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Summary Report

Optimizing Water Treatment Plant Performance with the Composite Correction Program

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Notice

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Contents

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SECTION 1
INTRODUCTION

Purpose

This document summarizes the results of an ongoing project to evaluate the utility of the Composite Correction Program (CCP) approach to improving the performance of drinking water treatment facilities. The CCP approach, which has already proven successful when applied to wastewater treatment plants, is described and the results of evaluating it at 13 drinking water plants to date are summarized.

The 13 "case studies" focus on the potential for the CCP approach to improve the performance of small drinking water systems in meeting the turbidity removal requirements of the Surface Water Treatment Rule (SWTR).

The CCP approach is still under development. The end product of this project will be a publication that describes the refined CCP approach and allows it to be applied by others.

Background

Many communities are now considering either construction of new facilities or major modifications to existing ones to meet drinking water regulations. An approach that allows communities to meet regulatory requirements by implementing changes in their operation, maintenance, and administration procedures instead of major capital improvements has obvious advantages. By maximizing the operational efficiency of their facilities, local administrators can both improve the ability of the facility to meet Safe Drinking Water Act (SDWA) requirements and minimize the financial impact to the community associated with major upgrades to the plant.

Recognizing that the CCP approach had been successfully developed and applied to small wastewater treatment plants to accomplish the same objectives, the State of Montana decided to evaluate the potential of modifying it for use at small drinking water plants. Based on the initial success of this evaluation, U.S. EPA decided to further develop and demonstrate the approach to ensure its applicability to other parts of the country.

Since 88 percent of the 60,000 community drinking water systems in the United States are small systems serving fewer than 3,300 individuals, the opportunity for widespread impacts are large. These small systems account for approximately 92 percent of the SDWA compliance problems reported each year. In 1987, more than 80 percent of the community drinking water systems experiencing significant compliance difficulties were small systems.

Small systems frequently can neither readily identify and address the factors that cause their compliance problems nor easily finance the upgrading of their facilities. The staff may be inadequate in numbers, experience and training to effectively solve the problems. Successful application of the CCP approach can identify cost-effective measures that can be taken to improve plant performance and comply with drinking water requirements.

The CCP approach is another tool that federal, state, or local regulators, technical personnel, and consultants familiar with the procedure can use to identify and correct factors that limit a plant's performance. Results to date suggest that it is both highly successful and cost effective.

Content

Section 2 of this document details the CCP approach, including facility review, performance analysis, and implementation of corrective measures. Section 3 summarizes the results of the case studies, highlighting specific instances where the CCP approach revealed problems that were not previously obvious to drinking water treatment plant operators. Also highlighted are instances where the CCP approach saved the facilities money that otherwise would have been spent in plant modification. Section 4 includes expanded information on the 13 case studies that have been conducted to date should the reader desire additional information.

SECTION 2

THE COMPOSITE CORRECTION PROGRAM APPROACH

The CCP approach consists of a Comprehensive Performance Evaluation (CPE) and a Composite Correction Program (CCP). The CPE is a systematic step-by-step evaluation of an existing treatment plant resulting in a comprehensive assessment of the unit treatment process capabilities and the impact of the operation, maintenance and administrative practices on performance of the plant.

It is conducted by a team of individuals with knowledge of drinking water treatment and results in the identification of a unique combination of factors limiting plant performance. This team reviews and analyzes the plant's physical capacity as well as its operational capability and associated maintenance and administration. Based on this analysis, the team projects the capabilities of the major unit processes within the plant, and identifies and prioritizes those factors affecting plant performance.

If the CPE indicates that optimization of existing major unit processes can result in desired finished water quality, the CCP phase is implemented. The CCP systematically addresses those factors identified and prioritized in the CPE phase.

Figure 2-1 graphically illustrates the CPE/CCP approach. The CPE team usually is composed of two individuals experienced in the design and operation of drinking water treatment facilities and in trouble shooting their operation. Teams composed of up to seven individuals were employed for each of the 13 case studies described in this document, although it is anticipated that teams this large will not be required to apply the finalized CPE/CCP approach. These larger teams were used to help evaluate and further refine the procedure as well as familiarize regulatory personnel with it.

The Comprehensive Performance Evaluation

The CPE begins with a plant tour and collection of information from plant records. Data are obtained by interviewing plant staff and key administrative personnel (for example, the mayor and other city administrators), reviewing the plant's physical capacity, examining the plant's operation and maintenance records, and reviewing budgets. Standardized forms are used to collect the data on raw and treated water quality, design and operating conditions for individual plant processes, plant operator coverage, user fees for water treatment, maintenance scheduling, and operating budgets. While the data collection efforts focus on the current status of the plant, the review also includes past records to account for factors such as seasonal variations in raw water quality and peak demand, and to establish an accurate record of plant performance.

In addition to gathering existing data, the CPE may involve collecting new data by conducting special studies. For example, the CPE team usually develops a turbidity vs. time profile on a plant's filters before and after backwashing to determine whether the filters were performing adequately (see Figure 2-2). At nearly all plants, such a profile revealed that a significant breakthrough of turbidity occurred after the backwash. When the CPE team sampled the clearwell at one end, they discovered turbidity values of 6.3 NTU, which clearly exceeded the regulatory criteria. Other special studies conducted as part of the CPE often reveal similar performance problems that may not be obvious to the plant staff.

