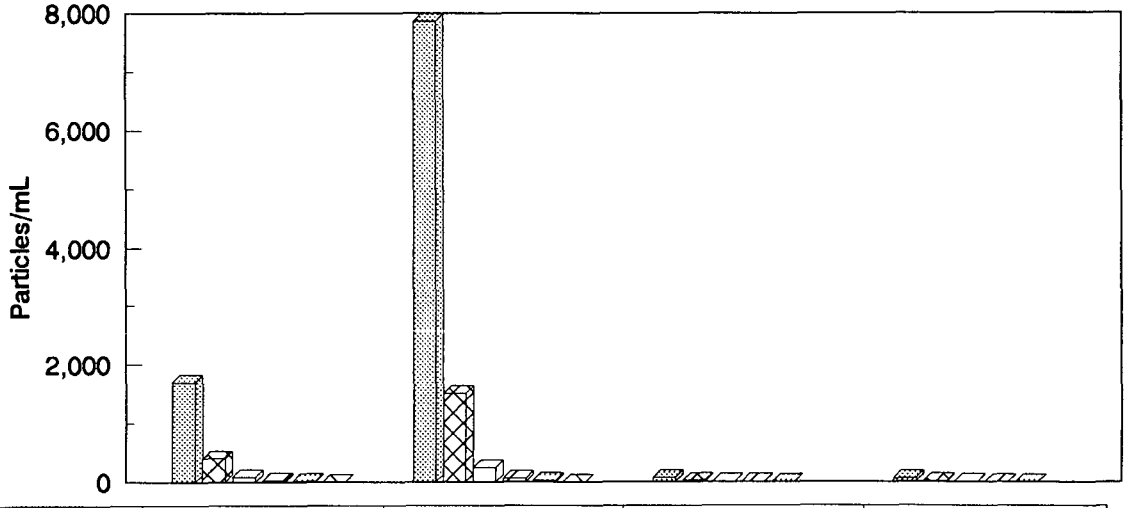
Note: Recycle began at time 0.

Figure 7.3 Filtered water turbidity during recycle for Bangor Water Treatment Plant; round 2



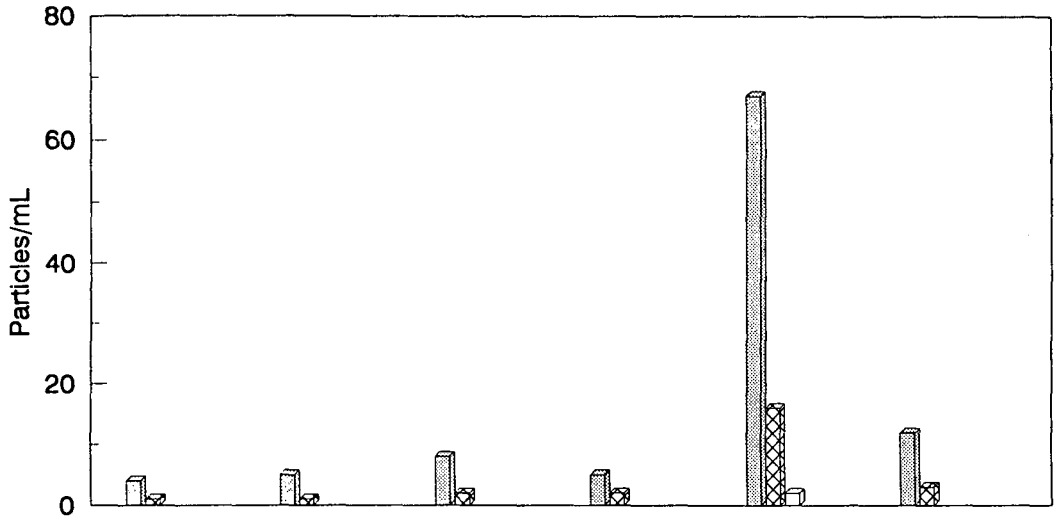
	Raw Water	Raw Water & Recycle	Filtered wo/Recycle	Filtered w/Recycle
2-4 microns	1,659	7,932	11	56
5-9 microns	396	1,630	2	7
10-15 microns	67	242	1	1
16-19 microns	12	36	0	0
20-39 microns	10	34	0	0
>40 microns	0	2	0	0

Figure 7.4 Round 1 particle count data for Bangor Water Treatment Plant



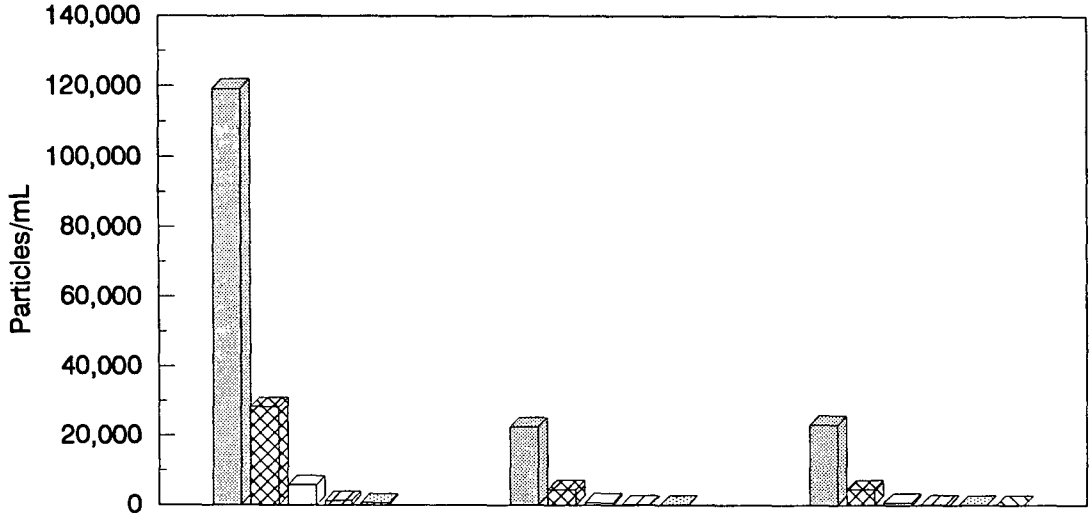
	Raw Water	Raw Water & Recycle	Filtered wo/Recycle	Filtered w/Recycle
2-4 microns	1,692	7,658	75	59
5-9 microns	405	1,513	22	15
10-15 microns	83	244	7	3
16-19 microns	30	61	3	2
20-39 microns	21	27	1	1
>40 microns	1	1	0	0

Figure 7.5 Round 2 particle count data for Bangor Water Treatment Plant



	Filter 1 wo/Recycle	Filter 1 w/Recycle	Filter 2 wo/Recycle	Filter 2 w/Recycle	Filter 3 wo/Recycle	Filter 3 w/Recycle
2-4 microns	4	5	6	5	67	12
5-9 microns	1	1	2	2	16	3
10-15 microns	0	0	0	0	2	0
16-19 microns	0	0	0	0	0	0
20-39 microns	0	0	0	0	0	0
>40 microns	0	0	0	0	0	0

Figure 7.6 Particle counts for individual filters at Bangor Water Treatment Plant



	No Settling	2 Hours Settling	20 Hours Settling
2-4 microns	119,137	22,520	23,161
5-9 microns	28,284	4,432	4,525
10-15 microns	5,725	606	645
16-19 microns	1,214	97	114
20-39 microns	525	31	48
>40 microns	0	0	2

Figure 7.7 Impact of settling time on particle counts in spent filter backwash water at Bangor Water Treatment Plant

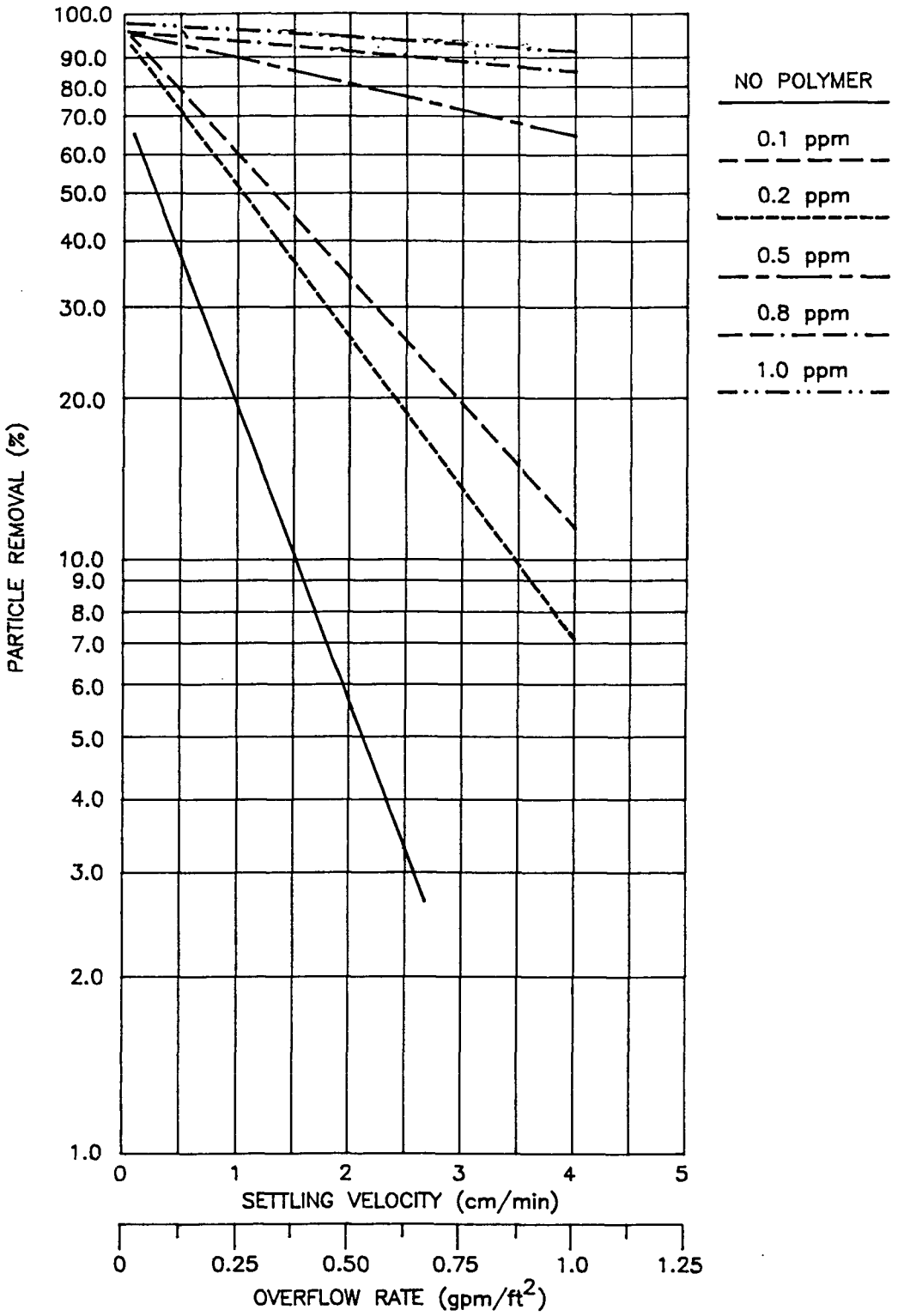


Figure 7.8 Removal of *Giardia*-size particles (5–15 μm) from spent backwash water at Bangor Water Treatment Plant using sedimentation (polymer: POL-E-Z 652)

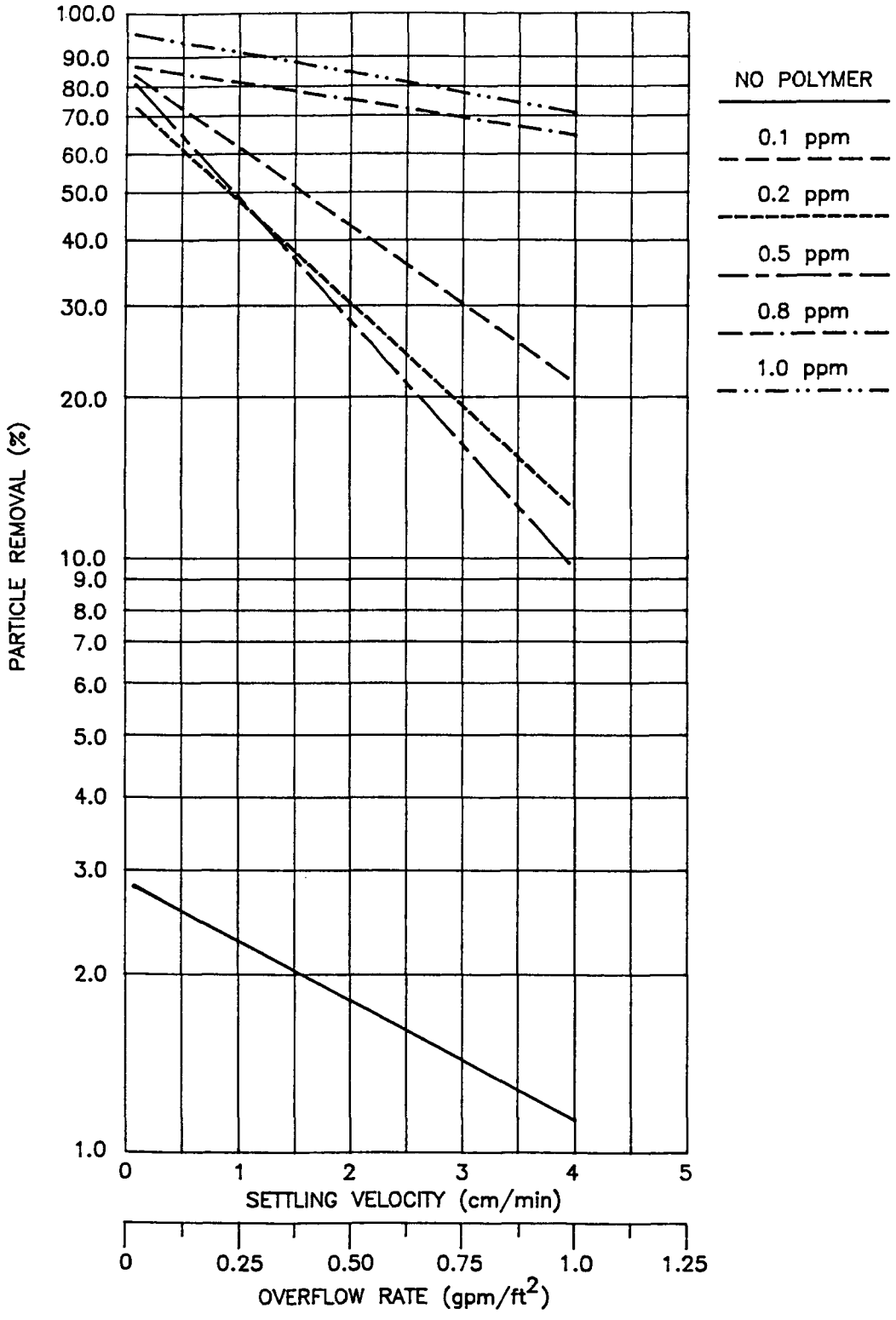


Figure 7.9 Removal of *Cryptosporidium*-size particles (3–5 μm) from spent backwash water at Bangor Water Treatment Plant using sedimentation (polymer: POL-E-Z 652)

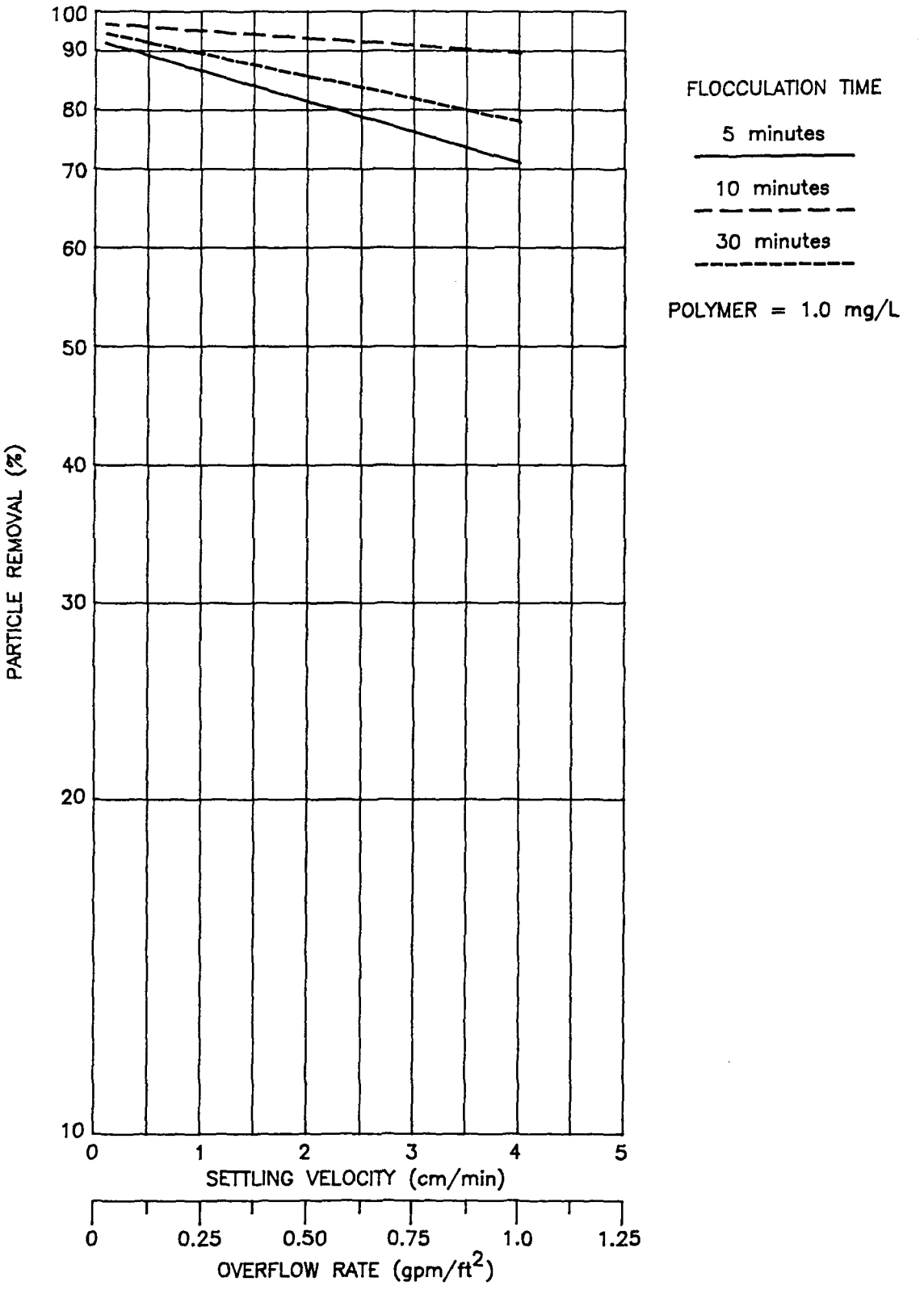


Figure 7.10 Removal of *Giardia*-size particles (5–15 μm) from spent backwash water at Bangor Water Treatment Plant using flocculation and sedimentation (polymer: POL-E-Z 652)

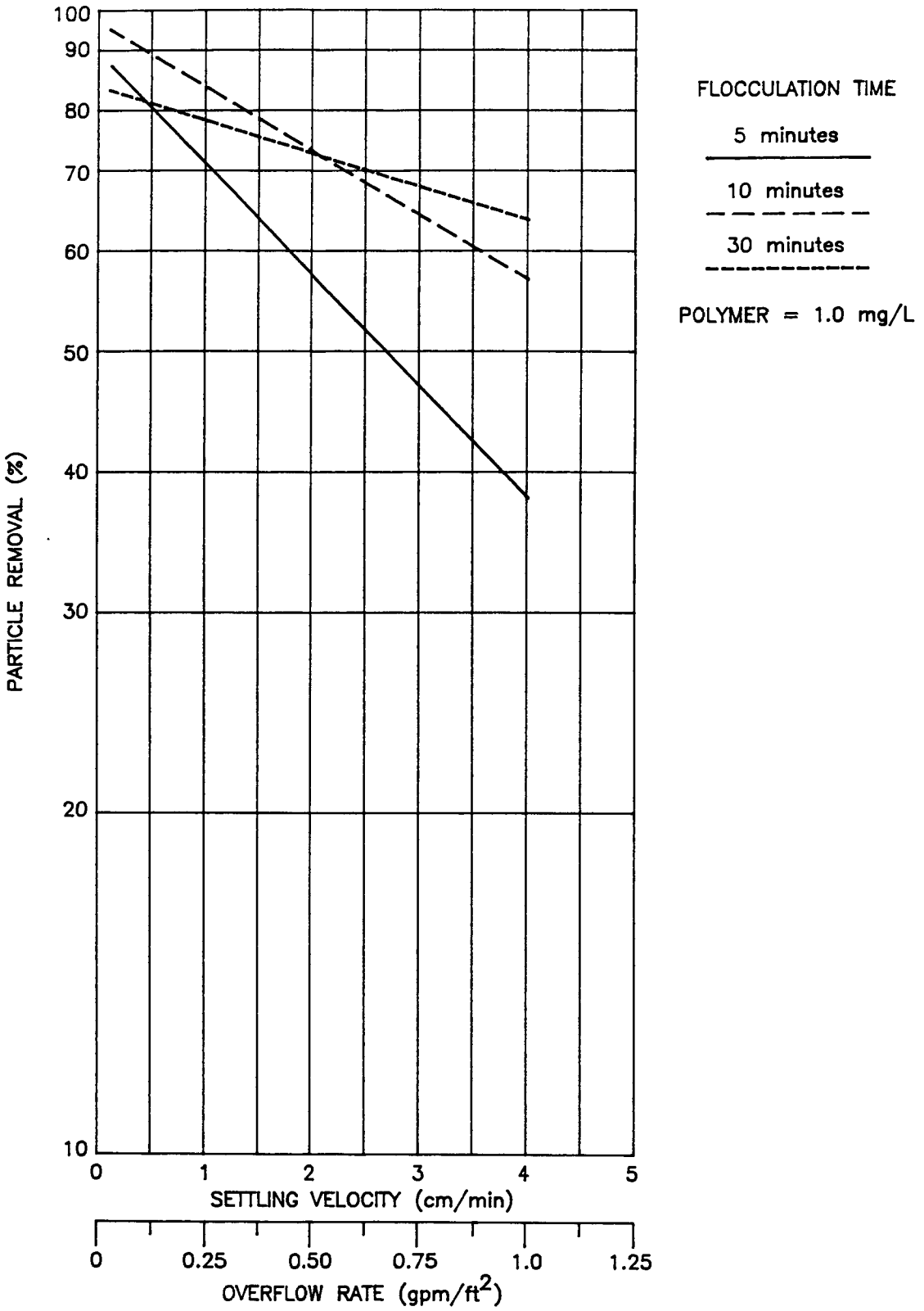


Figure 7.11 Removal of *Cryptosporidium*-size particles (3–5 μm) from spent backwash water at Bangor Water Treatment Plant using flocculation and sedimentation (polymer: POL-E-Z 652)