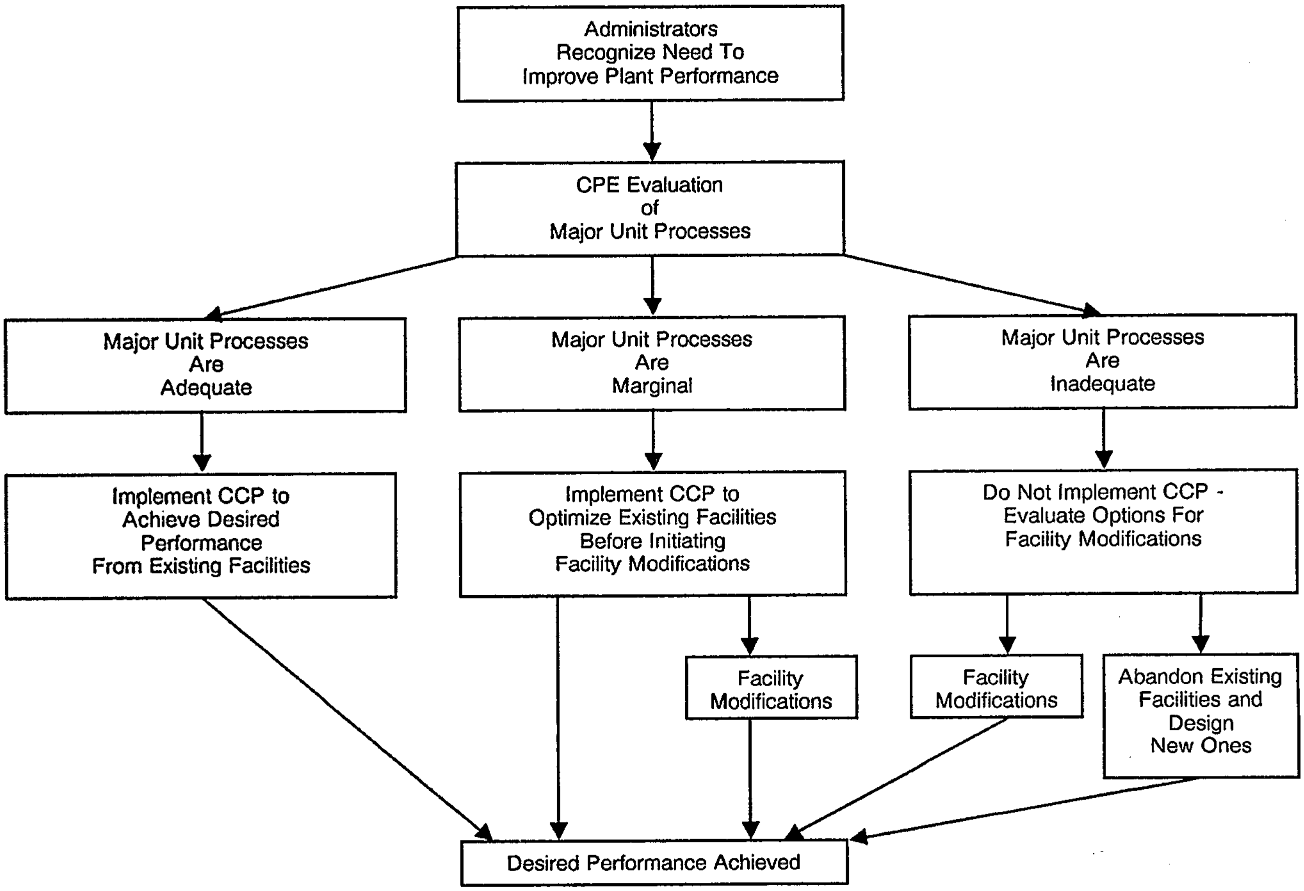
Design Components

The CPE team determines a plant's capacity by reviewing plant drawings and specifications, making field measurements, and reviewing information provided by the plant staff. In addition, the team applies its experience based on evaluations performed at other plants. The CPE evaluators then determine the projected capacity at which plant major unit processes (flocculation, sedimentation, filtration, and disinfection) can provide acceptable treated water quality. Projected values are compared with peak instantaneous operating capacity and current plant production. The comparison results are summarized using a performance potential graph (see Figure 2-3), which illustrates the strengths and weaknesses of the plant's unit processes.

Operation and Maintenance

Operational factors are assessed by evaluating procedures that the plant uses for process control adjustments and by determining if steps the plant

Figure 2-1   CPE/CCP schematic of activities.



takes to modify operations are based on proper application of water treatment concepts and methods. The CPE team discusses process control measures in detail with plant operators. This enables them to accurately assess the plant's operation and to avoid any misunderstandings related to terminology. Maintenance capabilities are evaluated by reviewing maintenance schedules and records, observing spare parts inventories, observing the condition of plant equipment, and discussing maintenance activities with plant personnel.

Administration

The CPE evaluators interview plant operators and administrative personnel (for example, city managers, town clerks, water board officials, etc.) to consider administrative factors such as staffing (including training, motivation, and morale), budgets, and rate structures.

Evaluating the Factors that Limit Performance

After critically studying the plant design, performance, maintenance, administration and operation, the CPE team assesses the performance of the plant and conducts an in-depth analysis to identify the specific factors that limit this performance. They use a checklist containing more than 65 performance-limiting factors (see Table 2-1) and define each factor according to its specific cause of poor plant performance. Once the factors have been identified, they are prioritized according to the magnitude of their adverse effects on plant performance. This is the major output from a CPE: a prioritized list of performance limiting factors.

Reporting

The CPE team conducts an exit meeting with administrative and operations personnel to communicate the results of the CPE directly to all concerned. This is followed up with a brief written report. The purpose of the report is to summarize the results of the CPE and list the prioritized factors limiting plant performance. A typical CPE report is 8 to 12 pages in length and addresses the following topics:

- Facility description
- Major unit process evaluation
- Performance assessment
- Performance-limiting factors
- Projected impact of a CCP

Figure 2-2. Filter effluent turbidity profile.

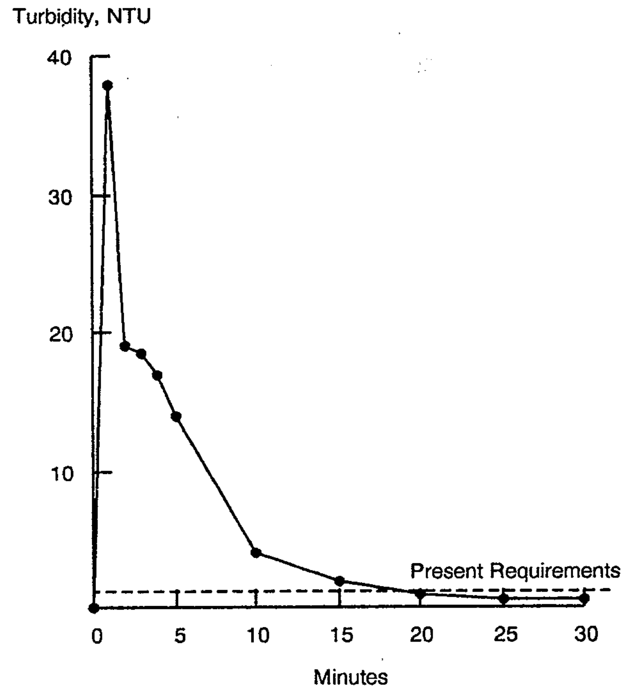
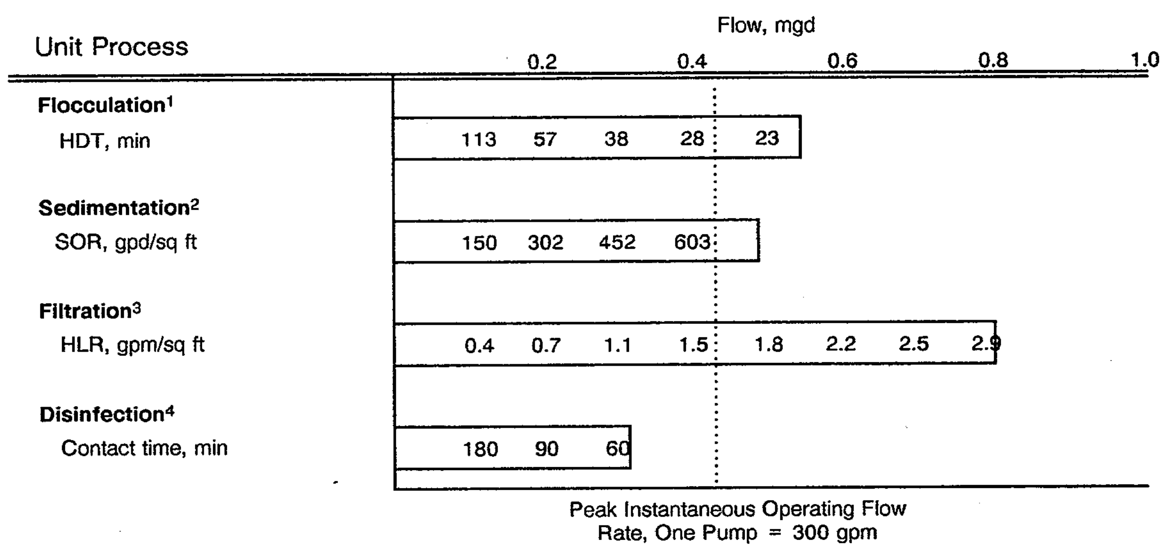


Figure 2-3. Sample performance potential graph.



[1] Rated at 20 min - assumes variable speed drive would be added.
[2] Rated at 750 gpd/sq ft - 12.5-ft depth discourages higher rating.
[3] Rated at 3 gpm/sq ft - control system considered limiting.
[4] Rated at CT = 127 with 2.4 mg/L Cl_2 dose, which requires a 53-min HDT; CT based on 4 log required reduction - 2.5 log in plant; 1.5 log disinfection, pH = 8, temperature = 5°C. Assumes 10% of usable clearwell volume for contact time..

Table 2-1. Performance-Limiting Factors

ADMINISTRATION
Plant Administrators
- Policies
- Familiarity with plant needs
- Supervision
- Planning

Plant Staff
- Manpower
  - number
  - plant coverage
  - work load distribution
  - personnel turnover
- Morale
  - motivation
  - pay
  - work environment
- Staff qualifications
  - aptitude
  - level of education
  - certification
- Productivity

Financial
- Insufficient funding
- Unnecessary expenditures
- Bond indebtedness

Water Demand

MAINTENANCE
Preventive
- Lack of program
- Spare parts inventory

Corrective
- Procedures
- Critical parts procurement

General
- Housekeeping
- References available
- Staff expertise
- Technical guidance
- Equipment age

Table 2-1. Performance-Limiting Factors (continued)

DESIGN
Raw Water
- THM precursors
- Turbidity
- Seasonal variation
- Watershed/Reservoir management

Unit Design Adequacy
- Pretreatment
  - intake structure
  - pre-sedimentation basin
  - pre-chlorination
- Low service pumping
- Flash mix
- Flocculation
- Sedimentation
- Filtration
- Disinfection
- Sludge treatment
- Ultimate sludge disposal
- Fluoridation

Miscellaneous
- Process flexibility
- Process controllability
- Process automation
- Lack of standby units for key equipment
- Flow proportioning units
- Alarm systems
- Alternate power source
- Laboratory space and equipment
- Sample taps
- Plant inoperability due to weather
- Return process streams

OPERATION
Testing
- Performance monitoring
- Process control testing

Process Control Adjustments
- Water treatment understanding
- Application of concepts and testing to process control
- Technical guidance (operations)
- Training
- Insufficient time on job

O&M Manual/Procedure
- Adequacy
- Use

Distribution System

MISCELLANEOUS

A CPE report does not recommend specific actions to be taken to correct individual performance-limiting factors, since this could lead to a piecemeal rather than an integrated approach to corrective actions. Corrective actions should be undertaken in the next phase - the CCP - with the help of the CPE team or similarly experienced individuals.