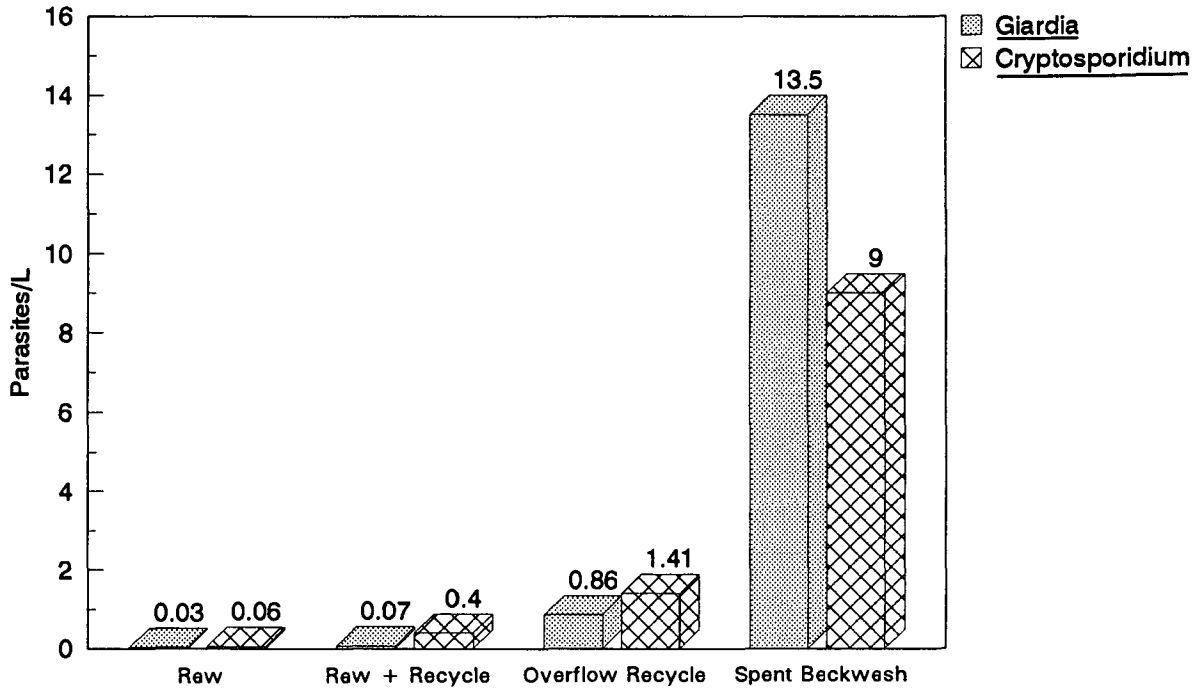


Figure 7.12 Round 1 parasite data for Bangor Water Treatment Plant

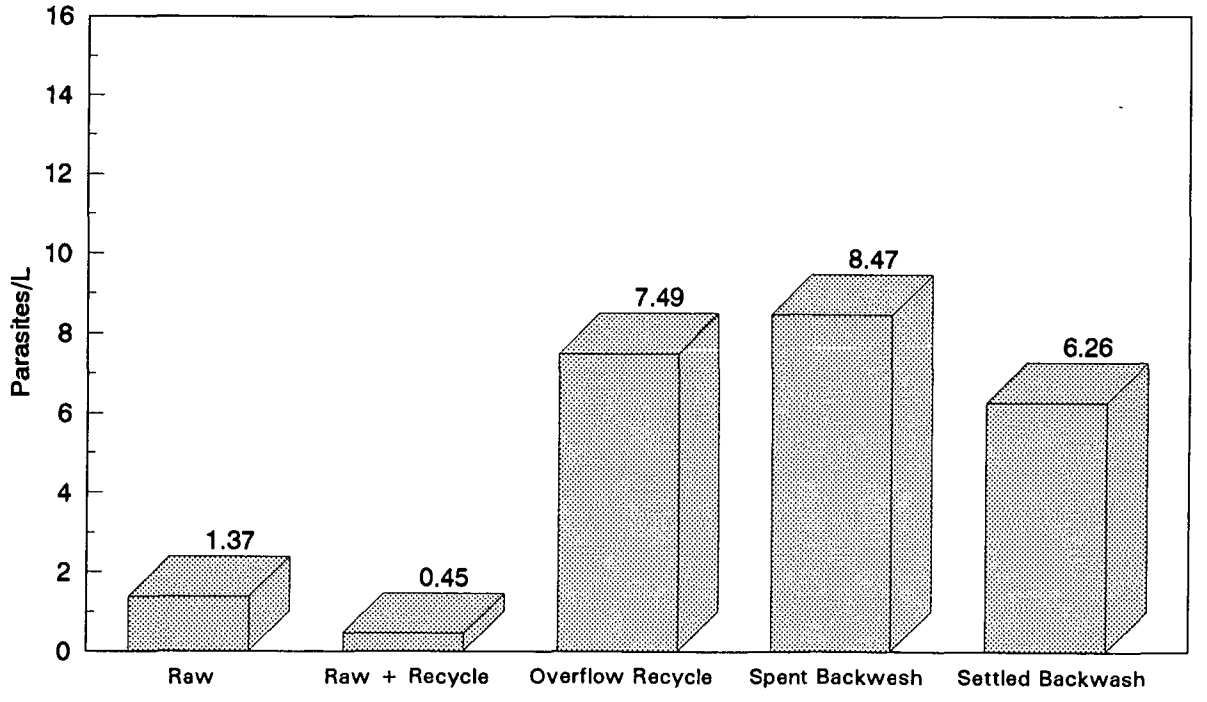


Figure 7.13 Round 2 *Cryptosporidium* data for Bangor Water Treatment Plant

Chapter 8

Moshannon Valley Water Treatment Plant

Plant Description

Treatment Process

The Moshannon Valley Water Treatment Plant, located in Philipsburg, Pa., is a 2.3-mgd (360-m^3/h) plant that obtains raw water from an impounded reservoir, a spring, and three wells. The mixed raw water has an average annual turbidity of 1.2 ntu. Two in-line static mixers provide rapid mixing. The chemically treated water, monitored with an SCD, flows upward through two high-rate adsorption clarifiers. Clarified water flows into one of four mixed media filters. The finished water flows by gravity to a 78,000-gal (295-m^3) clearwell and then to a 1.0-MG (3,800-m^3) storage reservoir. Finished water is delivered from the storage reservoir by gravity. Figure 8.1 shows the process flow schematic for the Moshannon Valley Water Treatment Plant.

Plant Flow

The plant is rated at 2.3 mgd (360 m^3/h). Seasonal flows range from 1.7 to 2.3 mgd (260 to 360 m^3/h) and average 1.8 mgd (285 m^3/h) The flow varies between 1.4 and 2.3 mgd (220 to 360 m^3/h) throughout the day.

There are two adsorption clarifiers, each rated at 1.15 mgd (181 m^3/h) at 8 gpm/ft^2 (19.6 m/h). Chemically treated raw water flows upward through the adsorption clarifiers. The clarified water then flows to four mixed media filters, each rated at 0.58 mgd (92 m^3/h) at 4 gpm/ft^2 (9.8 m/h).

Chemical Feed

Raw water chemical feed consists of the addition of chlorine, caustic soda, and alum. Filtered water at the plant is treated by the addition of chlorine, caustic soda, fluoride, and corrosion inhibitor. The plant also has the capability to add a filter aid to the clarified water. Typical chemical feed doses are shown in Table 8.1.

Solids Handling

The solids-handling process includes a 150,000-gal (568-m^3) wastewater clarifier and four sludge drying beds (total area = 6,400 ft^2 [600 m^3]). Waste streams include

Spent filter backwash water
Clarifier flush water
Sand bed filtrate
Filter-to-waste
Clarifier-to-waste

Solids generated by the backwashing of filters and the flushing of adsorption clarifiers flow to the wastewater clarifier. Settled solids are pumped to the drying beds once every 2 weeks. Filtrate from the drying beds is returned to the wastewater clarifier. Supernatant from the wastewater clarifier is returned to the raw water line at the head of the plant prior to chemical addition.

Recycle

Spent filter backwash water, adsorption clarifier flush water, filter-to-waste, clarifier-to-waste, and sand drying bed filtrate goes to the 150,000-gal (568-m^3) wastewater clarifier. Supernatant from this tank is recycled.

When the recycle pumps come on, there is an instant spike of turbidity in the adsorption clarifier effluent (from 0.5 ntu up to 1.5 ntu) that lasts for 10 minutes. It decreases to 1 ntu for the entire recycle process and then returns to 0.5 ntu within 30 minutes after the recycle pumps are shut off. The SCD increases the alum dosage during the first 15 minutes of recycle and then returns to normal. The recycle pumps are sized at about 0.4 mgd (63 m^3/h), which results in a recycle of about 20 percent of the plant production when the pumps are operating.

Water Quality

Raw and finished water quality data are summarized in Table 8.2. Both raw and finished water quality appear to be very good for all the parameters shown.

Preliminary sampling consisted of collecting a one-time grab sample of the recycle waste stream and the clarified water. The clarified water was sampled before and during recycling. Table 8.3 summarizes the results of this initial investigation.

Comprehensive Sampling Program

Overview

Two rounds of field sampling and analysis were performed at the Moshannon Valley plant. The parameters that were particularly evaluated at this plant were turbidity, particle counts, and *Giardia* and *Cryptosporidium* cysts. In addition to the sampling and analysis, clarifier waste and spent backwash water were also collected for bench-scale testing. Bench-scale testing evaluated methods to improve particle removal from these wastes prior to recycle of the supernatant.

Round 1 Sampling

Sampling was conducted over an 8-hour period. The water quality parameters analyzed were

Turbidity
Particle counts
Giardia
Cryptosporidium

The sample locations for these parameters are listed below. Numbers in parentheses indicate the sampling locations as shown in Figure 8.1.

Raw water (1)
Raw water with recycle (3)
Spent filter backwash water (5)
Clarifier flush (4)
Supernatant recycle (2)
Drying bed filtrate (6)
Thickener sludge (7)

Before the recycle stream was started, samples were collected on the treatment process. The normal recycle procedure was then started, and additional samples were taken from the treatment plant and waste streams. The recycle flow at the time of sampling was 0.43 mgd (68 m^3/h, 19 percent). The parasite data are contained in Table 8.4.

Round 2 Sampling

In round 2 parasite sampling was conducted on the unsettled and settled clarifier water. Composite samples for particle counting were collected in this round. In order to determine the effect of settling time in the wastewater clarifier, samples of the recycle water were taken immediately after a filter backwash and after 2 and 9 hours of settling. The parasite data are summarized in Table 8.5.

Laboratory-Scale Analysis

Removal of *Giardia*- and *Cryptosporidium*-size particles from several streams by the use of polymer and flocculation to enhance sedimentation was analyzed. The following list summarizes the tests performed:

Sample	Settling enhancement method
Spent backwash water	Different polymer doses (no flocculation)
Adsorption clarifier waste	Different polymer doses (no flocculation)
65 percent clarifier waste, 35 percent spent backwash water	Different polymer doses (no flocculation)
Adsorption clarifier waste	0.8 mg/L polymer and flocculation

In the first tests, spent filter backwash water, the adsorption clarifier waste, and the blended sample (65 percent clarifier waste and 35 percent spent backwash water) were placed in six 2-L Gator jars. POL-E-Z 652, a nonionic polymer, was added to these jars in dosages of 0.0, 0.1, 0.4, 0.8, and 3.0 mg/L. After all the jars

were mixed briefly, samples were collected at time intervals that corresponded to settling velocities of 4, 0.8, 0.4, 0.13, and 0.07 cm/min. Each sample was analyzed for particle counts.

In the second stage of the study, different times of flocculation were evaluated at a G of about 30 s^{-1}, representing a typical flocculation velocity gradient.

Trends

Turbidity

The turbidity of the raw water showed an initial spike after the recycle pumps were started. This spike was followed by a leveling of the influent turbidity at a value higher than the source water. The clarified water showed a similar trend; however, the filtered water turbidity was not impacted by the recycle. The turbidity results obtained in round 1 are shown in Figure 8.2.

Particle Counts

Two rounds of particle count sampling were performed. In both rounds, the addition of the recycle water greatly increased the particles in the 2-to-15-µm size range in the influent and clarified waters. Influent particle counts in the 2-to-15-µm size range increased by a factor of 3 to 4 in both rounds of sampling. Clarified particle counts in the 2-to-15-µm size range increased by about 2 times in round 1 and by about 7 times in round 2. However, the filtered water did not show an increase in particle counts for any size range during recycle for round 1 and, in fact, showed a decrease in particle counts during recycle for round 2 sampling. These results are shown in Figures 8.3 and 8.4. During both round 1 and round 2 sampling, the filters proved to operate at higher particle removal efficiencies during recycle. Table 8.6 summarizes the filter removal efficiencies for round 1 grab samples and round 2 composite samples.

The clarifier supernatant was sampled immediately after a filter backwash and after 2 and 9 hours of settling time. The samples were analyzed for particle counts. The results (see Figure 8.5) show that settling helped remove the smaller particles. After 2 hours, about 37 percent of the 2-to-4-µm particles was settled; 36 percent of the 5-to-9-µm particles; and 42 percent of the 10-to-15-µm particles. Increasing the settling time to 9 hours did not result in significant additional removal in any size range.

Figures 8.6 and 8.7 show the laboratory results obtained for particle removal by adding polymer to the adsorption clarifier waste stream prior to sedimentation. Without polymer, removal was very poor for both the *Giardia*-size and the *Cryptosporidium*-size particles. The addition of the nonionic polymer significantly improved particle removal. A dose of 0.8 mg/L of nonionic polymer resulted in removal of 80 to 85 percent of the 5-to-15-µm and the 3-to-5-µm particles.

Removal of particles from spent filter backwash water is shown in Figures 8.8 and 8.9. For this waste, removal was 70 to 80 percent even without polymer, and polymer treatment could achieve well over 90 percent removal of particles in both size ranges.

Tests were also conducted on blended waste that consisted of 65 percent adsorption clarifier waste and 35 percent spent filter backwash water. These tests were designed to simulate the mixture of wastes entering the plant's wastewater clarifier. The settling characteristics of the blended waste were much like the settling of the adsorption clarifier waste alone. Removals were relatively poor without polymer addition, as shown in Figures 8.10 and 8.11. Removals were similar to those found in full-scale testing: 30 to 40 percent. (Note that 2 hours of settling in the full-scale clarifier prior to sampling the supernatant would correspond to a very low settling velocity, approaching the zero values of Figures 8.10 and 8.11.) Polymer doses of 0.8 mg/L removed more than 80 percent of particles of both sizes.

Flocculation using 0.8 mg/L polymer was tested as an additional sedimentation aid for the clarifier waste. These results are shown in Figures 8.12 and 8.13. For both particle ranges, flocculation for about 15 minutes was able to improve particle removal from about 80 percent to 95 percent. Depending upon site-specific situations, the addition of flocculation may be warranted.

Parasite Data

Figures 8.14 and 8.15 summarize the results of round 1 and round 2 testing for parasites. High levels of cysts were found in both the spent filter backwash water and the adsorption clarifier sludge. The spent backwash water had 165 *Giardia* cysts/L and 166 *Cryptosporidium* cysts/L in round 1. The adsorption clarifier flush had 52 cysts/L and 26 cysts/L for *Giardia* and *Cryptosporidium,* respectively. Due to the large waste stream sedimentation tank and long settling time, the recycle stream had lower levels of cysts (0.7 cysts/L and 0.8 cysts/L for *Giardia* and *Cryptosporidium,* respectively, in round 1 sampling). The recycle stream had fewer *Giardia* than the raw water, and therefore recycling decreased the *Giardia* cyst concentration in the influent to the plant from 2.9 to 1.6 cysts/L. *Cryptosporidium* showed the opposite, with the recycle having 0.8 cysts/L compared to 0.13 cysts/L in the raw water, resulting in recycling increasing the *Cryptosporidium* cyst concentration to 0.3 cysts/L.

During round 2 sampling the cyst levels were lower but exhibited similar characteristics. The raw water had 0.6 and 0.2 *Giardia* and *Cryptosporidium* cysts/L without recycle, and the values increased to 0.79 and 4.76 cysts/L with recycle.

Table 8.1 Chemical feed data for Moshannon Valley Water Treatment Plant

Location	Chemical	Dose (mg/L)
Raw	Alum	2–4
	Caustic	—
	Chlorine	1.0
Filtered	Chlorine	0.6–1.5
	Corrosion inhibitor, ZOP	2.5-4.5
	Fluoride	1.0
	Caustic	8.0

— indicates not applicable

ZOP = zinc orthophosphate

Table 8.2 Average annual water quality data for Moshannon Valley Water Treatment Plant

Parameter	Raw	Finished
Turbidity, ntu	1.2	0.12
Color, cu	<5	<5
Iron, mg/L	0.11	<0.05
Manganese, mg/L	0.04	0.01
pH	6.8	7.3
Alkalinity, mg/L $CaCO_3$	14	18
Ammonia, mg/L	<0.01	<0.01
Aluminum, mg/L	NA	0.05
Coliform, number/100 mL	28	<1
TOC, mg/L	NA	NA
TTHM, µg/L	NA	<10
Free Cl_2, mg/L	<0.1	2.2

NA = no data available

Table 8.3 Preliminary sampling results for Moshannon Valley Water Treatment Plant

		Clarifier effluent	
Parameter	Recycle stream	Without recycle	With recycle
Turbidity, ntu	3.6	0.45	0.55
pH	6.9	6.6	6.7
Total chlorine, mg/L	0.7	1.1	1.1
Free chlorine, mg/L	0.5	1.0	0.9
Alkalinity, mg/L as $CaCO_3$	13	12	13
Coliform, number/100 mL	<1	<1	<1
Heterotrophic plate count, colonies/mL	14	<1	<1
Aluminum, mg/L	0.89	0.08	0.15
Iron, mg/L	0.10	<0.05	<0.05
Manganese, mg/L	0.03	<0.02	0.02
TSS, mg/L	28	1	1
TOC, mg/L	2.1	1.5	1.6
TTHM, µg/L	18	1	3
THMFP, µg/L	199	65	125

Table 8.4 Round 1 parasite data for Moshannon Valley Water Treatment Plant

Sample site	*Giardia* (cysts/L)	*Cryptosporidium* (cysts/L)
Raw (1)*	2.94	0.13
Mixed raw and recycle (3)	1.59	0.32
Sludge (7)	40.05	80.11
Clarifier flush (4)	52.84	26.42
Spent backwash (5)	165.13	166.13
Drying bed filtrate (6)	0.21	<0.21
Supernatant recycle (2)	0.71	0.82

*Numbers in parentheses indicate sampling locations as shown in Figure 8.1.