The Composite Correction Program

The objective of this phase is to improve the performance of a drinking water treatment plant by implementing the findings of the CPE when it indicates that the plant is likely to meet treatment requirements with the existing major unit processes. The CCP focuses on systematically addressing the factors that limit the plant in achieving the desired finished water quality.

Implementing the Composite Correction Program

To successfully implement the CCP and achieve improved performance, facilities must utilize the CPE results and implement a long-term process control program. A factor in any one of the performance-limiting areas (design, maintenance, administration, and operation) can contribute to poor performance. It is unlikely, however, that a single factor limits performance; rather it is usually a unique combination of factors that causes poor water quality. Plant operators and administrators must understand the relationship among these areas and water treatment plant product water quality. It is the operation of the plant that enables a physically capable plant to produce adequately treated water.

Maintaining Long-Term Involvement

One of the keys, as already noted, to successfully implementing a CCP program is long-term effort (typically involving several months to a year). Long-term involvement is critical for several reasons:

- Repeat training is more effective than one-time only training. Training should be conducted under a variety of operating and administrative conditions (for example, when seasonal water quality or demand changes) in order for staff to develop confidence in new techniques or procedures.

- Time is required to make the necessary physical and procedural changes. This is especially true for any changes that require administrative approval or funding appropriations.

- Necessary changes in staff attitude may mean personnel changes are needed. If the staff do not support the CCP approach, the CCP will require additional effort and perhaps personnel changes to be successful.

- Time is required to identify and eliminate any additional performance-limiting factors found during the CCP.

Since the goal of implementing the CCP is to correct performance-limiting factors until the desired water quality is achieved, the details of the implementation often will be site-specific and, therefore, should be left to the individuals implementing the CCP.

SECTION 3
RESULTS OF CASE STUDIES

Thirteen CPEs were conducted in 1988 and 1989; 11 at conventional drinking water treatment facilities and 2 at facilities using direct filtration. Of the 13, 9 were completed in Montana, and 2 each were completed in Ohio and Kentucky. The plants ranged in size from 3.8 to 202 L/s (86,000-10,000,000 gpd). Table 3-1 summarizes the design capacity and type of plants evaluated. Conventional plants are defined as using flash mix, flocculation, sedimentation, filtration, and disinfection unit processes primarily for turbidity removal and disinfection.

Table 3-1. Summary of Plants Where CPEs Have Been Conducted

Plant No.	Design Capacity	Process Type
1	7 mgd	Lime Softening*/Conventional
2	3 mgd	Conventional
3	5 mgd	Conventional
4	60 gpm	Conventional
5	3 mgd	Direct Filtration
6	4 mgd	Lime Softening*/Conventional
7	10 mgd	Conventional
8	250 gpm	Lime Softening*/Conventional
9	650 gpm	Direct Filtration
10	350 gpm	Conventional
11	300 gpm	Conventional
12	500 gpm	Conventional
13	1.5 mgd	Conventional

* Equipped with reactor clarifiers combining flocculation and sedimentation in one basin.

CPE Findings

Nearly all 13 case studies revealed significant information about each plant's condition, administration, and operation, including findings that had not been identified in previous inspections.

- At Plant 6, the CPE team discovered that plant staff bypassed the reactor clarifier during winter months and proceeded to operate using direct filtration without any chemical coagulant aids. This practice was discovered by thoroughly examining plant operating records and conducting followup interviews with the plant staff. While the operating records provided only a hint of a problem, the CPE team was able to pinpoint the problem by posing directed questions to the staff.

- At Plant 3, a direct discharge of backwash water to a stream was identified. This practice violated the State's discharge regulations.

- At Plant 12, the CPE team learned that the dilapidated condition of the plant prevented it from providing acceptable finished water to the community. While it originally appeared that the plant would not be able to afford the necessary repairs, the CPE team's review of the plant's operating budget and available resources led the community to believe that sufficient funds were in fact available to repair the plant and to redirect priorities.

The case studies also clearly indicate that the involvement of community administrators is a critical part of the CPE and, ultimately, to improving a plant's performance. Administrators frequently had not been informed of previous inspection results and potential or existing problems and, therefore, had not implemented remedial actions. In a CPE, the administrators are involved from the outset and informed of the evaluation results during the exit meeting. Informing administrators of performance problems during this meeting often led to their decision to change priorities regarding water treatment improvements and policies at the plant. Without the CPE results, existing plant staff frequently were unable to enlist the support of administrators or to set priorities for remedial actions.

- At Plant 2, the CPE team discovered that the plant operated at its peak rate 24 hr/day during maximum demand seasons. When the team reviewed data on the service population, they learned that per capita water use was excessive. By lowering peak demands to more typical rates, the plant could operate within acceptable loading rates to achieve compliance with applicable standards. When the CPE team informed administrators of this fact during the exit meeting, they decided to change the water rate structure and penalize high consumption.

At the same time, administrators initiated a leak detection survey and identified a major leak into an old, abandoned oak stave pipeline. Together, these administrative actions substantially reduced water demand and enabled the plant to achieve acceptable treated water quality without major expenditures.