Table 8.5 Round 2 parasite data for Moshannon Valley Water Treatment Plant

Sample location	*Giardia* (cysts/L)	*Cryptosporidium* (cysts/L)
Raw	0.6	0.2
Mixed raw and recycle	0.79	4.76
Wastewater clarifier (not settled)	0	9.25
Wastewater clarifier (settled)	1.98	3.96
Supernatant recycle	0	4.2

Table 8.6 Particle removal efficiencies by filtration at Moshannon Valley Water Treatment Plant

	Percent removal	Log removal
Round 1, grab sample		
Combined filter effluent (without recycle)		
All particles (1–100 μm)	99.2	2.10
Giardia size (5–15 μm)	99.1	2.05
Cryptosporidium size (2–9 μm)	99.2	2.10
Combined filter effluent (with recycle)		
All particles (1–100 μm)	99.7	2.52
Giardia size (5–15 μm)	99.7	2.52
Cryptosporidium size (2–9 μm)	99.7	2.52
Round 2, composite sample		
Filter 2 effluent (without recycle)		
All particles (1–100 μm)	91.6	1.08
Giardia size (5–15 μm)	91.1	1.05
Cryptosporidium size (2–9 μm)	91.2	1.06
Filter 2 effluent (with recycle)		
All particles (1–100 μm)	99.6	2.40
Giardia size (5–15 μm)	99.6	2.40
Cryptosporidium size (2–9 μm)	99.6	2.40

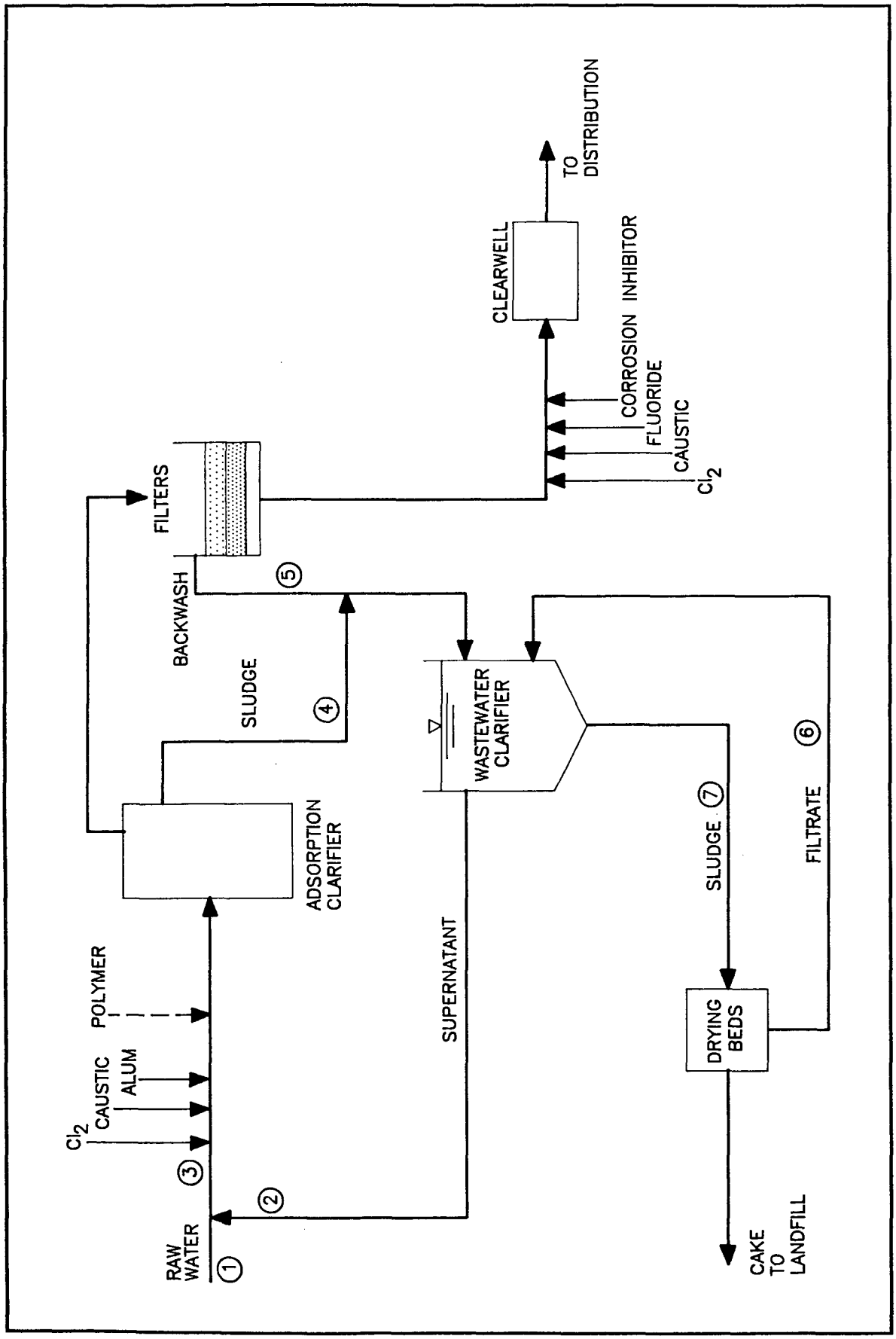


Figure 8.1 Process flow diagram and sample point locations for Moshannon Valley Water Treatment Plant

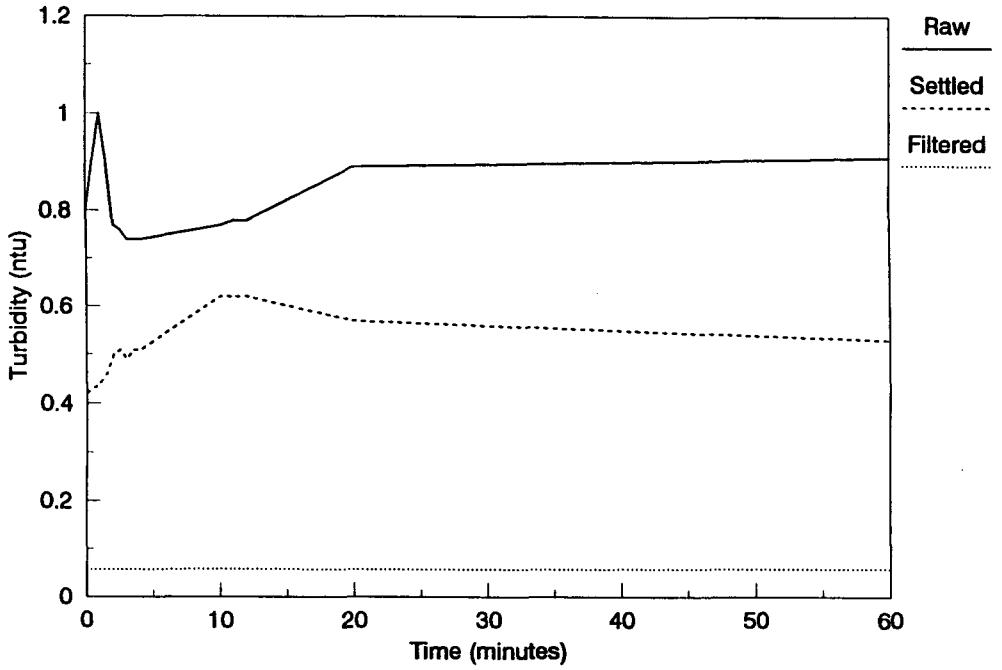
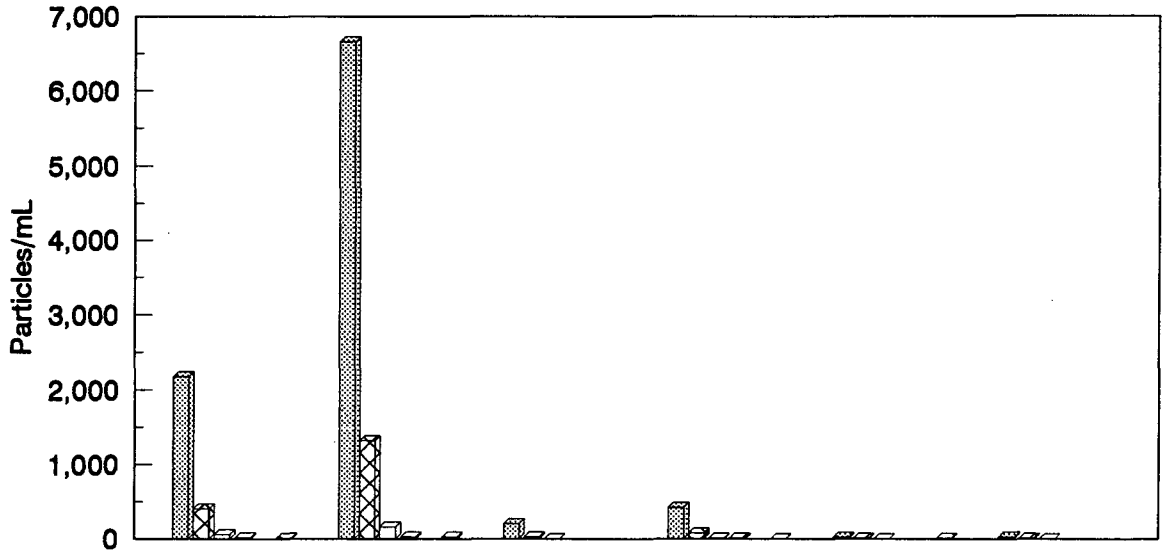
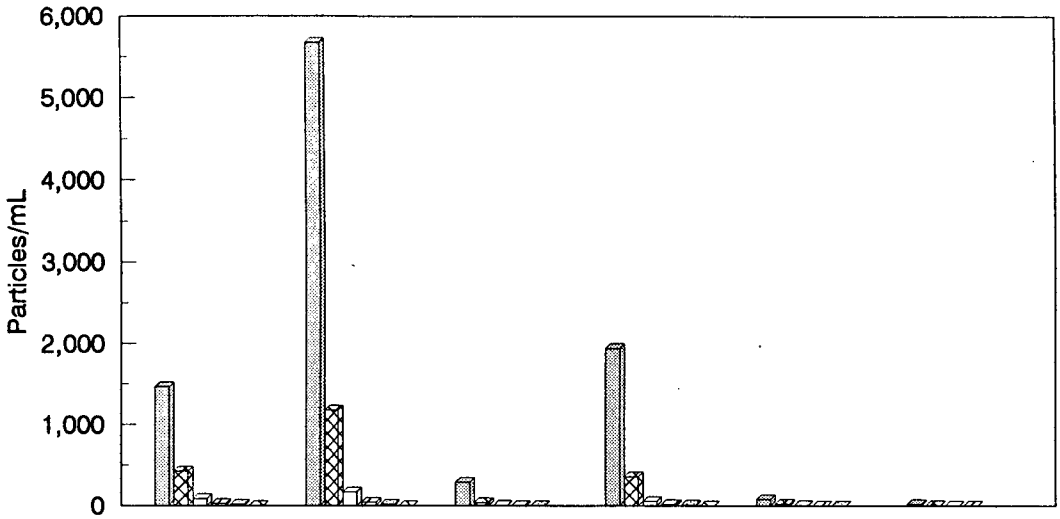


Figure 8.2 Round 1 turbidity results at Moshannon Valley Water Treatment Plant



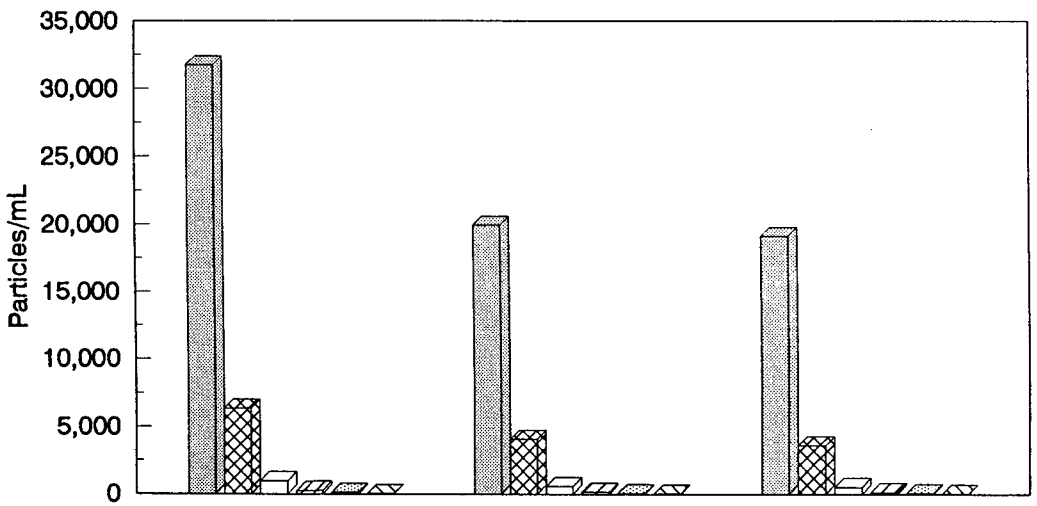
	Raw	Raw + Recycle	Clarified wo/Recycle	Clarified w/Recycle	Filtered wo/Reycle	Filtered w/Recycle
2-4 microns	2,180	6,662	204	419	18	19
5-9 microns	406	1,320	21	71	3	3
10-15 microns	54	160	1	6	1	1
16-19 microns	10	22	0	2	0	0
20-39 microns	0	0	0	0	0	0
>40 microns	6	22	0	1	3	0

Figure 8.3 Round 1 particle count data at Moshannon Valley Water Treatment Plant



	Raw	Raw + Recycle	Clarified wo/Recycle	Clarified w/Recycle	Filtered wo/Recycle	Filtered w/Recycle
2-4 microns	1,462	5,669	292	1,938	82	22
5-9 microns	427	1,175	37	360	21	5
10-15 microns	88	168	4	55	6	1
16-19 microns	27	44	1	17	3	1
20-39 microns	15	16	1	9	1	0
>40 microns	1	1	0	1	0	0

Figure 8.4 Round 2 particle count data at Moshannon Valley Water Treatment Plant



	No Settling	2 Hours Settling	9 Hours Settling
2-4 microns	31,741	19,922	19,112
5-9 microns	6,345	4,072	3,588
10-15 microns	947	548	500
16-19 microns	248	138	122
20-39 microns	117	56	49
>40 microns	6	2	2

Figure 8.5 Impact of settling time on particle counts in the recycle stream at Moshannon Valley Water Treatment Plant

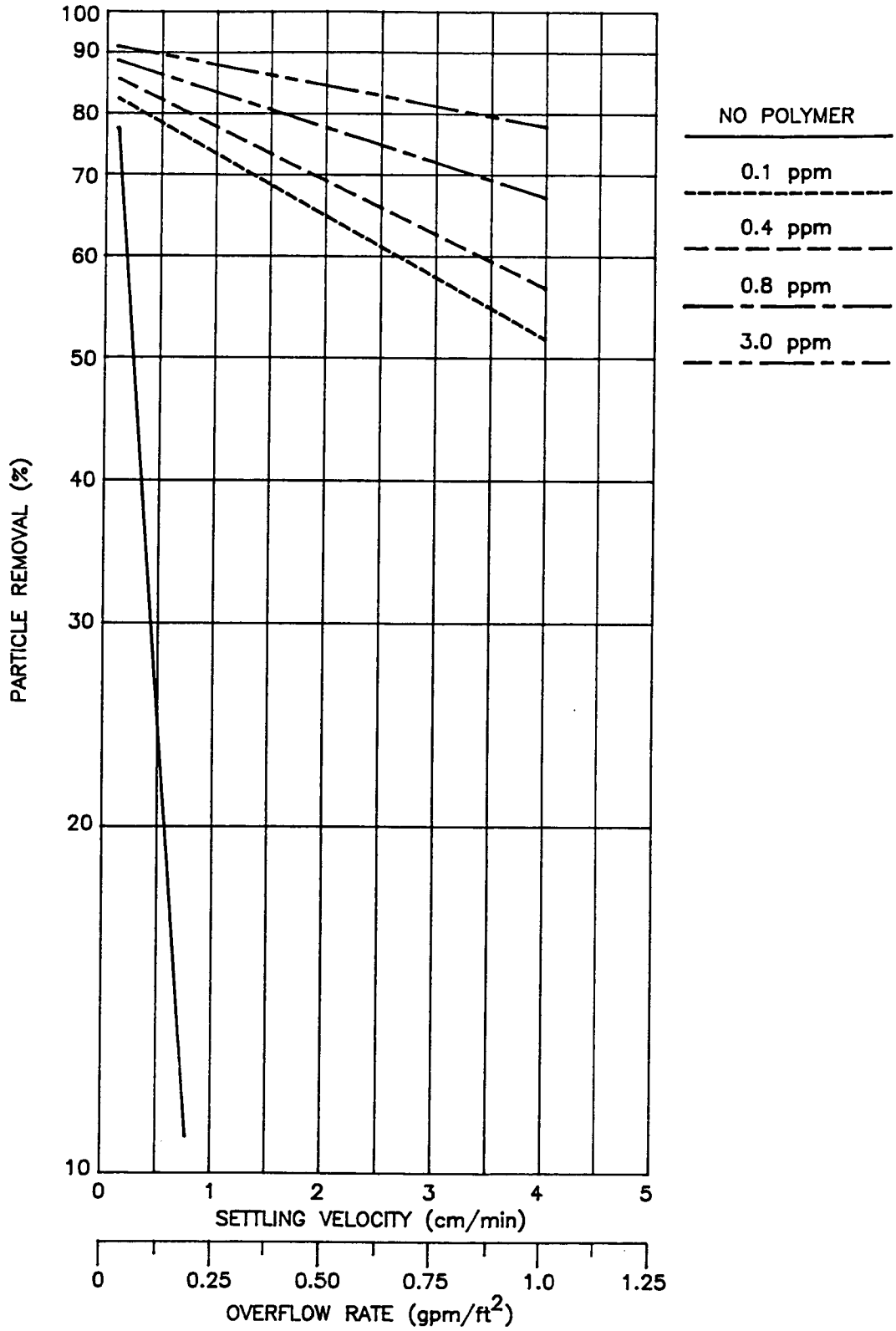


Figure 8.6 Removal of *Giardia*-size particles (5–15 μm) from adsorption clarifier sample at Moshannon Valley Water Treatment Plant using sedimentation (polymer: POL-E-Z 652)

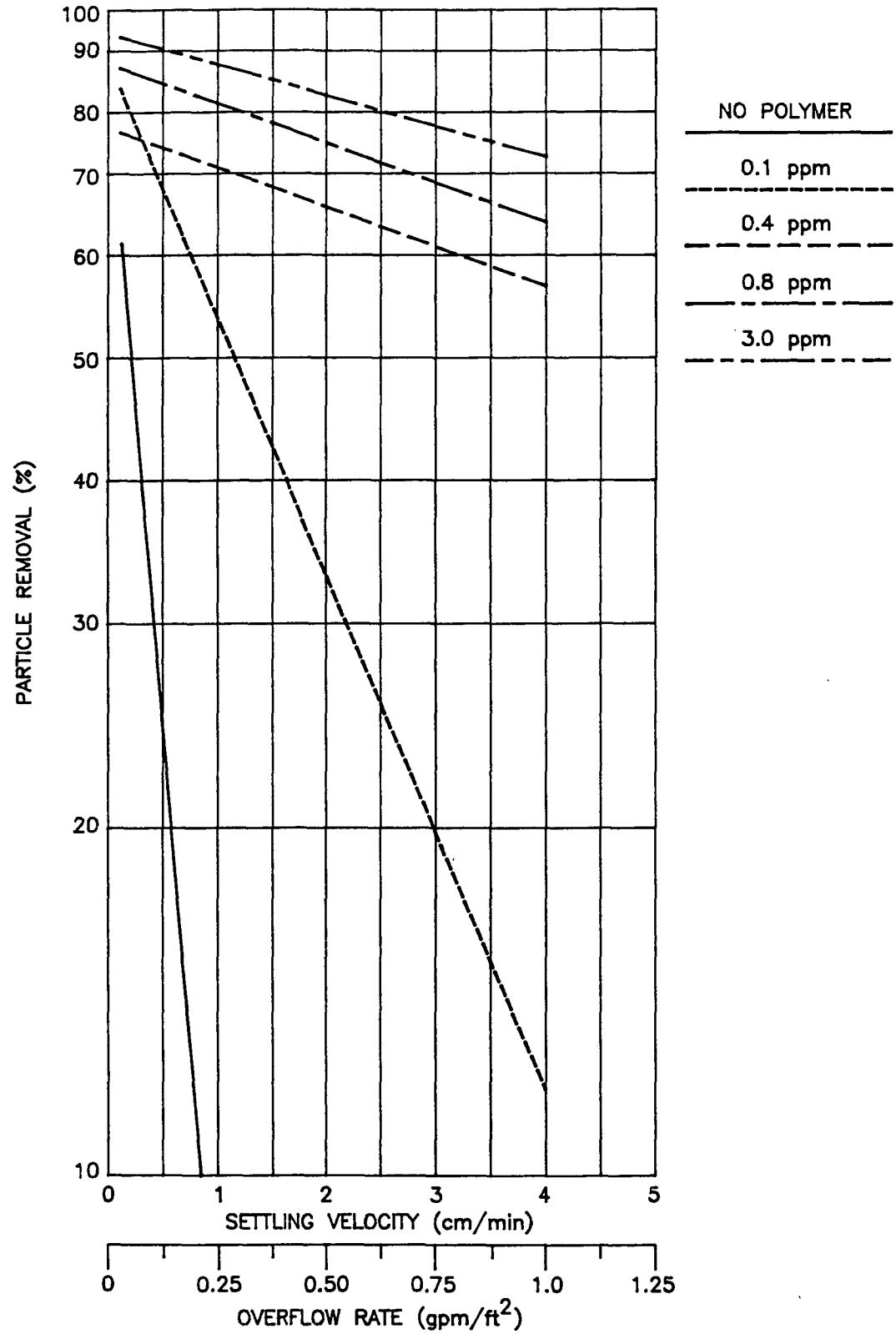


Figure 8.7 Removal of *Cryptosporidium*-size particles (3–5 μm) from adsorption clarifier sample at Moshannon Valley Water Treatment Plant (polymer: POL-E-Z 652)

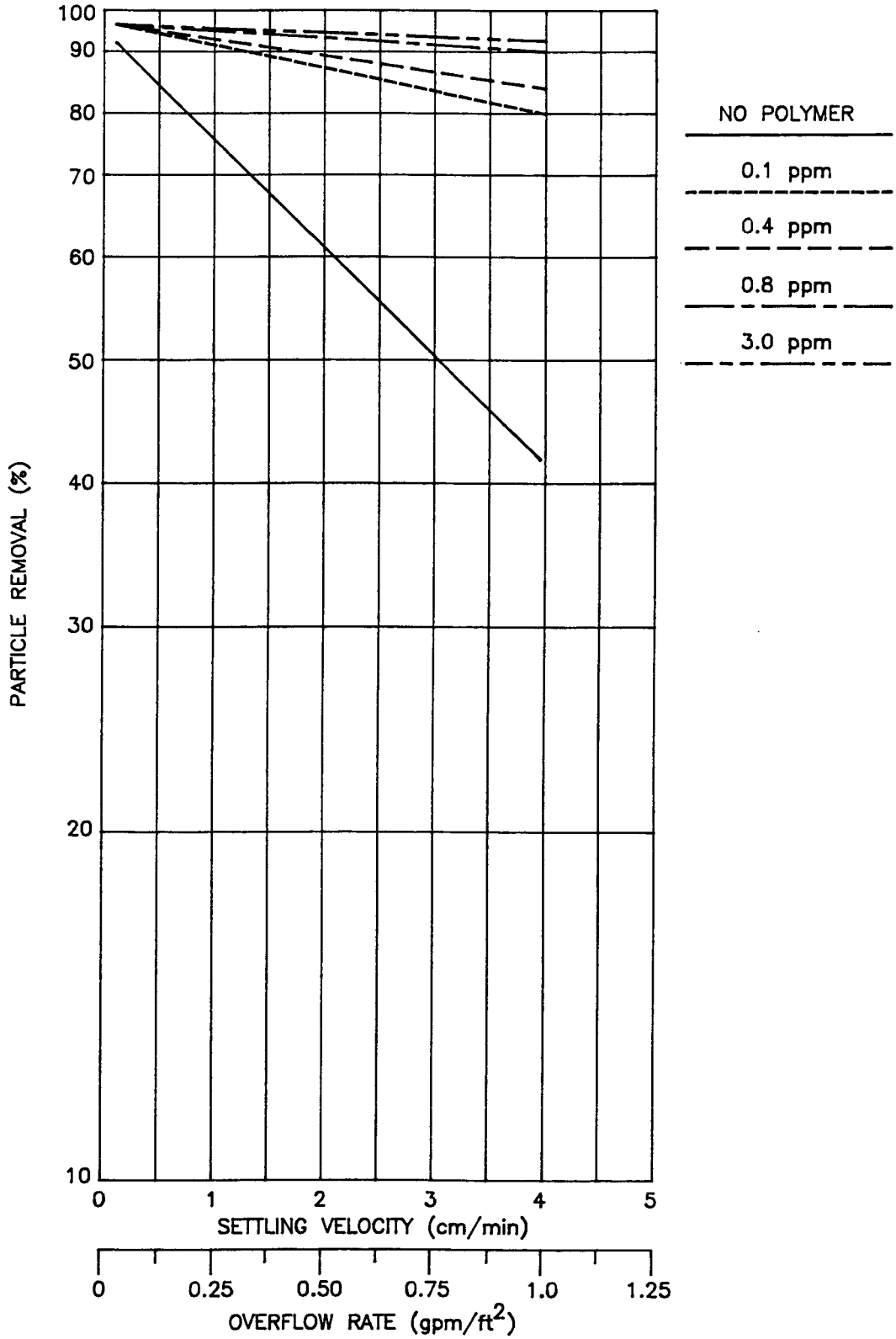


Figure 8.8 Removal of *Giardia*-size particles (5–15 μm) from spent filter backwash water at Moshannon Valley Water Treatment Plant using sedimentation (polymer: POL-E-Z 652)

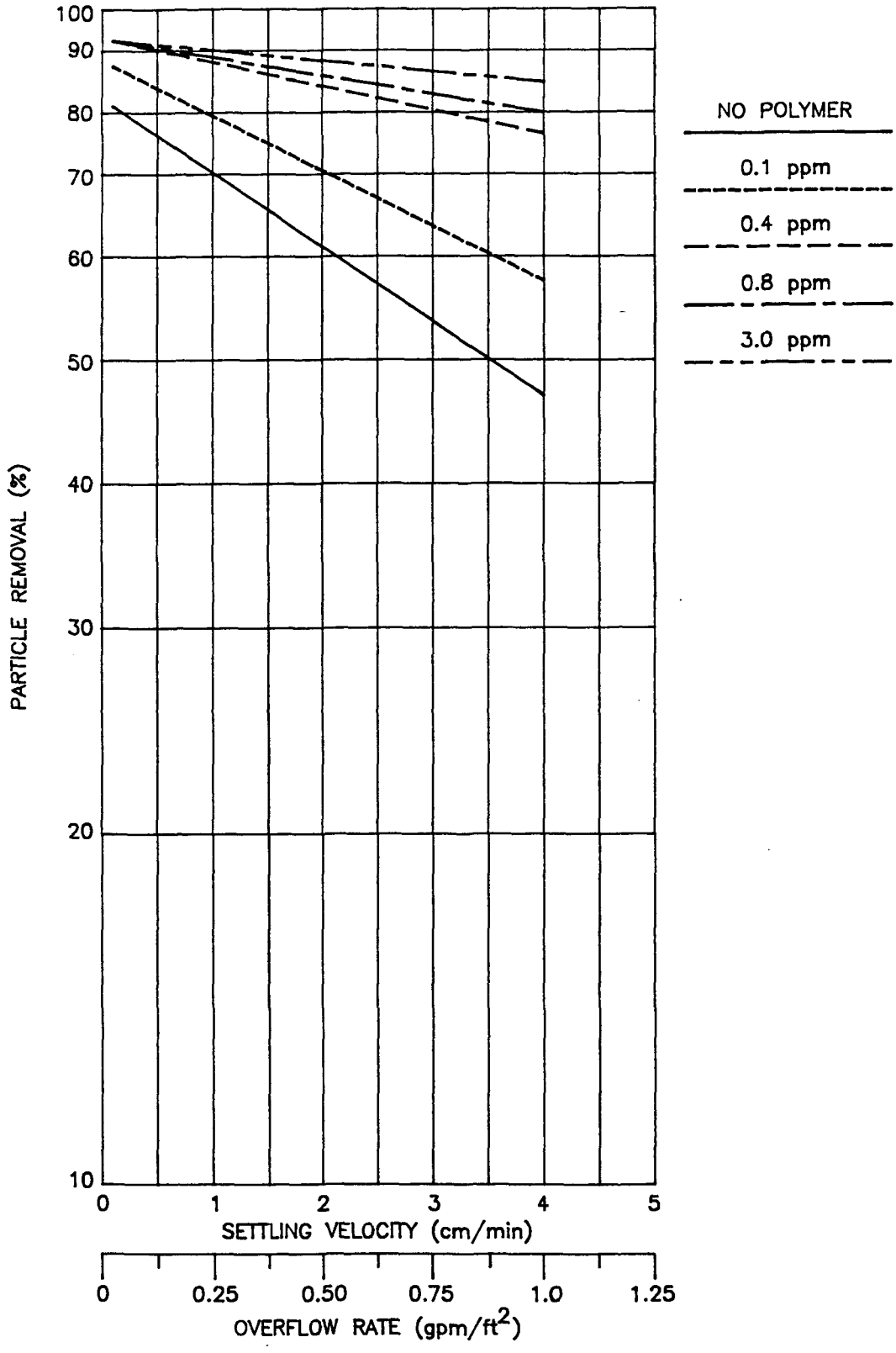


Figure 8.9 Removal of *Cryptosporidium*-size particles (3–5 μm) from spent filter backwash water at Moshannon Valley Water Treatment Plant using sedimentation (polymer: POL-E-Z 652)

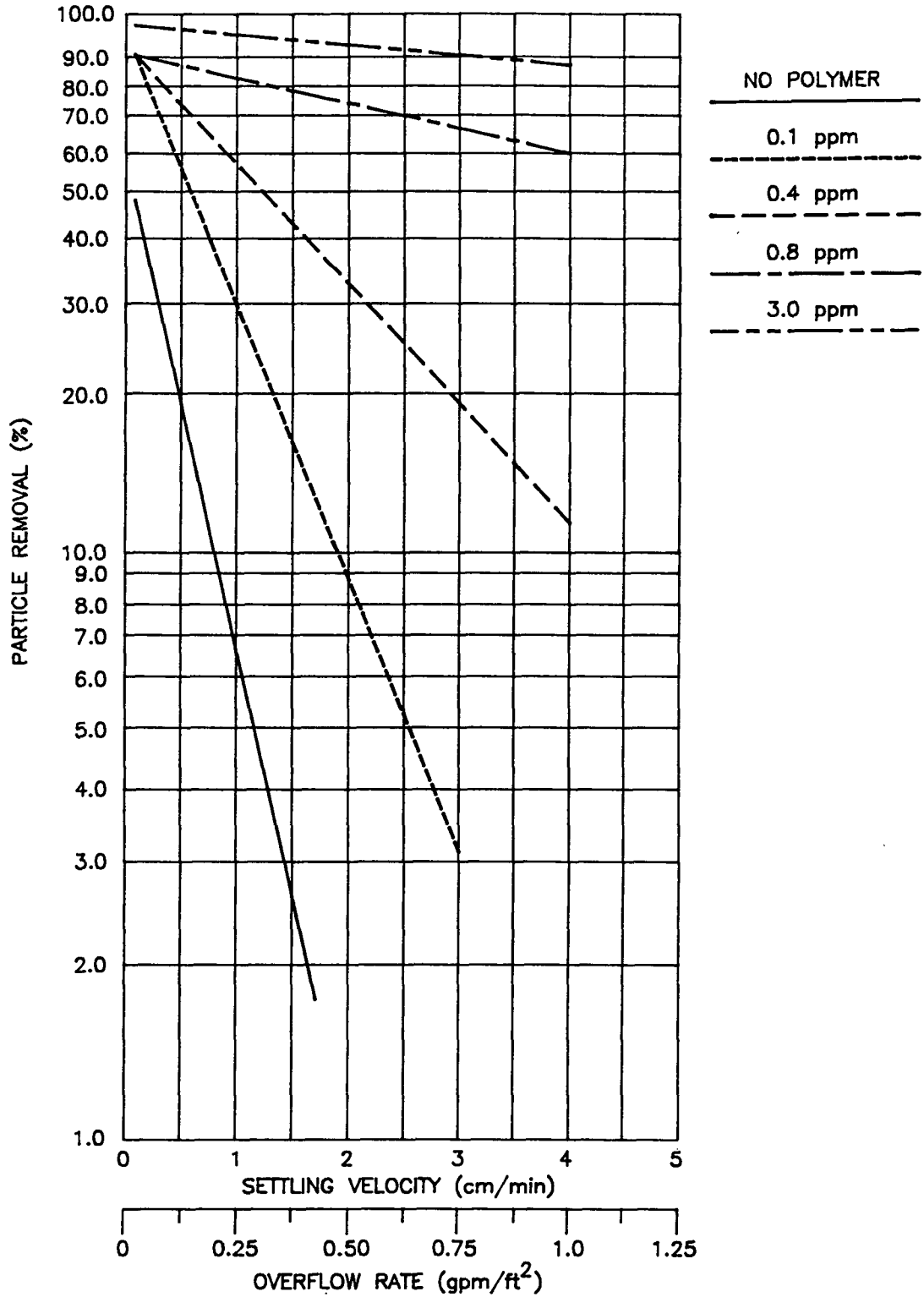


Figure 8.10 Removal of *Giardia*-size particles (5–15 μm) from a blended sample (65 percent adsorption clarifier water and 35 percent backwash water) at Moshannon Valley Water Treatment Plant using sedimentation (polymer: POL-E-Z 652)

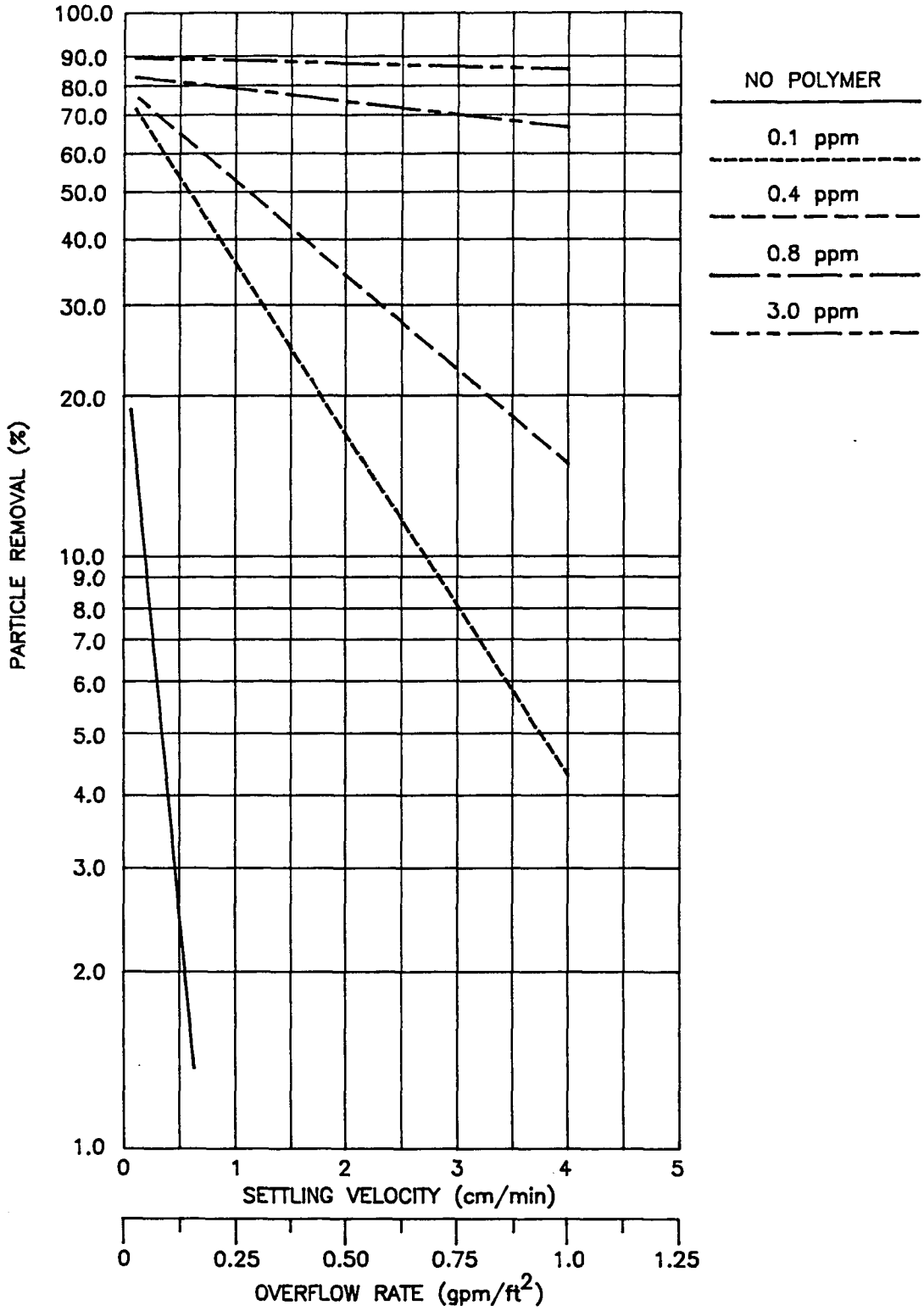


Figure 8.11 Removal of *Cryptosporidium*-size particles (3–5 μm) from a blended sample (65 percent adsorption clarifier water and 35 percent backwash water) at Moshannon Valley Water Treatment Plant using sedimentation (polymer: POL-E-Z 652)

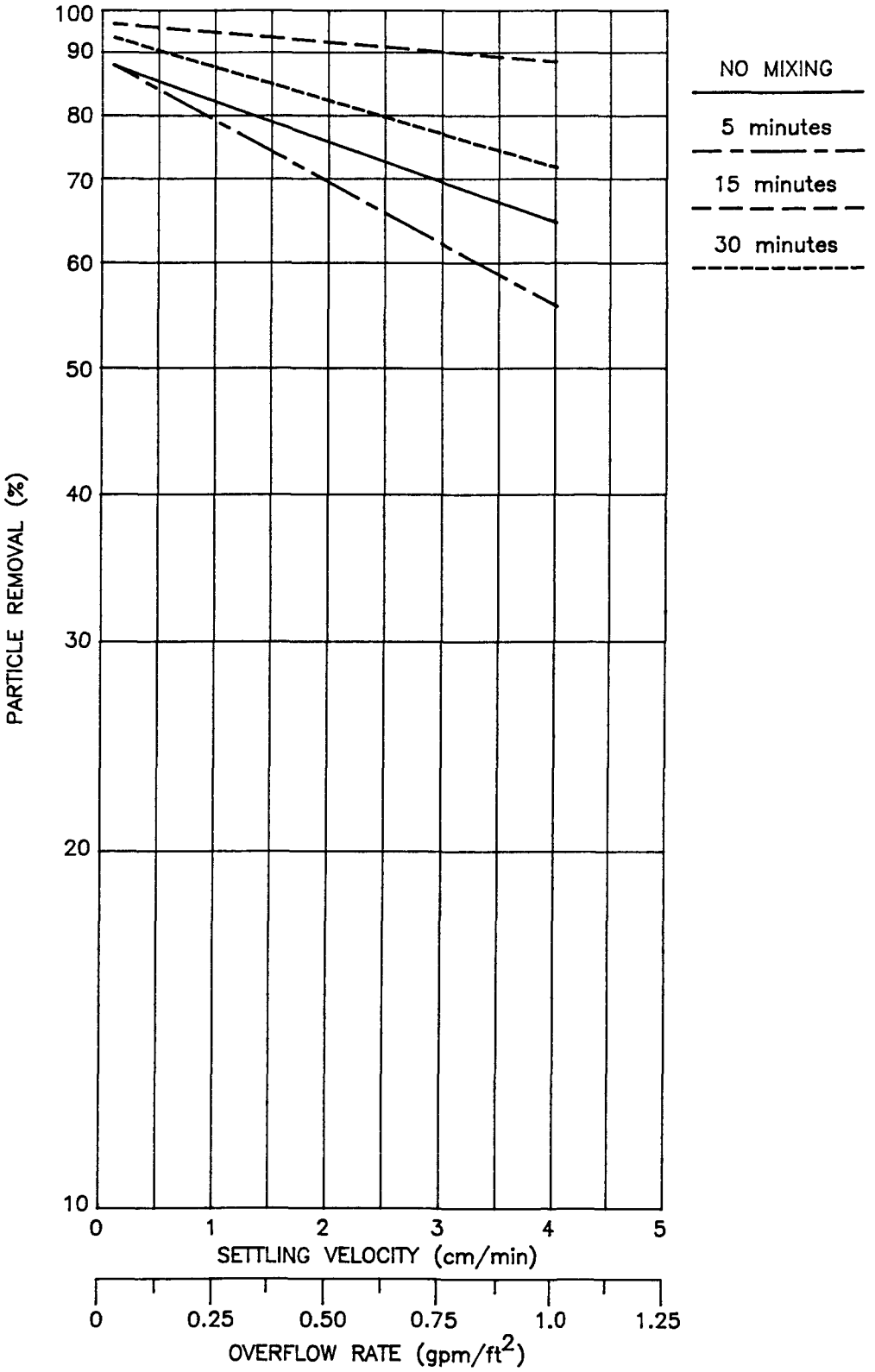


Figure 8.12 Removal of *Giardia*-size particles (5–15 μm) from adsorption clarifier sample at the Moshannon Valley Water Treatment Plant (polymer: POL-E-Z 652)