- At Plant 12, the team identified severe finished water quality problems (very high finished water turbidity levels) that previously went undetected or unreported. Mechanical equipment was in a state of disrepair, thereby adding to the plant's performance problems. In addition, plant administrators had scheduled several major extensions to the distribution system; however, when informed by the CPE team of the performance problems, the administrators intended to redirect their resources from the distribution extensions to upgrading the water treatment plant facilities.

- Town administrators for Plant 13 had signed long-term agreements to supply water to a new industry and another water district. Some aspects of the agreement were considered major concessions to attract the industry, which would employ 500 people. First, it was estimated that when these users came on line they would represent one third of the plant's current capacity, possibly necessitating facility modifications to provide additional plant capacity. In addition, the agreement also required the town to supply the water at a lower cost than that currently paid by the town's own drinking water customers. When the CPE team presented town administrators with this information, they indicated that they would consider initiating a rate study and examine the need to renegotiate these agreements to supply water.

The case studies showed that in all plants but three, plant performance was much worse than previously reported data had indicated. In two cases, finished water quality was so poor that the state threatened to institute a boil order unless the facilities immediately made improvements. The CPE teams discovered these performance problems despite the fact that monthly operating reports usually showed that finished water quality met drinking water standards. These findings indicate that the present requirement to sample turbidity from the clearwell on a daily basis does not accurately reflect actual finished water quality at many plants. The CPE team initiated special studies that included developing turbidity vs. time profiles on filtered water.

- At Plant 2, 12 months of data previously submitted to the State revealed no violations. However, when the CPE team measured turbidity before and after the filter backwash and plotted the data (see Figure 3-1), they discovered a turbidity breakthrough of 5.8 NTU. Figure 3-1 also reveals that a decision to delay the backwash resulted in a significant increase in filtered water turbidity just prior to initiating the backwash cycle. Similarly, when the CPE team reviewed operating data for a 1-yr period at Plant 12, they learned that finished water turbidities were very consistent and rarely exceeded 1.0 NTU (see Figure 3-2). However, when the team measured turbidities during the CPE, they discovered clearwell turbidities in excess of 6.0 NTU. The data reported to the State must be representative of actual operating conditions.

These results indicate that data from daily grab samples may not reflect true performance and that data collected over shorter time periods (such as hours or minutes) is necessary. This suggests that facilities should perform either in-line continuous turbidity monitoring and recording on each filter, or manual monitoring of each filter effluent on an hourly basis. Less frequent monitoring would likely miss turbidity spikes.

The case studies indicated that plant operators and administrators generally did not recognize the serious public health impacts of short-term digressions in treated water quality. For example, at Plants 2, 4, and 6, plant operators and administrators did not take immediate action to correct short-term breakdowns even when they were aware of performance problems.

A key finding of the studies is that, because most small water treatment facilities are only operated for 8 or 12 hr/day, they tend to have excess capacity. The excess capacity results from being able to operate at a lower flow rate for longer periods of time, enabling many small plants to address unit process limitations. For example, Plant 8 operated at its 16-L/s (250-gpm) capacity for only several hours each day even when turbidity levels in the surface water exceeded the plant's treatment capability. The CPE projected that, by reducing the plant flow to 8 L/s (125 gpm) and operating for up to 12 hr, the plant could treat turbidities of any anticipated level. Likewise, at Plant 5, reducing the plant flow from 132 L/s (2,100 gpm) to 69 L/s (1,100 gpm) relieved a severe air binding problem and enabled the plant to operate successfully. At Plants 8 and 5, water demands were met even with reduced plant flows; however, this may not always be the case.

The case studies revealed that proper control of the filtration process is key to improving plant performance.

- At Plant 2, filter rate controllers malfunctioned causing the filter effluent valves to open and close every few seconds. The filter flow rate changed from 0 to 63 L/s (1,000 gpm). The filter effluent turbidities also varied, indicating that particles previously filtered were washed through the filter to the clearwell. While plant staff knew that the valve

Figure 3-1. Plant 2 turbidity profile.