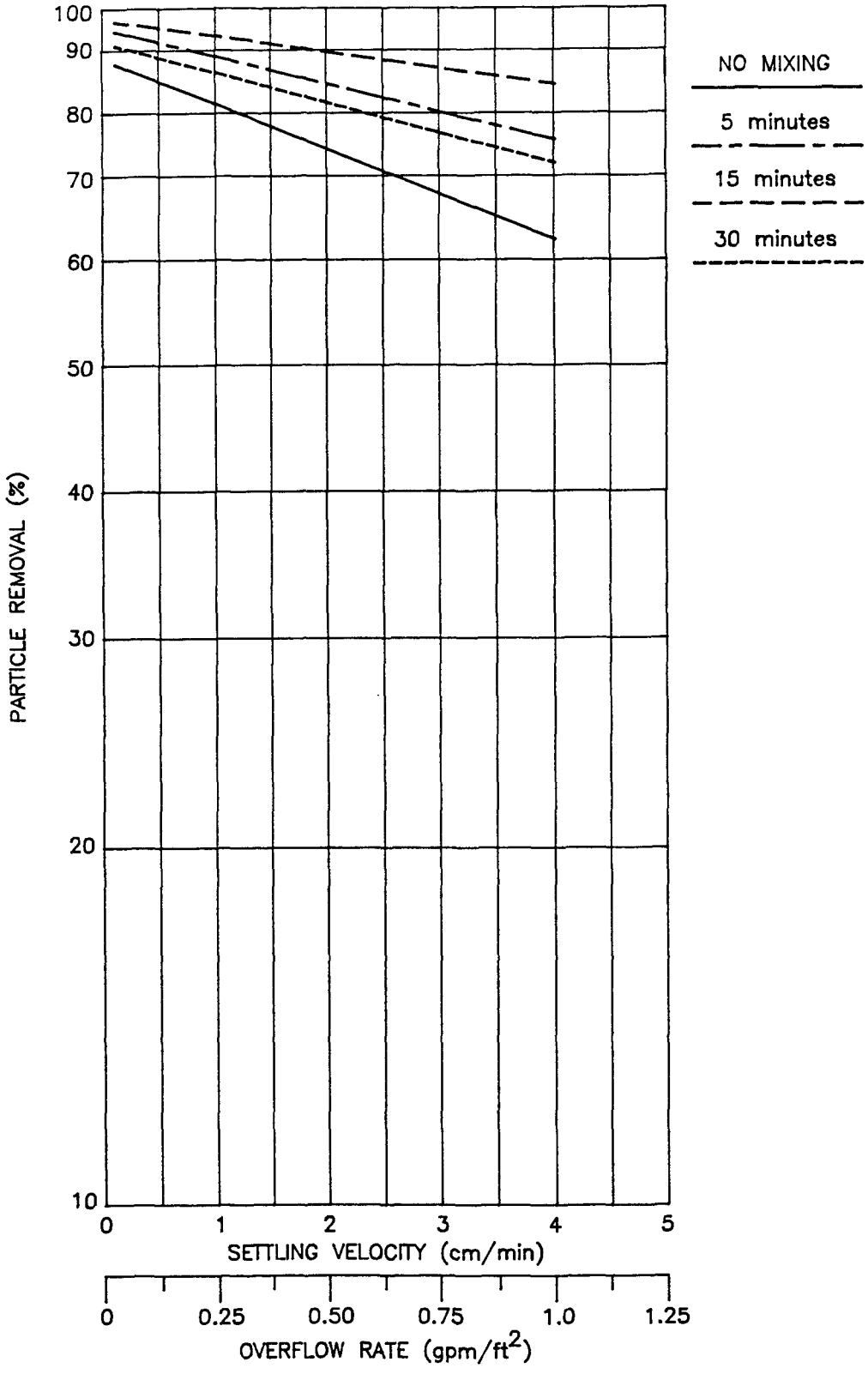
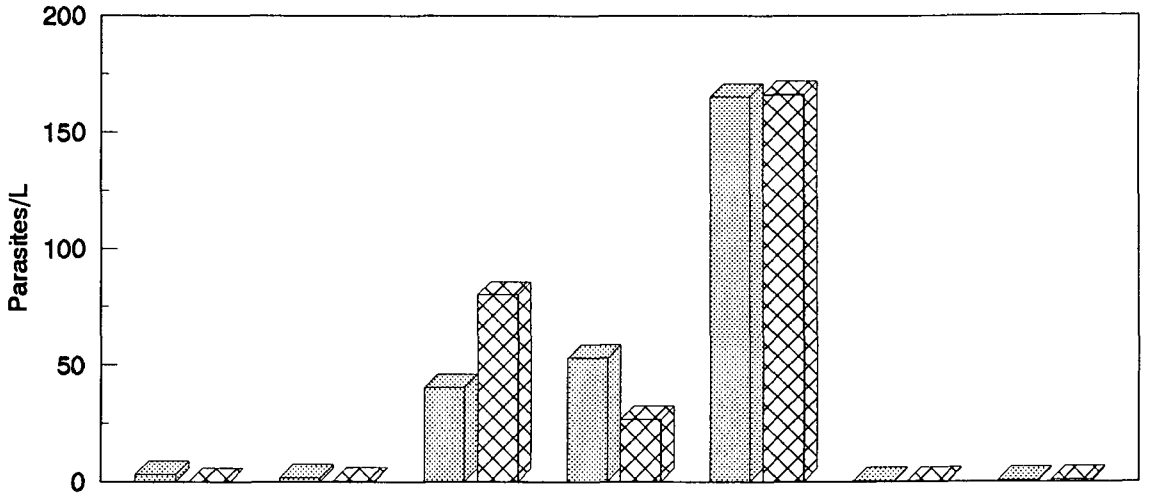
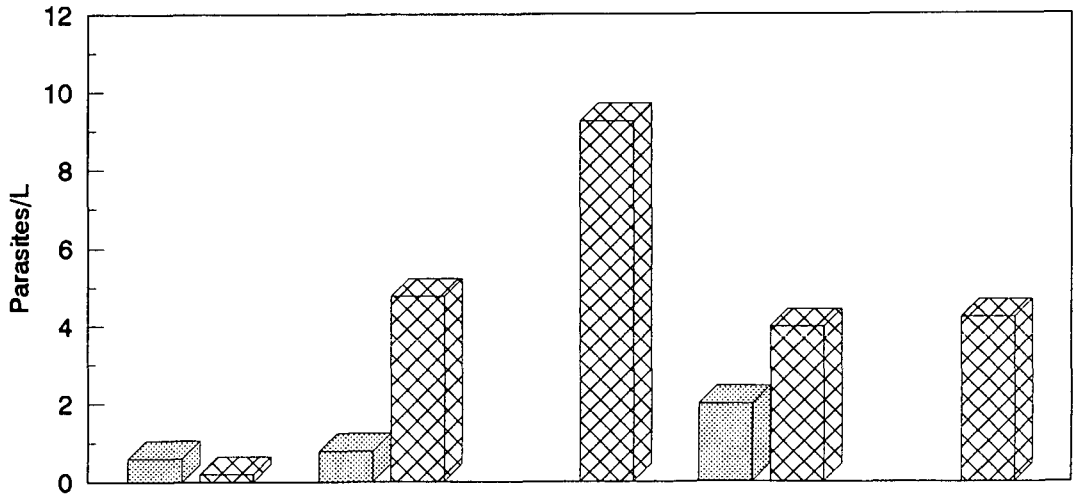


Figure 8.13 Removal of *Cryptosporidium*-size particles (3–5 μm) from adsorption clarifier sample at Moshannon Valley Water Treatment Plant using flocculation and sedimentation (polymer: POL-E-Z 652)



Sampling Location	Raw	Mixed Raw & Recycle	WW Clarifier Sludge	Adsorp. Clar. Flush	Filter Backwash	Drying Beds Filtrate	Recycle
Giardia	2.9	1.6	40.1	52.6	165.0	0.2	0.7
Cryptosporidium	0.13	0.32	80.11	26.41	166.00	0.21	0.82

Figure 8.14 Round 1 parasite data for Moshannon Valley Water Treatment Plant



Sampling Location	Raw	Mixed Rew & Recycle	WW Clarifier Sludge	Settled Sludge Clar.	Recycle
Giardie	0.60	0.79	0.00	1.98	0.00
Cryptosporidium	0.20	4.76	9.25	3.96	4.20

Figure 8.15 Round 2 parasite data for Moshannon Valley Water Treatment Plant

Chapter 9

Williams Water Treatment Plant

Plant Description

Treatment Process

The Williams Water Treatment Plant, located in Durham, N.C., was chosen for a study of the effects of sludge storage within a sedimentation basin (i.e., a manually cleaned basin) on settled water quality. The Williams Water Treatment Plant is a surface water plant rated at 22 mgd (3,500 m^3/h). Treatment processes consist of rapid mix, flocculation, sedimentation, and filtration. This plant has basins that use both mechanical and manual sludge removal. The process flow schematic of the Williams plant is shown in Figure 9.1. Chemical dose information is shown in Table 9.1.

Eight settling basins collect settled solids from the treatment process. Seven of the basins do not have mechanical sludge removal equipment and are cleaned manually. These basins hold the settled solids between 1 and 4 months until they are manually cleaned. The accumulated sludge at the time of cleaning is usually 5 to 7 ft (1.5 to 2.1 m) deep but can be as deep as 10 to 12 ft (3 to 3.7 m), out of a total of 15 ft (4.6 m) water depth. The eighth basin was recently equipped with a continuous sludge removal system. Settled solids are removed daily from this basin.

Water Quality

Raw and finished water quality data on the Williams Water Treatment Plant are summarized in Table 9.2.

Comprehensive Sampling Program

Overview

In order to prepare for the sampling program, one manually cleaned basin and the mechanically cleaned basin were both drained, flushed, and cleaned of sludge. Both basins were then put into service. The mechanically cleaned basin was cleaned daily. Sludge built up with no cleaning in the manually cleaned basin for the 8-week test period. In addition to the field sampling, sludge from the Williams Water Treatment Plant was also collected for bench-scale testing.

Round 1 Sampling

Influent to and effluent from the manually cleaned basin and the mechanically cleaned basin were sampled weekly.

Sampling lasted for 8 weeks. The following parameters were measured:

TTHM
TTHMFP
TOC
Manganese
Turbidity

The sample locations for these parameters are listed below. The numbers in parentheses indicate the sampling locations as shown in Figure 9.2.

Basin influent (1, 3)
Manually cleaned basin effluent (4)
Mechanically cleaned basin effluent (2)

All samples were collected at the basin surface.

Laboratory-Scale Analysis

Sludge from the plant was put into two 4-L beakers; it was tested for pH and DO levels once a week and for manganese levels 3 times a week. DO was analyzed in both the supernatant and settled sludge, whereas manganese and pH were analyzed in the supernatant only. One beaker was kept at a pH of approximately 5.5 and one at a pH of approximately 7.0. This pH range represents the normal pH range for alum sludges. Samples were filtered through 0.45-mm filter paper prior to analysis.

Trends

Manganese

Figures 9.3 and 9.4 show the total and dissolved manganese concentrations obtained during the 8-week field sampling program. Of most concern to the Williams Water Treatment Plant operators was the level of dissolved manganese going on to the filters, because the plant removed manganese primarily by adsorption and oxidation on the filter media. The amounts of dissolved manganese leaving the two basins were almost identical until week 6. Between weeks 6 and 8 a trend developed whereby the amount of manganese leaving the manually cleaned basin was increasingly greater than that leaving the mechanically cleaned basin, with differences of 0.05, 0.17, and 0.56 mg/L for weeks 6, 7, and 8, respectively. At week 8 the operators were concerned by the high manganese levels in the filters from the basin, and they cleaned the basin, which ended the testing program. DO readings were taken throughout in the manually cleaned sedimentation basin; the results are shown in Figure 9.5. These data were collected just prior to the cleaning of the basin. The data show that the lower levels of the sludge blanket were anaerobic.

A sludge sample was collected from the mechanical sludge removal system and stored in the lab to determine the potential for release of manganese from the sludge. The manganese levels in the laboratory sludge sample showed steady

increases over time. Figure 9.6 presents the data for two pH conditions. DO levels in the settled sludge are shown in Figure 9.7. The data indicate that very high levels of manganese were released from the sludge.

TTHM and TTHMFP

The results from both TTHM and TTHMFP sampling of the mechanically cleaned and the manually cleaned basins showed little variation in concentrations as a result of storing the sludge. Figures 9.8 and 9.9 show these results graphically. TTHM values for both basins showed little difference between the basins' influent and effluent. Little difference in TTHMFP values was found between the effluents of the mechanically and manually cleaned basin.

Turbidity

A slightly higher turbidity was present in the effluent of the sludge storage basin than in that of the mechanically cleaned basin. The manually cleaned basin had effluent turbidities of 0.8 to 1.0 ntu, whereas the mechanically cleaned basin's turbidities were 0.6 to 0.8 ntu. Figure 9.10 shows the turbidities of the influent and effluent streams.

TOC

The TOC level appeared to be higher in the manually cleaned basin after about week 3, as shown in Figure 9.11. The TOC concentration of the sludge storage basin's effluent was as much as 25 percent higher than that of the mechanically cleaned basin. However, since this was total organic carbon, not dissolved organic carbon, some of the difference could be due to the difference in solids concentrations, which were also 20 to 25 percent higher in the manually cleaned basin

Table 9.1 Chemical feed data for Williams Water Treatment Plant

Location	Chemical	Dose (mg/L)
Raw	Alum	10–40
	Caustic	—
Prefilter	Chlorine	5–10
	Polymer	0.03–0.05
Filtered	Fluoride	1.0
	Caustic	—
	Corrosion inhibitor, ZOP	1.5

— indicates not applicable

ZOP = zinc orthophosphate

Table 9.2 Average annual water quality data for Williams Water Treatment Plant

Parameter	Raw	Finished
Turbidity, ntu	30	0.05
Color, cu	30	<5
Iron, mg/L	4	<0.05
Manganese, mg/L	1	<0.02
pH	6.9	7.0
Alkalinity, mg/L $CaCO_3$	25	15
Ammonia, mg/L	<0.01	<0.01
Aluminum, mg/L	<0.001	0.05
Coliform, number/100 mL	NA	<1
TOC, mg/L	4	2
TTHMFP, µg/L	300	200
Total Cl_2, mg/L	NA	2.0
Free Cl_2, mg/L	NA	1.5