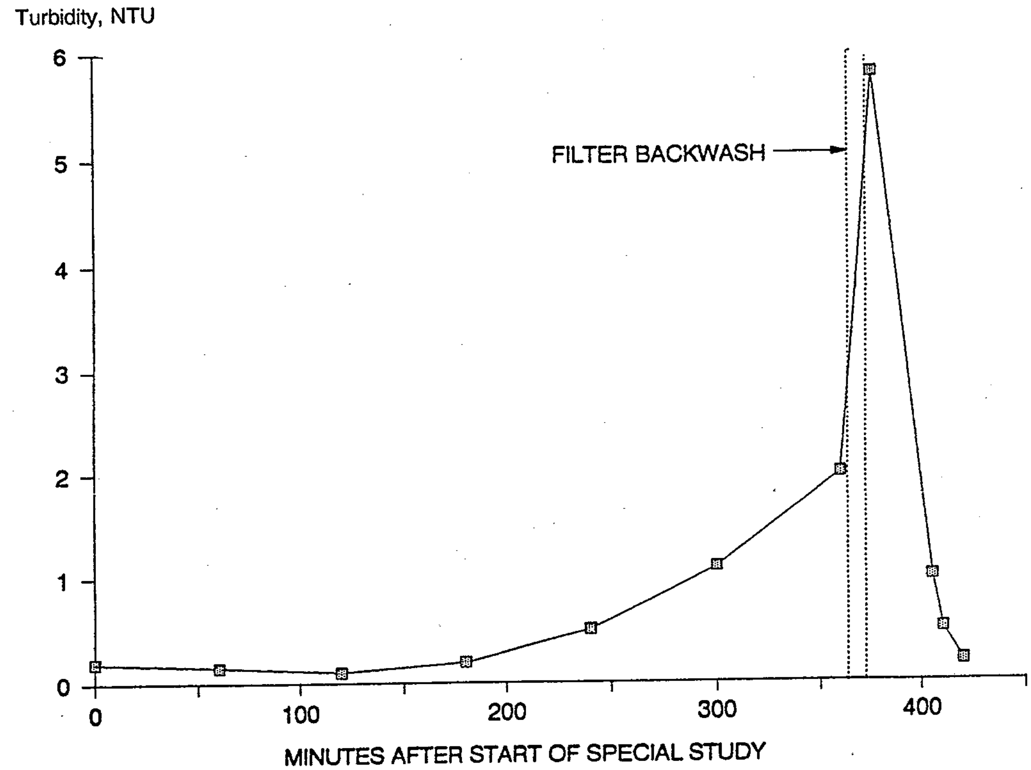
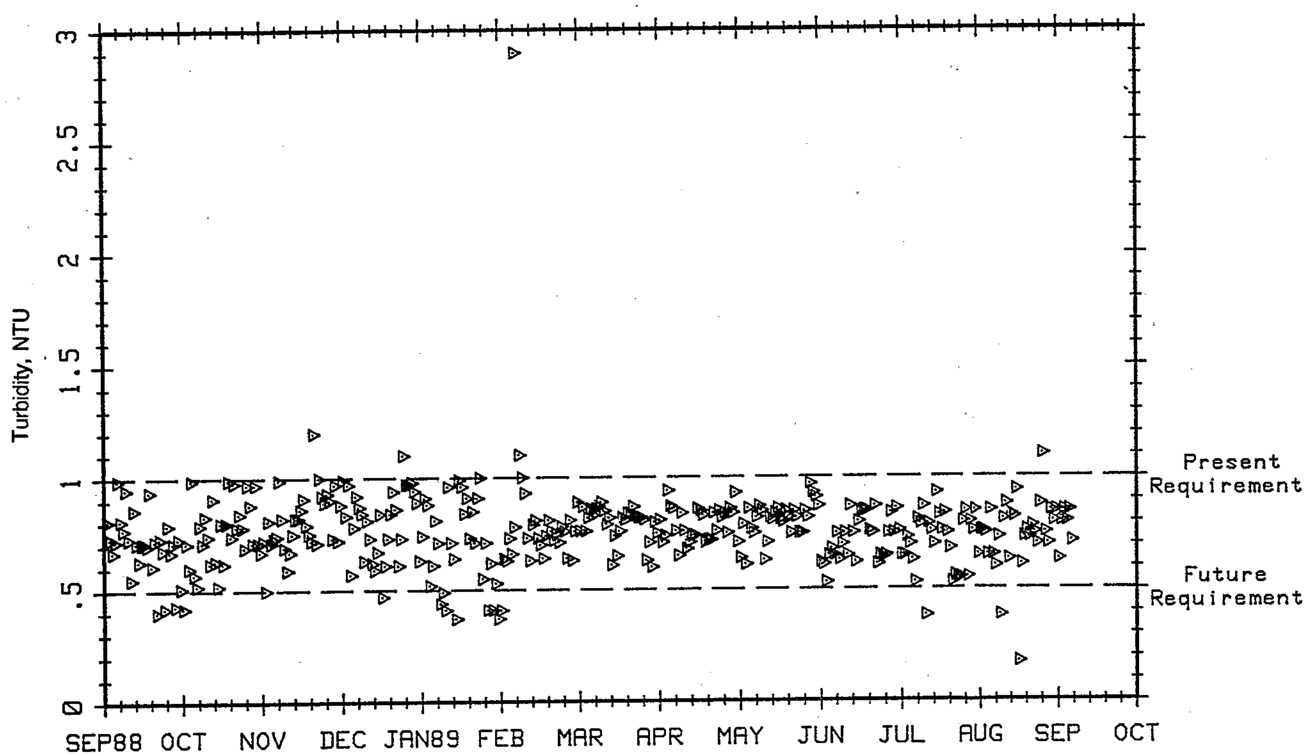


Figure 3-2. Plant 12 finished water turbidity profile.



"jumped around," they did not realize that it affected filter performance. The studies clearly indicate that filter rate controllers must be properly maintained to allow the filters to operate correctly.

- At Plant 2, when plant staff removed one filter for washing, the entire plant flow was directed to the remaining filter. This caused severe turbidity breakthrough.

- At Plant 8, filters were "started dirty," causing a serious detrimental effect on filtered water quality.

- At Plant 2, operators changed the flow rate without adjusting chemical feed rates. This resulted in improper feed of coagulant chemicals and subsequent degradation in finished water quality.

The case studies revealed that all 13 plants implemented only limited process control efforts. Little testing or data interpretation, both of which are imperative to making informed operating decisions, were conducted. As a result, improper operating practices, such as bumping filters or waiting too long to backwash filters, were widespread. For example, at Plant 12, water was allowed to drop from the troughs onto the filter media, which clearly violates basic principles of filter operation.

CCP Findings

CCPs were implemented at 2 of the 13 plants. The objective of the CCP studies was to determine if the approach could improve plant performance and enable the plants to comply with the SWTR without major capital improvements. The specific findings of the CCPs, which were conducted at Plants 1 and 5, are also presented in Section 4.

Implementation of these CCPs enabled both plants to meet the future finished water turbidity requirements of the SWTR by implementing process control programs and providing operator training. The approach demonstrated the potential for drinking water treatment facilities to meet regulatory requirements through improved operation, maintenance, and administration rather than major capital improvements.