NA = no data available

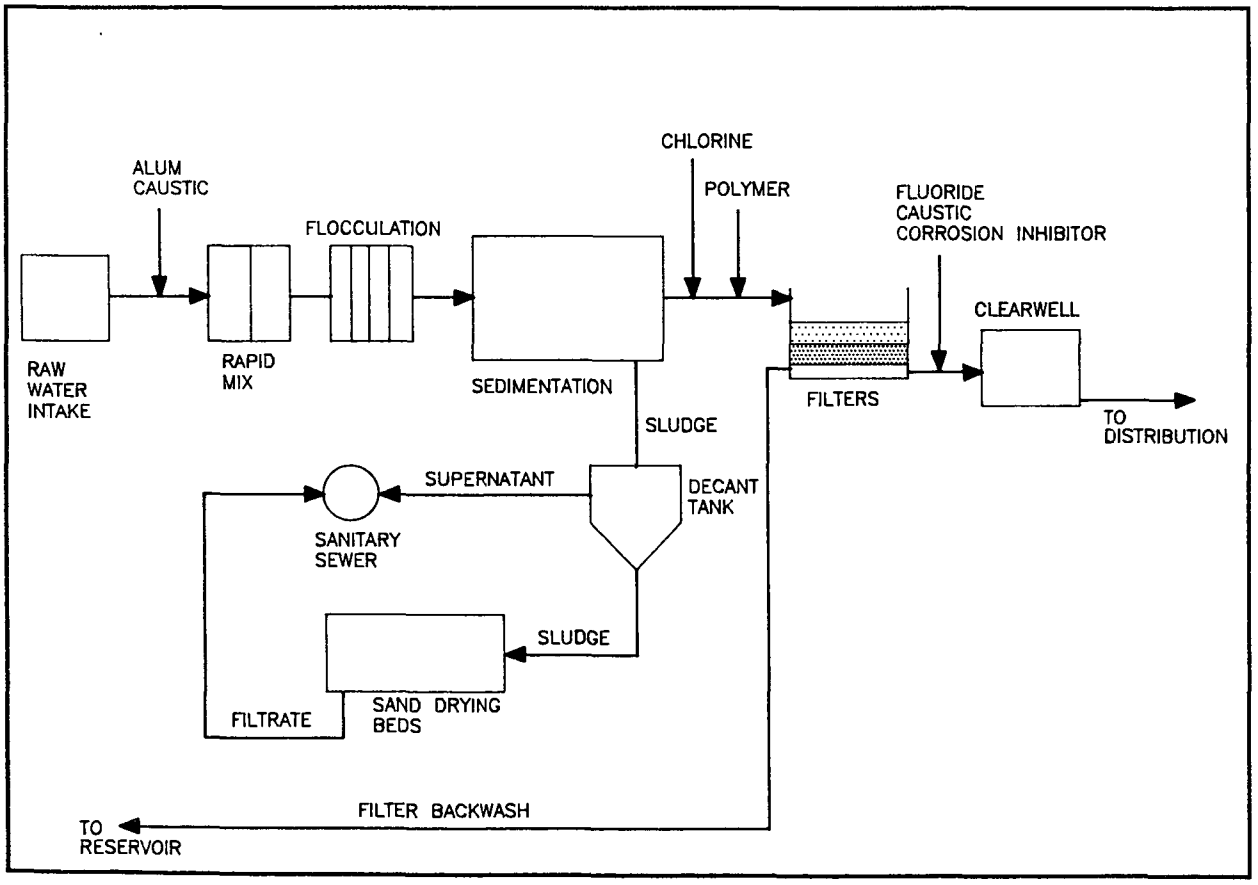


Figure 9.1 Process flow diagram for Williams Water Treatment Plant

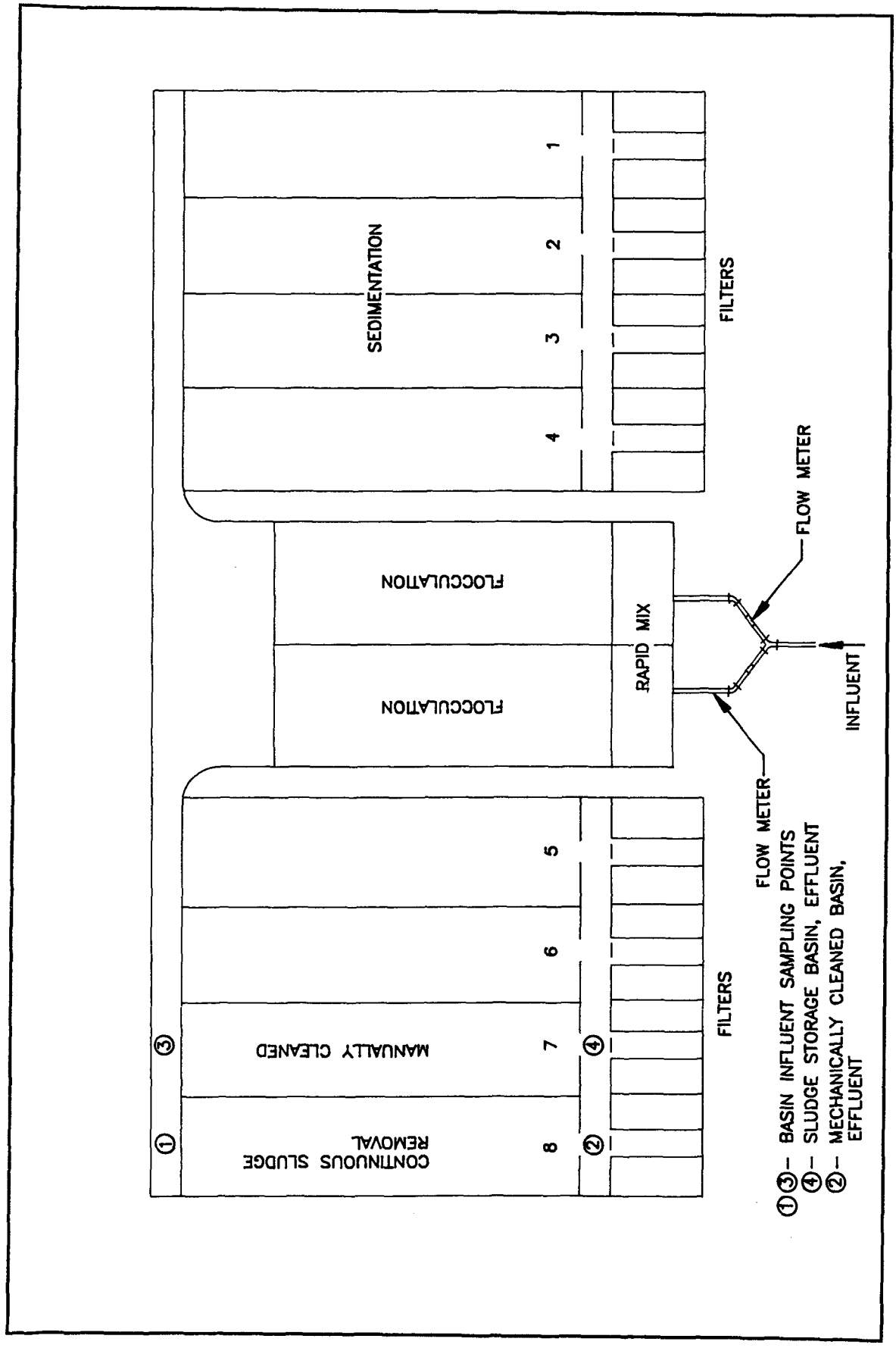


Figure 9.2 Sampling locations for Williams Water Treatment Plant

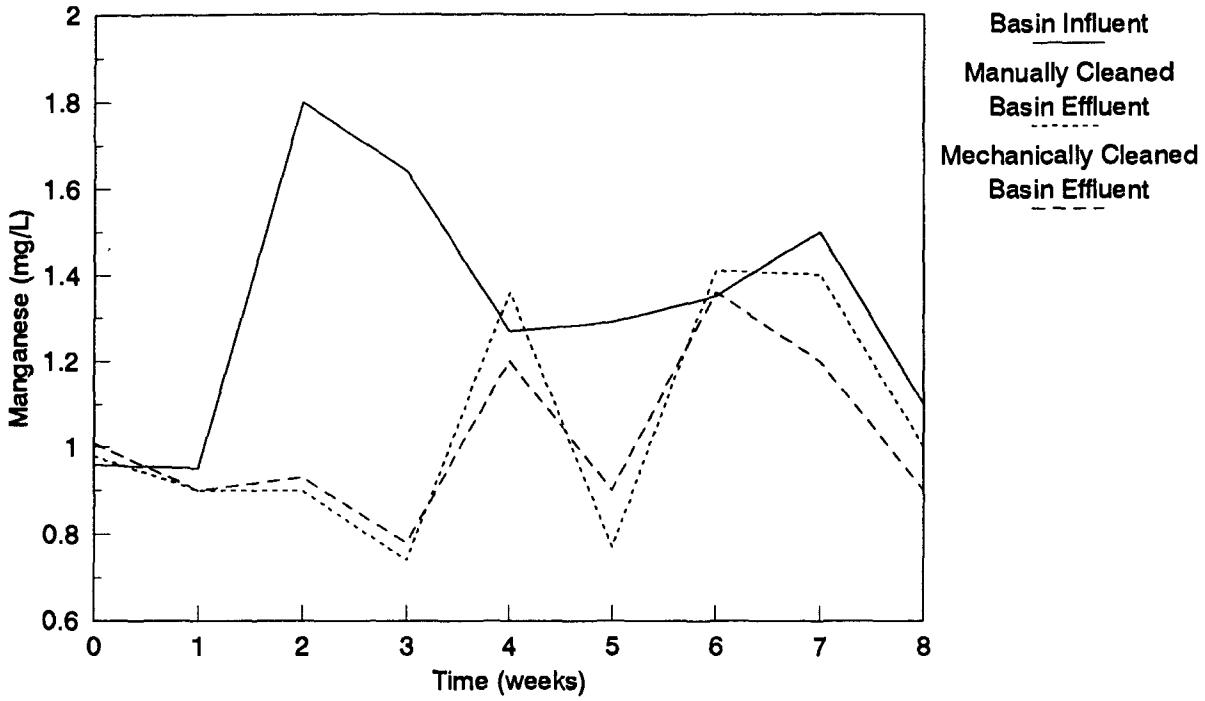


Figure 9.3 Total manganese in clarified water at Williams Water Treatment Plant

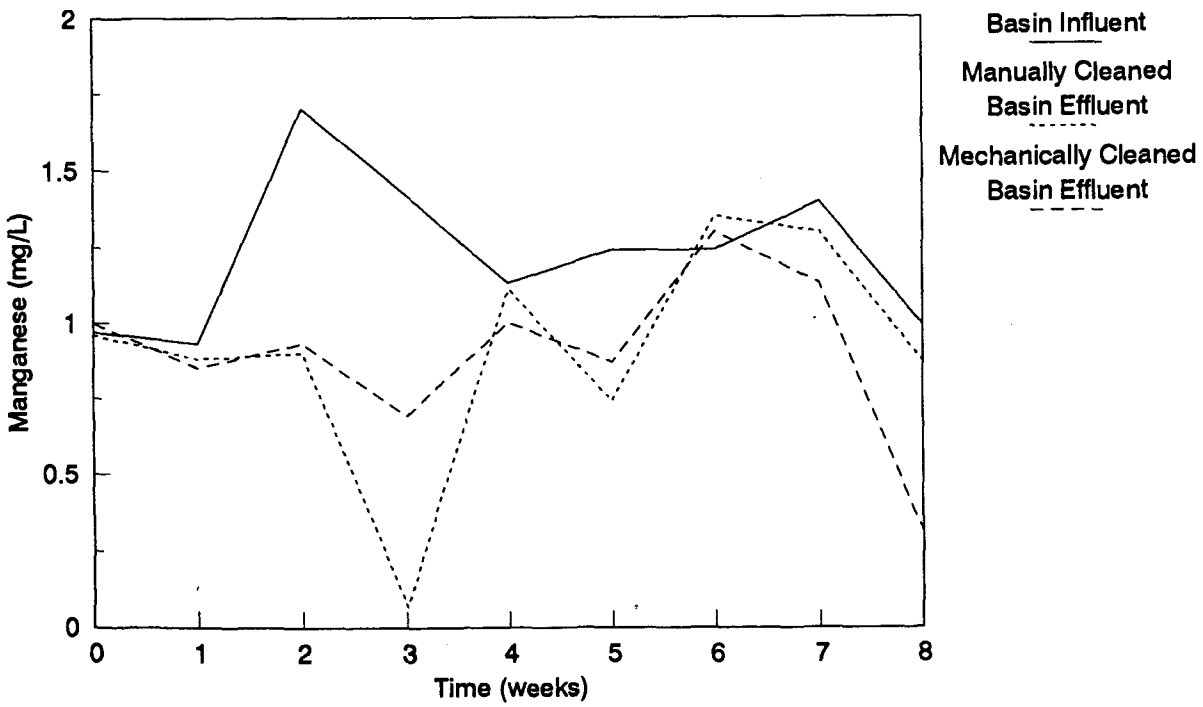


Figure 9.4 Dissolved manganese in clarified water at Williams Water Treatment Plant

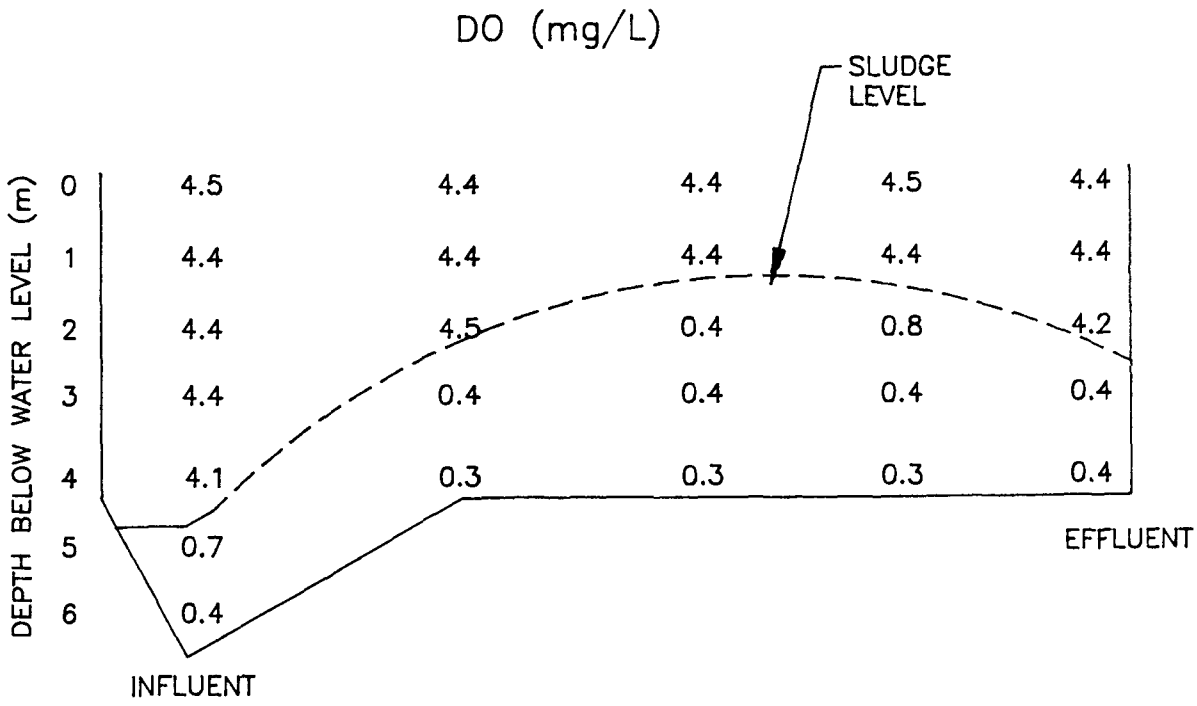


Figure 9.5 Dissolved oxygen profile in the manually cleaned sedimentation basin of Williams Water Treatment Plant

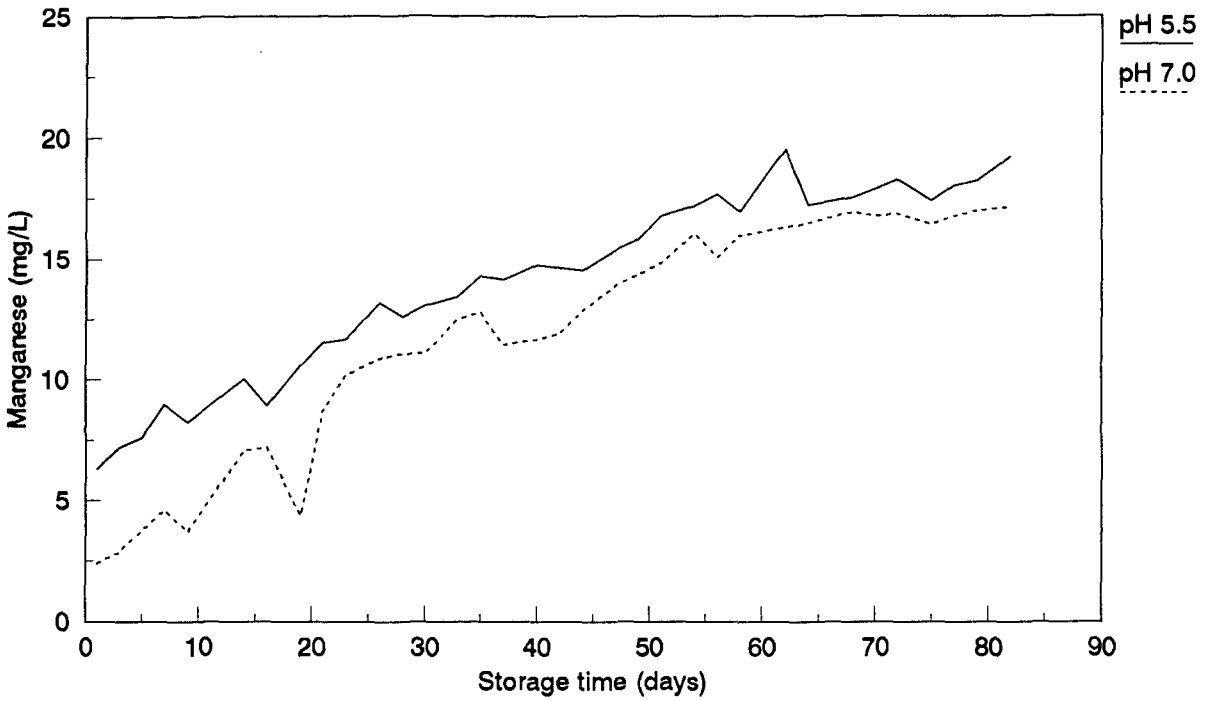


Figure 9.6 Manganese released by storing Williams Water Treatment Plant sludge

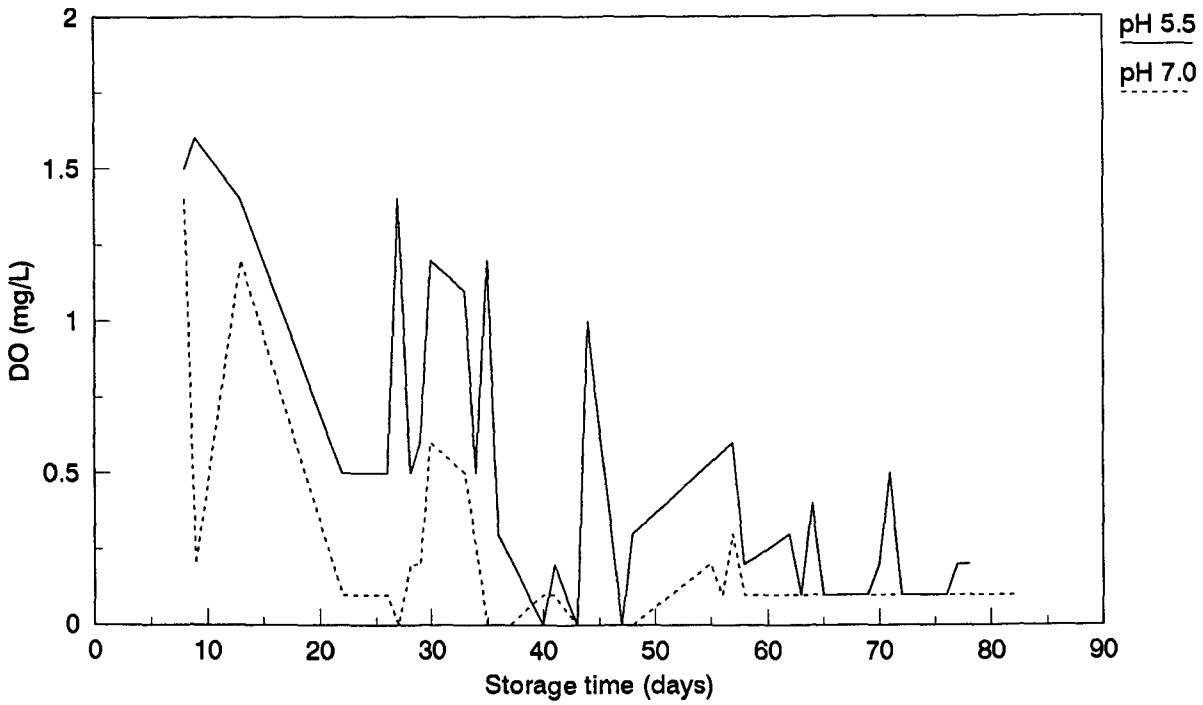


Figure 9.7 Dissolved oxygen concentrations for Williams Water Treatment Plant sludge

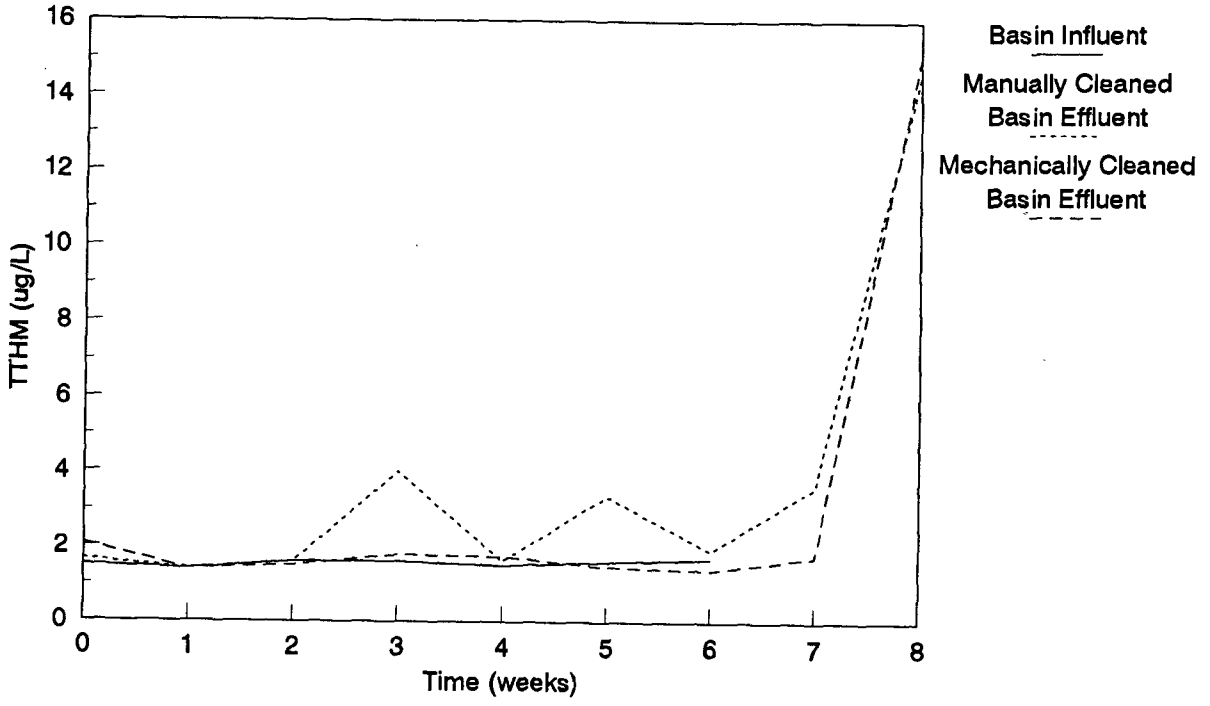


Figure 9.8 TTHM in clarified water at Williams Water Treatment Plant

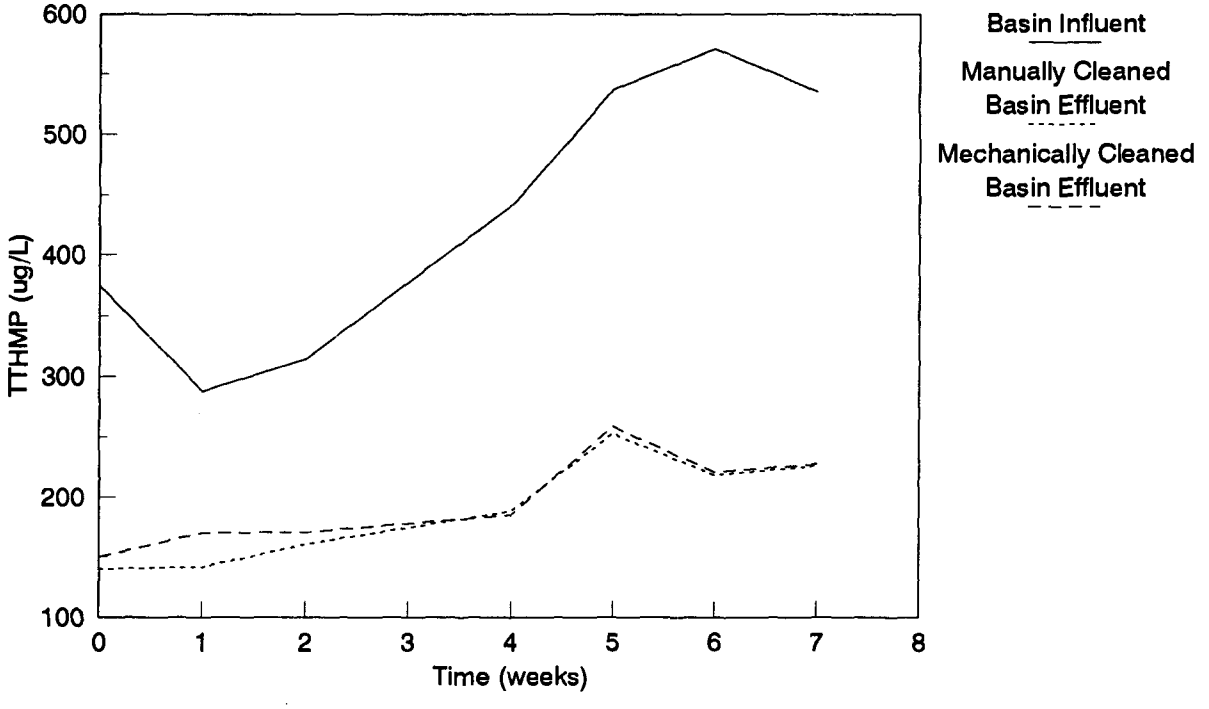


Figure 9.9 TTHMFP in clarified water at Williams Water Treatment Plant

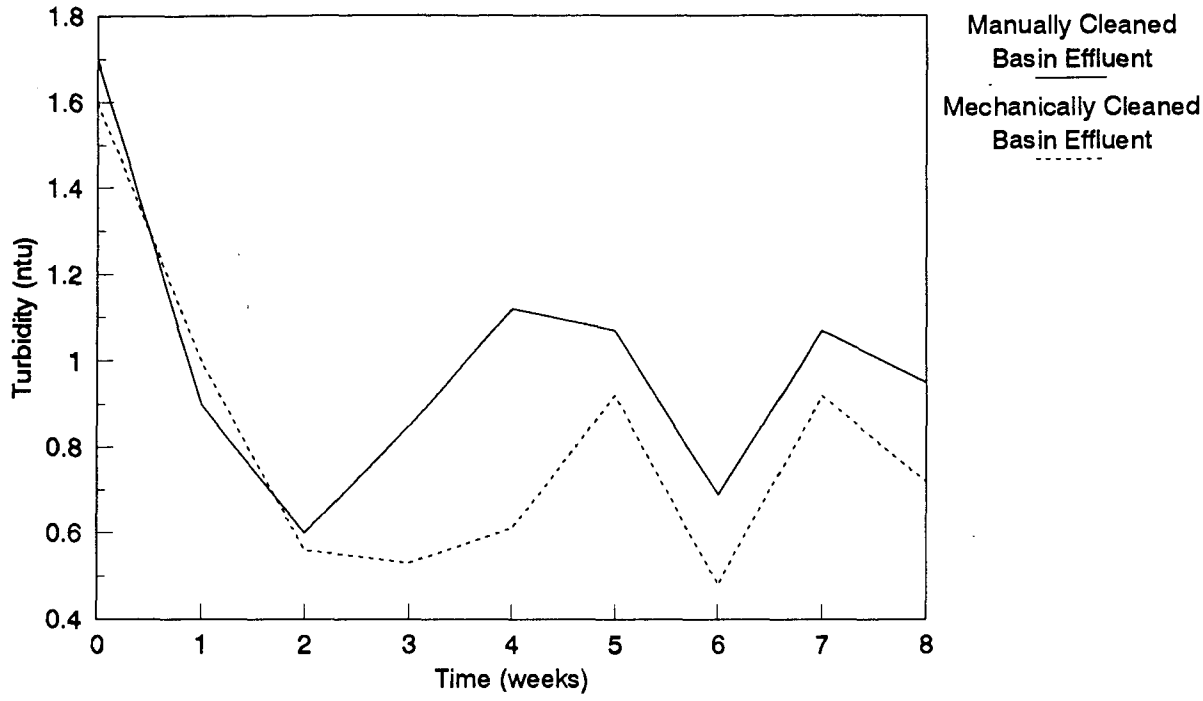


Figure 9.10 Turbidity in clarified water from mechanically and manually cleaned basins at Williams Water Treatment Plant

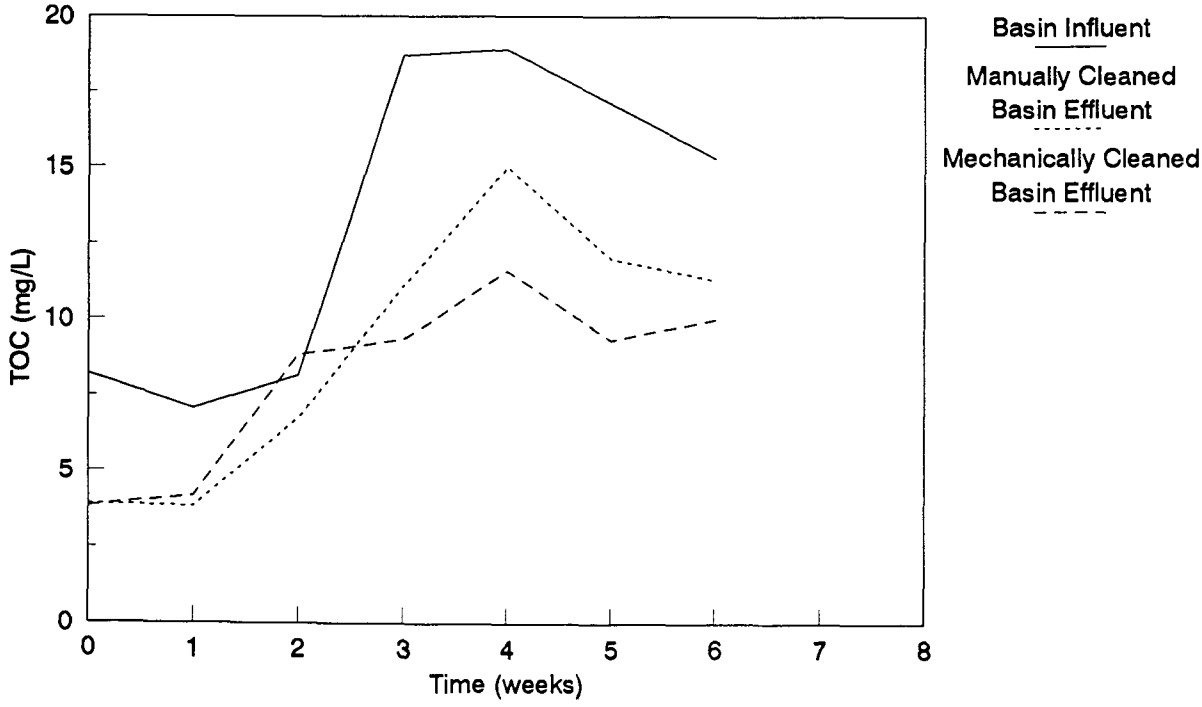


Figure 9.11 TOC in clarified water from mechanically and manually cleaned basins at Williams Water Treatment Plant

Chapter 10

Appomattox River Water Authority

Plant Description

The Appomattox River Water Authority (ARWA), located in Petersburg, Va., operates a conventional water treatment plant rated at 48 mgd (7,570 m^3/h). Raw water is obtained from an impoundment on the Appomattox River. The treatment train consists of rapid mix, flocculation, sedimentation, and filtration. Three of the six sedimentation basins are equipped with continuous sludge removal equipment, and the other three basins are manually cleaned about once every 3 months. This plant was chosen for a study of the impacts of sludge storage in the sedimentation basins on applied water quality.