- At Plant 5, city administrators originally had planned to spend approximately $1 million to construct sedimentation basin facilities and related improvements. They felt the major capital improvements were necessary to ensure that the plant could achieve compliance with the forthcoming SWTR turbidity requirements. After the CCP was conducted, however, construction of the improvements was delayed until such time that water demands required that the plant operate at higher rates. As a result of the CCP, plant staff developed increased confidence that, by implementing process controls, the plant could produce excellent water quality despite high raw water turbidities. The CCP also revealed that accurate coagulant doses could be selected by using the jar test/filter paper procedure.

- At Plant 1, the CCP dramatically improved plant performance. Turbidity removal in the reactor clarifiers was improved and stabilized, and chemical requirements were minimized. The improvement resulted from a combination of process control and monitoring, as well as several major process adjustments.

To achieve the desired results, CCPs should be implemented over a period of at least 6 months, since time is necessary to implement process control programs, purchase equipment, provide training, and document stable finished water quality for variable raw water conditions. The case studies demonstrated that process control programs improved the performance of individual unit processes at the two plants, thereby leading to improved finished water quality.

Overall Factors Limiting Performance

A CPE team evaluated 65 performance-limiting factors at each of the 13 plants; the top 10 performance-limiting factors are presented in Table 3-2. It is important to remember that <u>no one factor was responsible for limiting plant performance, but rather a unique combination of factors contributed to performance problems</u>.

Table 3-2. Top Ranking Performance-Limiting Factors Identified at 13 Facilities

Rank	Factor	No. Plants	Category
1	Operator Application of Concepts and Testing to Process Control	13	Operations
2	Process Control Testing	11	Operations
3	Process Controllability/ Flexibility	13	Design
4	Disinfection	9	Design
5	Sedimentation	10	Design
6	Staff Number	7	Administration
7	Filtration	7	Design
8	Policies	7	Administration
9	Flocculation	6	Design
10	Maintenance	7	Maintenance

- <u>The highest ranking performance limiting factors fell in the operations category</u>, and were related to the inability of plant staff to respond to water quality changes with appropriate chemicals in appropriate doses. In addition, plant staff frequently made improper operating decisions because they lacked understanding of unit processes and associated controls. Compounding these problems was a lack of process control testing programs at all but two of the plants.

- Design factors represented 5 of the performance limiting factors in the top 10 list. Process controllability and flexibility was the highest ranked design limitation. It was cited most frequently because of limitations in type and location of chemical feed options, and in control aspects such as filter- regulating valves or plant flow control valves. The CPE team noted that minor modifications could address these performance limiting factors at the facilities.

- Disinfection facilities were identified as a performance limiting factor at 9 plants because of inadequate detention time in clearwells or transmission lines. The SWTR will require a plant to provide a certain CT value, which is obtained by multiplying the disinfectant concentration by the actual contact time. Most of the plants relied on unbaffled clearwells to provide most of the required detention time. These clearwells were projected to provide inadequate CT because of expected severe short circuiting. However, modifications to the clearwells, such as installing baffles, may allow these plants to meet the CT requirements of the SWTR. Findings of disinfection inadequacy were based on the CPE team's estimates of the allowable contact time at each plant. No thorough hydraulic analyses, as required by the SWTR, could be conducted within the scope of this project. The identification of disinfection inadequacy was tentative and is meant as a signal that current operation might not be adequate to meet the disinfection requirements to be established by each State.

- Sedimentation basin design was identified as a performance-limiting factor at 10 plants. The impact was periodic and seasonal during high turbidity or high- demand episodes. The CPE team projected that improved operation could minimize the impact that the marginal basins had on plant performance (for example, longer run times at lower flow rates or improved coagulation control).

- Filters presented problems at 7 of the facilities. The CPE team identified this factor because of air binding (2 plants), backwash limitations (2 plants), and possible filter underdrain or support gravel problems (three plants). The team felt that the air binding and backwash limitations could be minimized or overcome by improved operational practices, and that the underdrain or support gravel damage could have been avoided if the operations personnel had better understood the filtration process. This damage appeared to be caused by introduction of air or by excessive instantaneous hydraulic load at the beginning of a backwash.

- Flocculation capability was identified as performance limiting at 6 plants because of limited basin volume and lack of staging. The CPE team concluded that improved operations could minimize the impact of this factor (for example, lowering hydraulic loadings, installing baffles, modifying coagulants).

- Administrative factors (including staff number and administrative policies) also were included in the top 10 list. An inadequate number of staff to properly run the facilities was noted at 7 plants. This deficiency was critical considering the need to add a process control program and associated responsibilities at these plants. Frequently, administrators were unaware of operating requirements, or had set water rates too low to maintain adequate treatment or establish a self-sustaining utility. Few administrative personnel understood the severity of short-term excursions from high quality treated water.

- Maintenance factors were identified as impacting 7 of the plants. Operators who lacked understanding of process operations abandoned many of the automatic and/or manual control systems at the plants. The CPE team identified several facilities where maintenance activities were completely neglected, sometimes due to administrative indifference. The team concluded that improved understanding of operations and maintenance, coupled with an improved administrative attitude, could lead to improved plant performance.

SECTION 4
CASE HISTORIES

The following case histories provide a detailed summary of the results from each of the 13 CPEs on which this report is based. Each case history consists of a facility description, results of the Major Unit Process Evaluation and Performance Assessment, and a discussion of the factors found limiting the plant's performance. The applicability of a CCP is also discussed for each plant as are the results of the CCPs completed at two plants. These CPEs were completed as part of the project to develop and formalize these procedures for water treatment plants. Some aspects of the procedures were refined as more CPEs were completed. As the procedures evolved through these refinements, some of the ways in which the results are presented have changed. Some inconsistencies between the presentation of the results of the different case histories, therefore, may be observed.