Chemical Feed

Raw water chemical feed at the Appomattox River Water Treatment Plant consists of the addition of alum, lime, and chlorine. Prefiltered water is treated with the addition of chlorine. Also, postfiltered water is treated with chlorine, fluoride, and lime. Typical chemical dose information is shown in Table 10.1.

Water Quality

Raw and finished water quality data are summarized in Table 10.2. The raw water contains manganese at highly variable levels, ranging from 0.1 to 1 mg/L. Parameters of interest at the ARWA plant include manganese, TTHM, TTHMFP, iron, and turbidity.

Comprehensive Sampling Program

Overview

One round of field sampling was performed at the ARWA plant. Samples were taken over a 7-week period at the inlet and outlet of two sedimentation basins. One of the sedimentation basins was cleaned daily with continuous sludge removal equipment; sludge was allowed to accumulate in the other basin. In addition to the field sampling, a pilot-scale analysis was performed. The pilot study evaluated manganese release from the sludge stored in a 6.5-in-diameter (16.5 cm), 14-ft-high (4.3 m) column. The depth was chosen to simulate a sedimentation basin, thickener, or lagoon.

Round 1 Sampling

Figure 10.1 shows the sample locations for round 1 sampling. Parameters tested for during the full-scale sampling were:

pH
Turbidity
Manganese (total)
Manganese (dissolved)
TTHMFP
Iron (total)
Iron (dissolved)

Laboratory-Scale Analysis

The pilot-scale analysis consisted of storing ARWA plant sludge in a 6.5-in-diameter (16.5 cm), 14-ft-high (4.3 m) clear polyvinyl chloride column. Various sampling points allowed sampling of the sludge supernatant to be made at several levels above the settled sludge. The original water that separated from the sludge was drawn from the top of the column and replaced with actual supernatant from the ARWA Plant's sedimentation basin so that the clear water above the sludge would start with a low manganese concentration and the release of manganese could be better monitored. Figure 10.2 shows the approximate dimensions of the column and its sampling points. Samples were drawn from all three ports approximately every 2 days and tested for dissolved manganese concentrations.

Trends

Manganese

Figures 10.3 and 10.4 show the total and dissolved manganese concentrations obtained during the 7-week in-plant sampling program. Comparison of Figures 10.3 and 10.4 shows that about one-half to two-thirds of the total manganese was suspended and was efficiently removed by both sedimentation basins. However, the dissolved manganese levels shown in Figure 10.4 are quite revealing. Influent levels of dissolved manganese were between 0.01 and 0.02 m^2/L throughout the study period. The levels of dissolved manganese leaving the mechanically cleaned basins were the same or lower than the influent levels. For the first 2 weeks the manually cleaned basin effluent also had dissolved manganese levels at or below the influent levels. However, beginning in week 2 the dissolved manganese levels in the effluent steadily rose in the manually cleaned basin and exceeded the influent level. The source of the manganese had to be the sludge sediment in the basin. It can also be seen in Figure 10.4 that as soon as the sludge storage basin was cleaned the manganese level dropped below the influent level. DO readings were taken throughout the sludge storage basin, including within the settled sludge just prior to the cleaning of the basin. Figure 10.5 shows these data.

Pilot-Scale Analysis

The pilot column of sludge showed definite increases of total manganese concentrations in the supernatant over time. Figure 10.6 graphically shows the manganese concentrations of the samples from three sampling points. Very high levels of manganese are associated with the water surrounding the sludge stored in sedimentation basins.

Iron

Effluent from the sludge storage basin and that from the mechanically cleaned basin showed no substantial difference in concentrations of total and dissolved iron. Results are shown in Figures 10.7 and 10.8.

Turbidity and TTHMFP

Effluent from the sludge storage basin and that from the mechanically cleaned basin showed no significant differences in turbidity or TTHMFP concentrations. Figures 10.9 and 10.10 show these results.

Table 10.1 Chemical feed data for Appomattox River Water Treatment Plant

Location	Chemical	Dose (mg/L)
Raw	Alum	20–40
	Cl_2	5
	Lime	—
	$KMnO_4$ (seasonal)	0.5
Filtered	Chlorine	3.0
	Fluoride	1.0
	Caustic	—

— indicates not applicable

Table 10.2 Average annual water quality data for Appomattox River Water Treatment Plant

Parameter	Raw	Finished
Turbidity, ntu	20	0.03
Color, cu	100	<5
Iron, mg/L	1.0	0.02
Manganese, mg/L	0.1–1.0	<0.04
pH	6.3	7.0
Alkalinity, mg/L $CaCO_3$	15	20
Ammonia, mg/L	NA	<0.01
Aluminum, mg/L	NA	0.05
Coliform, number/100 mL	NA	<1
TOC, mg/L	5–6	NA
TTHMFP, µg/L	400	100
Free Cl_2, mg/L	NA	1.0

NA = no data available

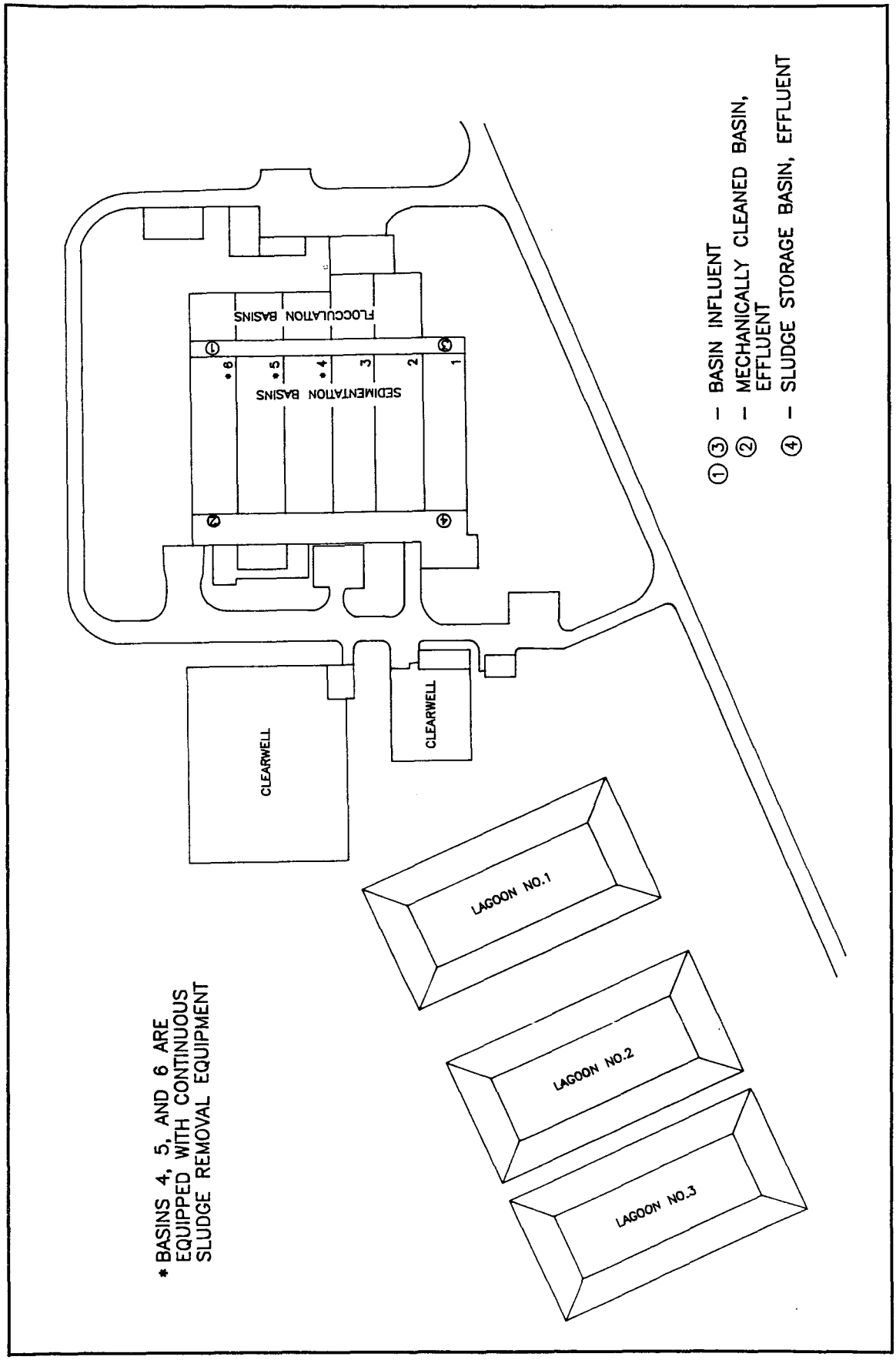


Figure 10.1 Sampling locations for Appomattox River Water Treatment Plant

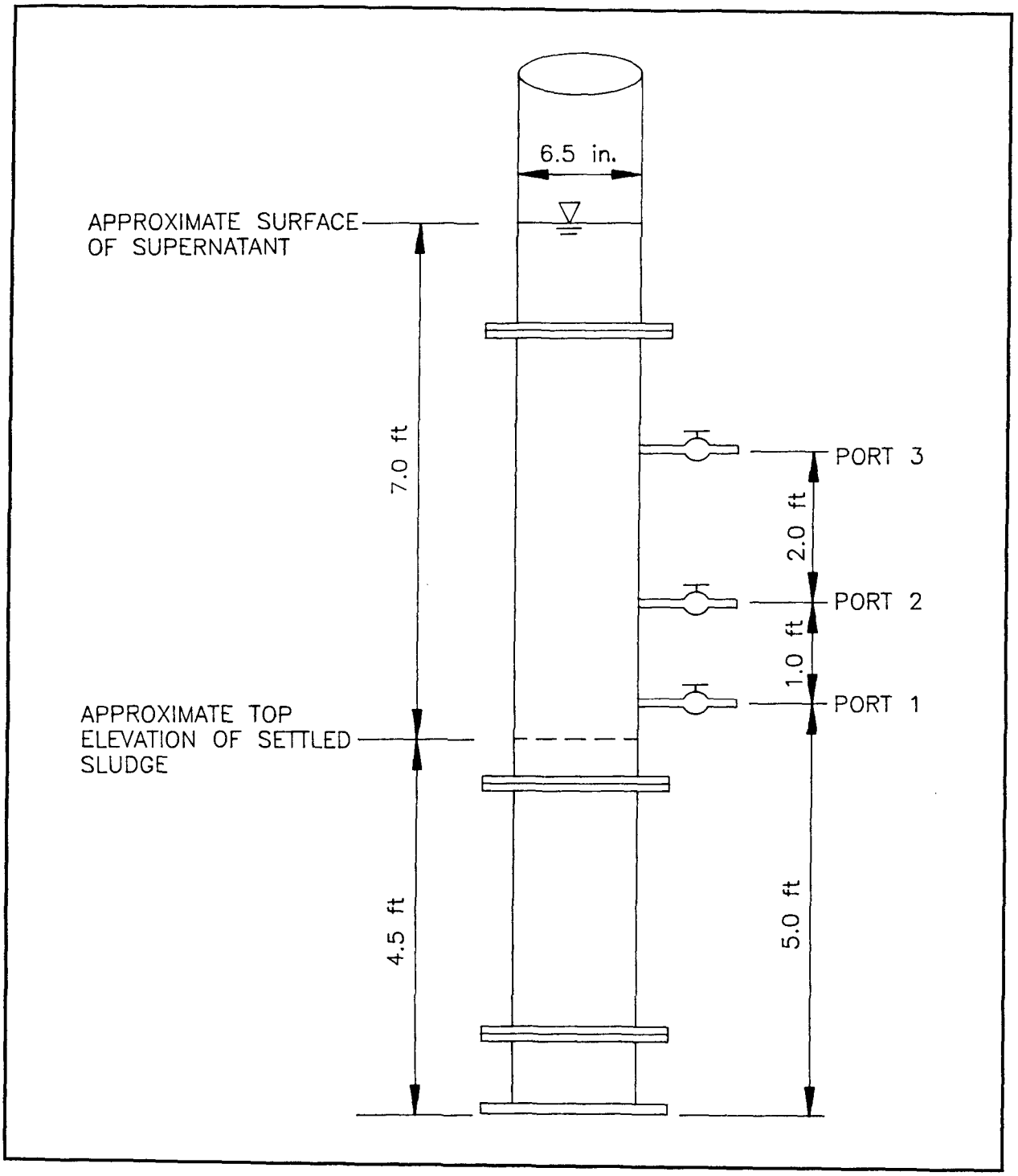
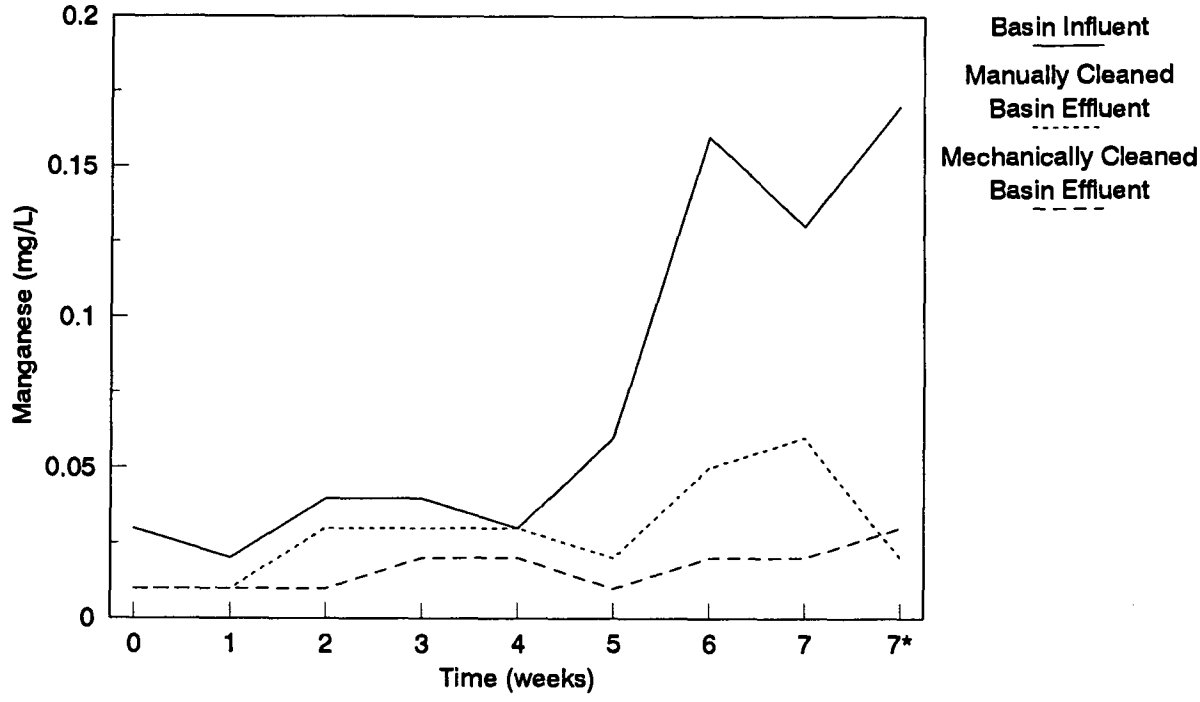
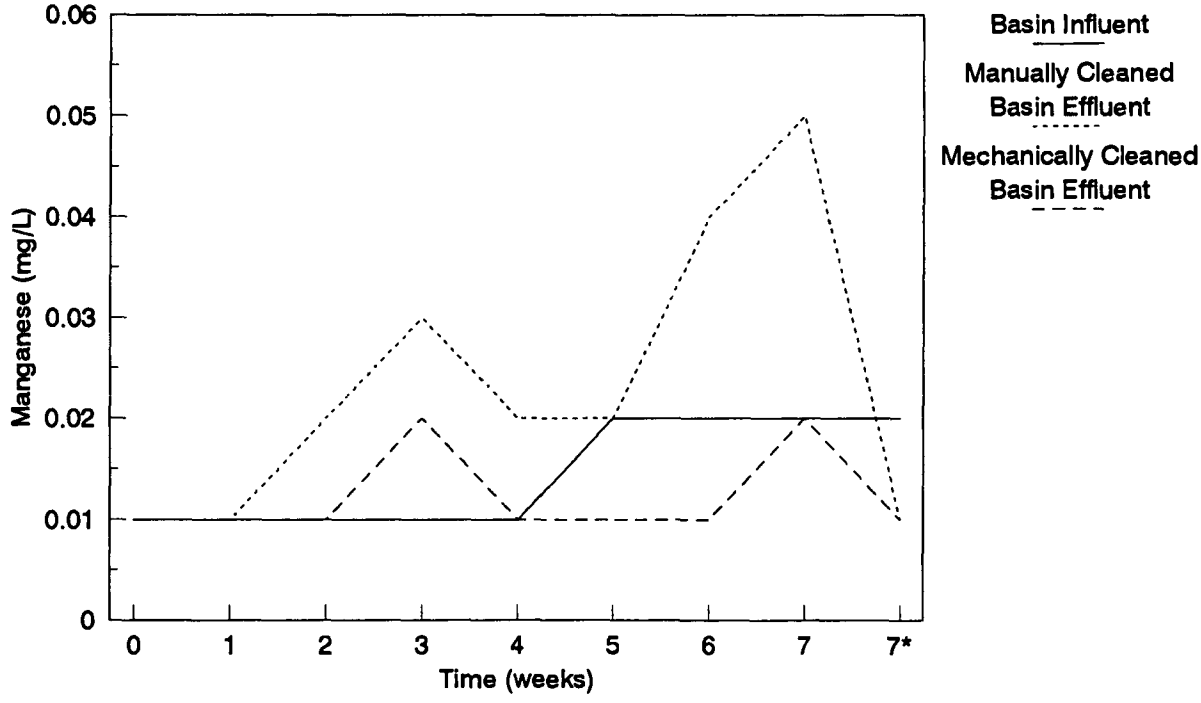


Figure 10.2 Pilot column used for sludge storage tests



*Sample taken just after basin was cleaned.

Figure 10.3 Total manganese in clarified water from manually and mechanically cleaned basins at Appomattox River Water Treatment Plant



*Sample taken just after basin was cleaned.

Figure 10.4 Dissolved manganese in clarified water from manually and mechanically cleaned basins at Appomattox River Water Treatment Plant

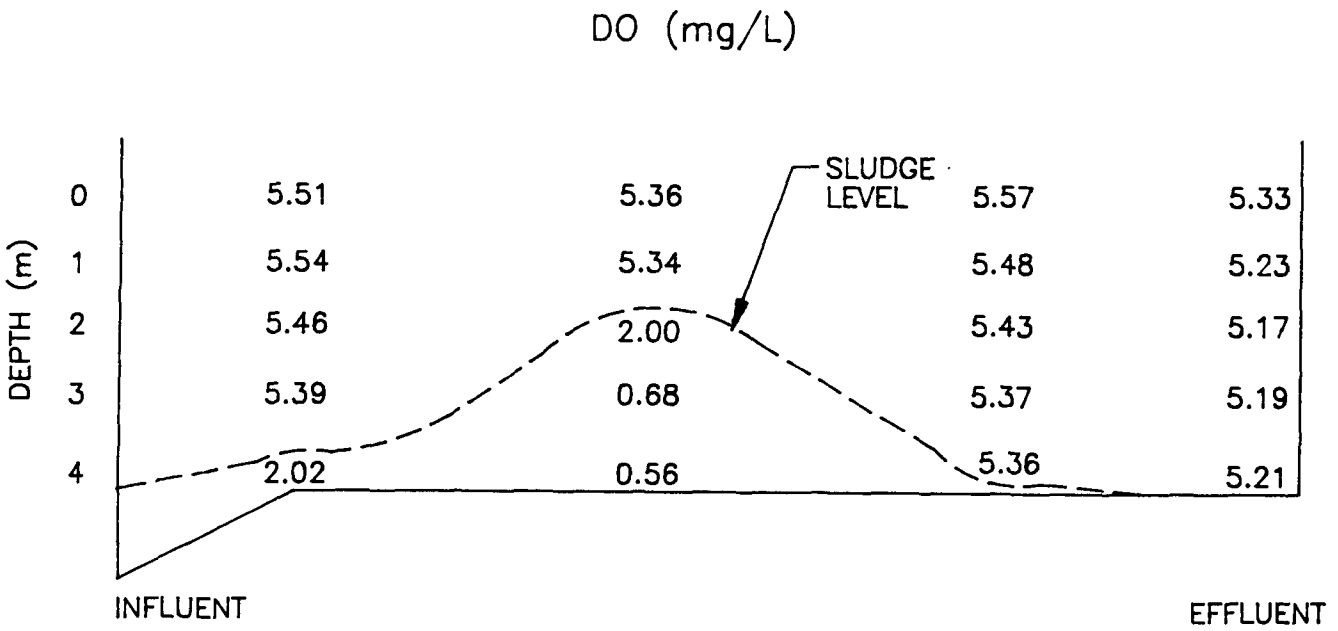


Figure 10.5 Dissolved oxygen concentrations in manually cleaned sedimentation basin at Appomattox River Water Treatment Plant

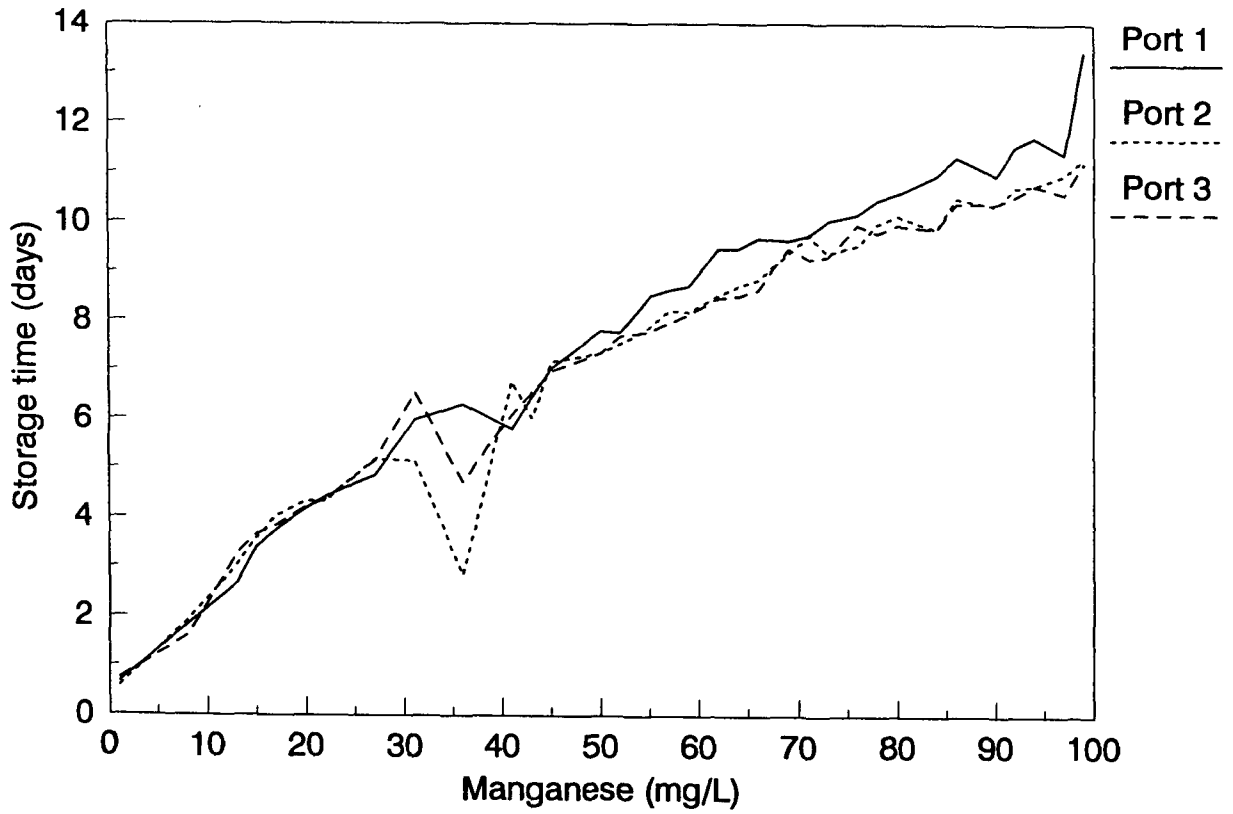
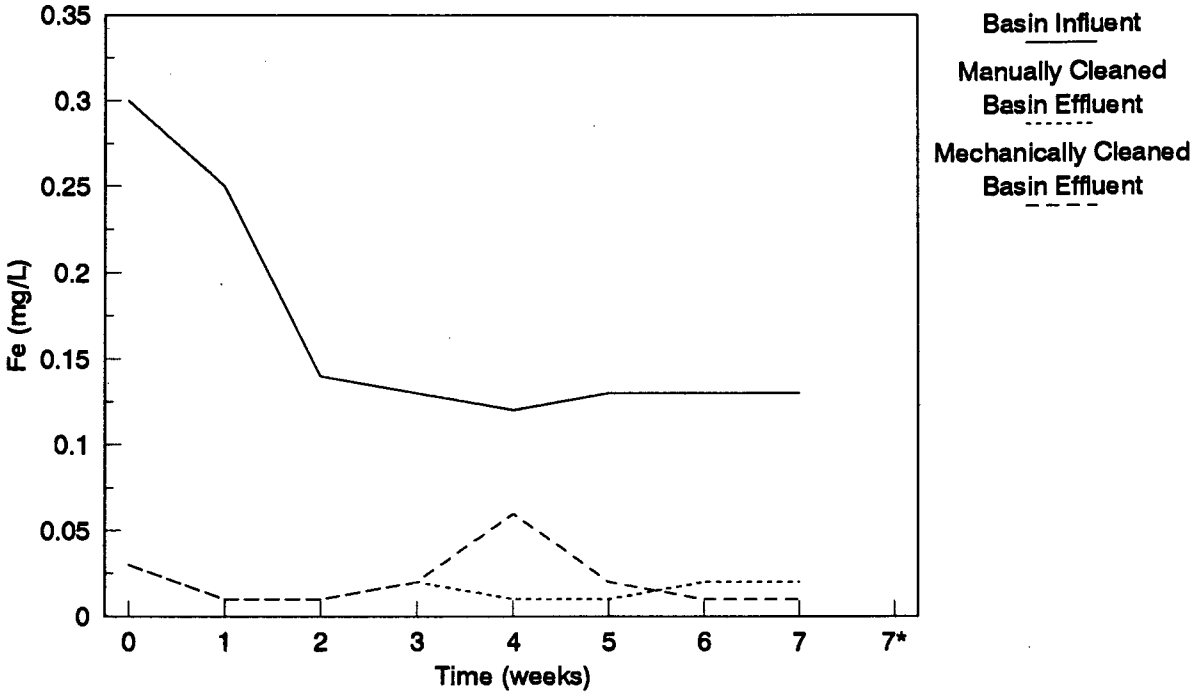
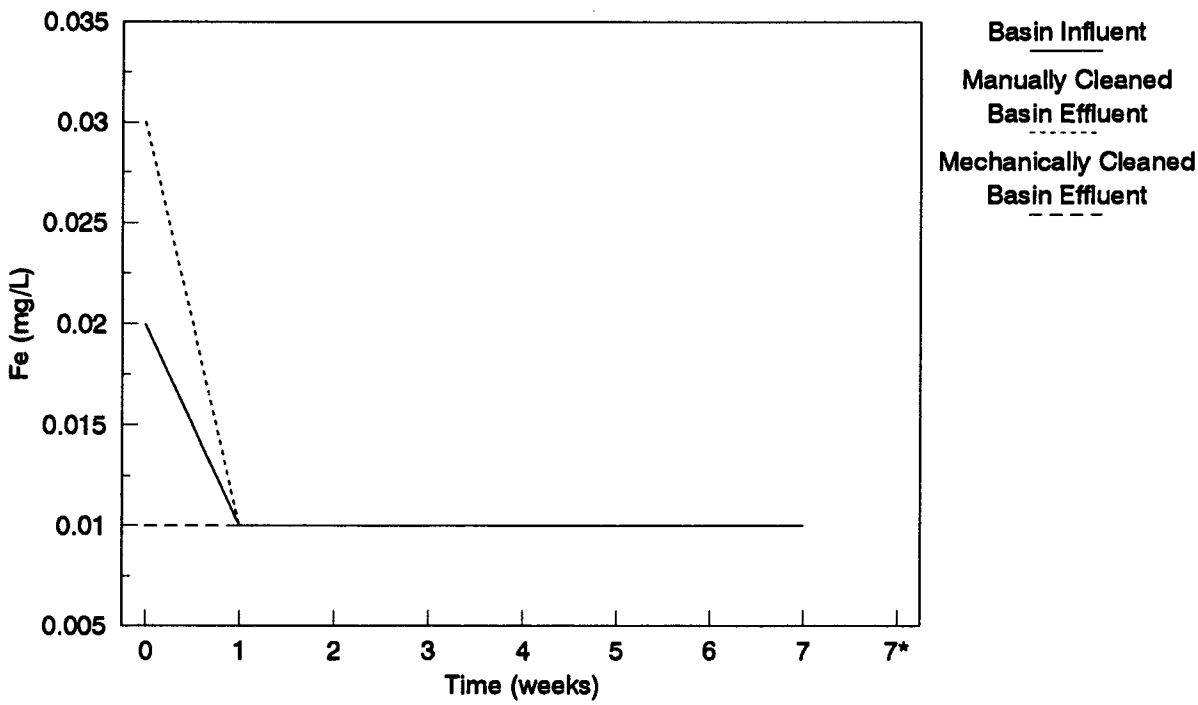


Figure 10.6 Manganese released from Appomattox River Water Treatment Plant sludge stored in pilot column



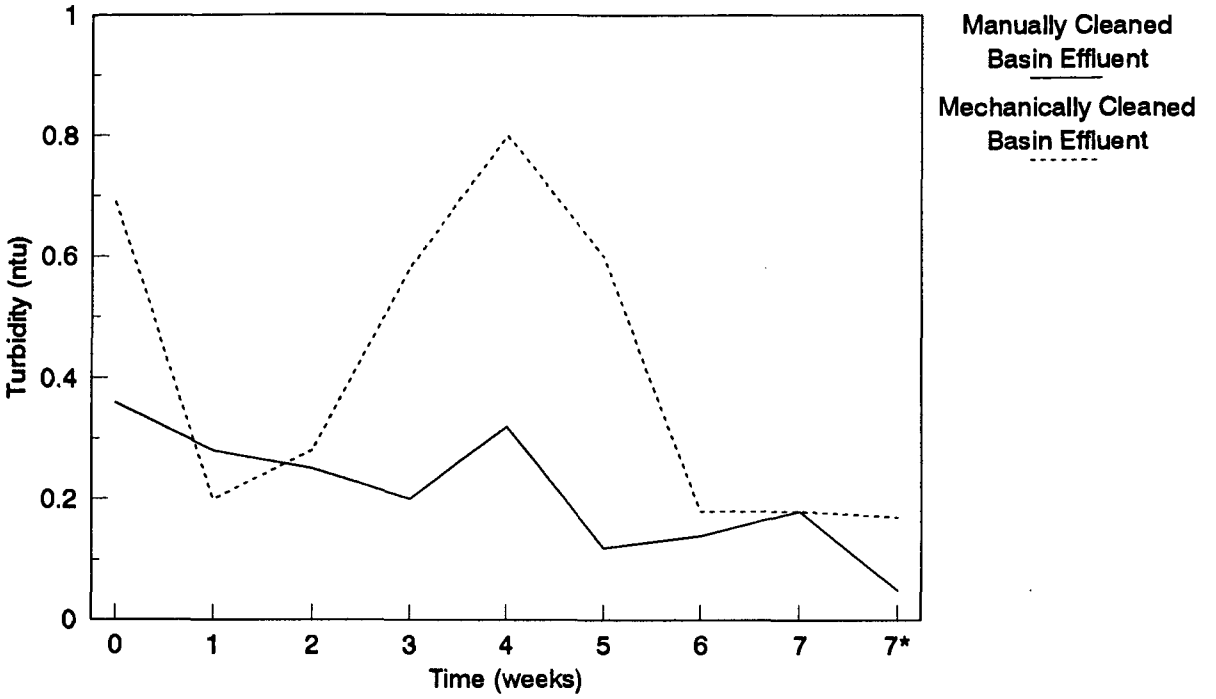
*Sample taken just after basin was cleaned.

Figure 10.7 Total iron in clarified water from manually and mechanically cleaned basins at Appomattox River Water Treatment Plant



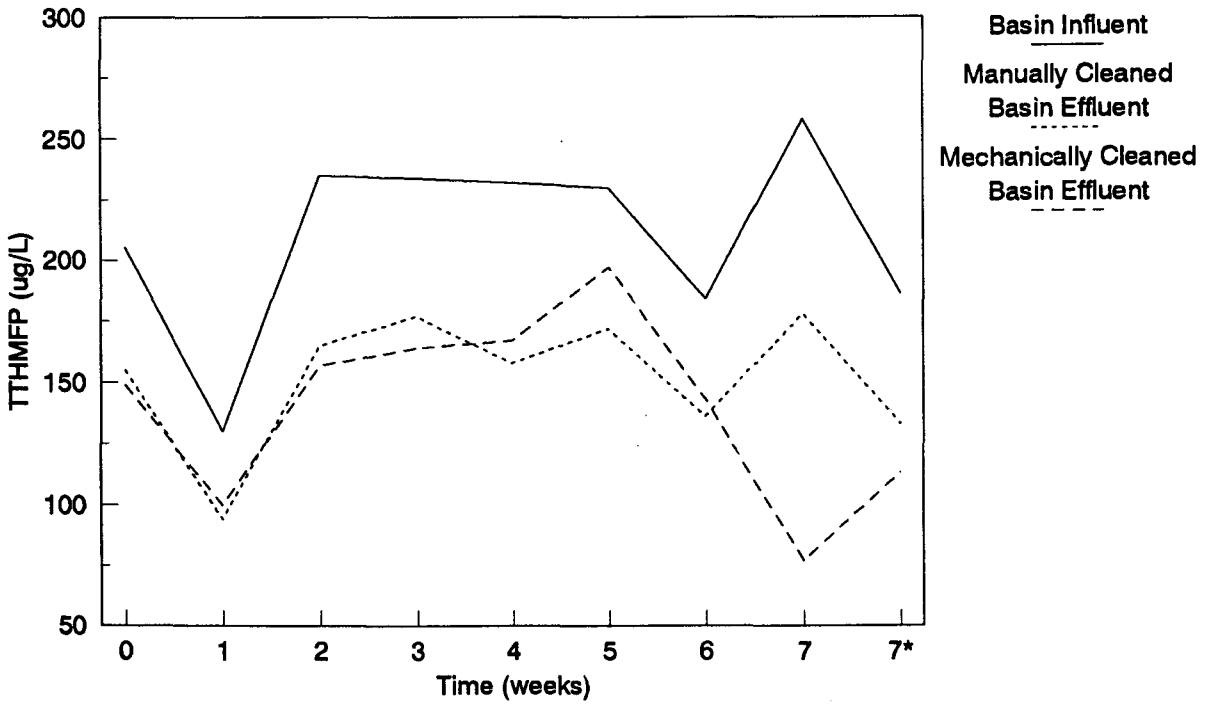
*Sample taken just after basin was cleaned.

Figure 10.8 Dissolved iron in clarified water from manually and mechanically cleaned basins at Appomattox River Water Treatment Plant



*Sample taken just after basin was cleaned.

Figure 10.9 Turbidity in clarified water from manually and mechanically cleaned basins at Appomattox River Water Treatment Plant



*Sample taken just after basin was cleaned.

Figure 10.10 TTHMFP in clarified water from manually and mechanically cleaned basins at Appomattox River Water Treatment Plant

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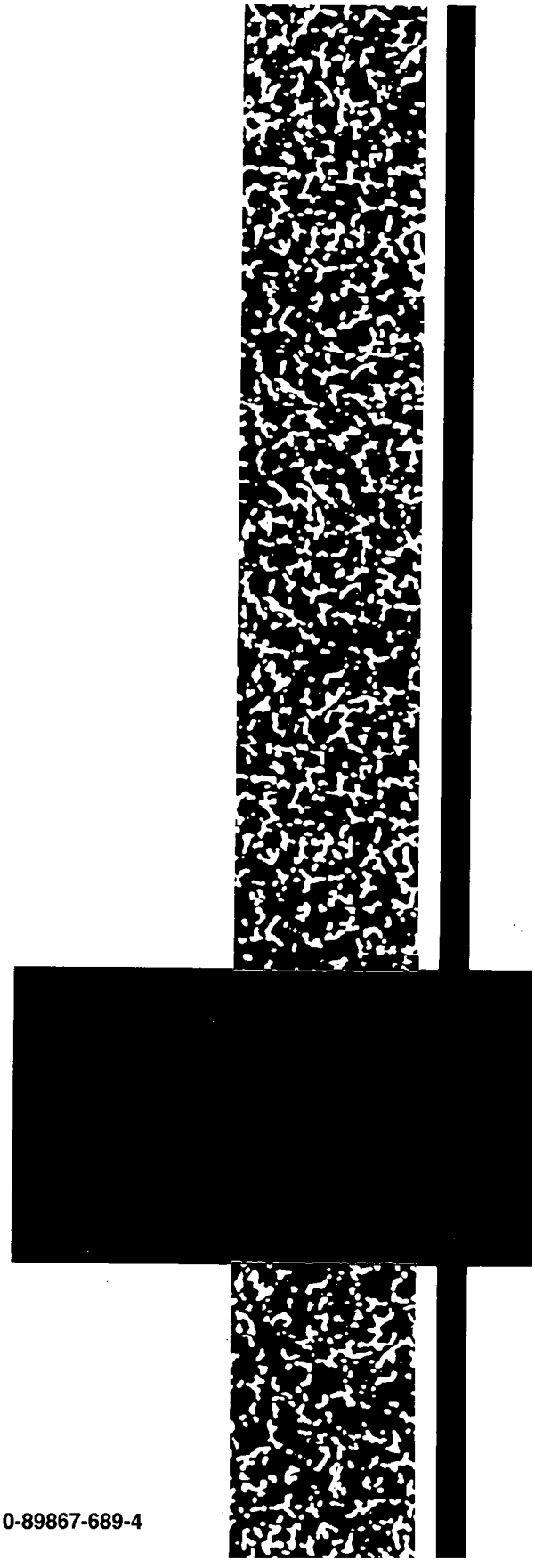
Abbreviations

AOC	assimilable organic carbon
ARWA	Appomattox River Water Authority
ASTM	American Society of Testing and Materials
AWWA	American Water Works Association
AWWARF	American Water Works Association Research Foundation
AWWSC	American Water Works Service Company
cm	centimeter
cu	color unit
DO	dissolved oxygen
DOC	dissolved organic carbon
ES	effective size
ft	foot
ft^2	square feet
G	universal gravitational constant
GAC	granulated activated carbon
gal	gallon
gpm	gallons per minute
gpm/ft^2	gallons per minute per square foot
in.	inch
L	liter
mg	milligram
MG	million gallons
mgd	million gallons per day
mg/L	milligrams per liter
µg	microgram
µg/L	micrograms per liter
µm	micron, micrometer
min	minute
mL	milliliter
NOX	bacteria strain of *Pseudomonas fluorescens*
ntu	nephelometric turbidity unit
PAC	powdered activated carbon
P17	bacteria strain of *Spirillium*
PVC	polyvinyl chloride
s	second
SCD	streaming current detector
SWTR	Surface Water Treatment Rule
THM	trihalomethane
TOC	total organic carbon
TSS	total suspended solids
TTHM	total trihalomethane
TTHMFP	total trihalomethane formation potential
w	with
wo	without



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