Plant 1

Facility Description
Constructed in 1974, Plant 1 is owned and operated by the city and serves approximately 10,000 persons, with no significant industrial water users. It consists of a pre-sedimentation basin followed by conventional treatment and is used as a softening facility during winter months. Average daily flow for a 12- month period was 66 L/s (1.5 mgd), with an average daily flow during the peak month of 131 L/s (3 mgd). The plant includes the following unit processes (see Figure 4-1):

- Three constant-speed, raw water pumps: two 25-hp, 126-L/s (2,000-gpm) and one 15-hp, 91-L/s (1,450-gpm)
- 8.7 million-L (2.3 mil-gal) earthen pre-sedimentation basin
- Three 15-hp, 113-L/s (1,800-gpm) constant-speed, low-service pumps
- Chemical addition (alum, lime, and Dycafloc 587-C)
- Two 17.7-m x 17.7-m (58-ft x 58-ft) upflow clarifiers, 6.4 m (21 ft) and 6.0 m (19.8 ft) deep
- Recarbonation with liquid carbon dioxide
- Four 7.6-m x 7.6-m (25-ft x 25-ft) dual media filters
- 1.1 million-L (300,000-gal) clearwell
- Disinfection
- Fluoridation (sodium silica fluoride)
- Sludge removal and thickening
- Sludge drying beds
- Three high-service pumps: 100, 113, and 157 L/s (1,600, 1,800 and 2,500 gpm)

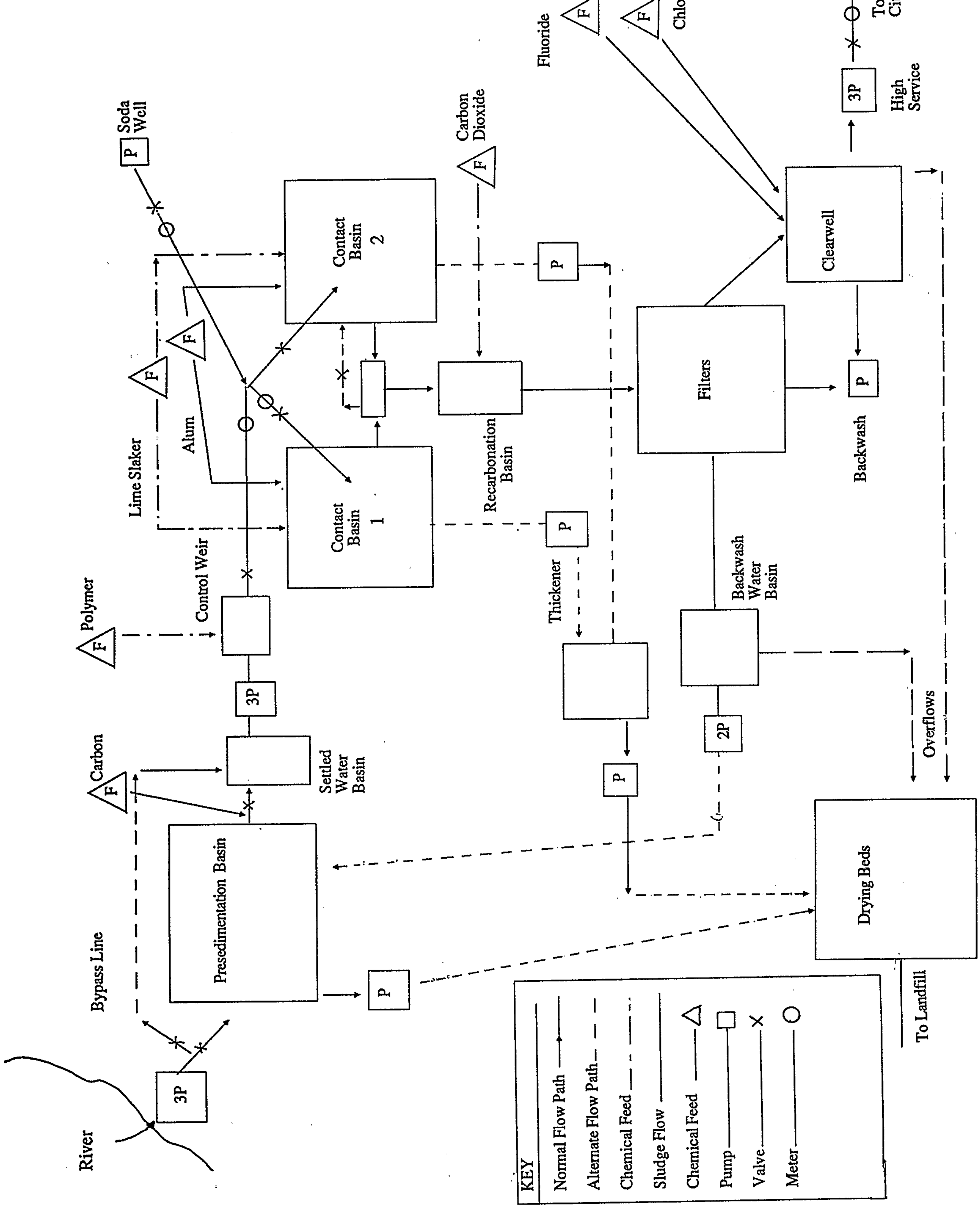
The three raw water pumps transfer water from the nearby river through a 61-cm (24-in) line to the pre-sedimentation basin. The three low-service pumps lift the water from the pre-sedimentation basin approximately 18 cm (7 in), so that it can flow by gravity through the plant's unit processes.

Powdered activated carbon is added to the water in the pre-sedimentation basin for taste and odor control and a cationic polymer is injected following the raw water pumps. Alum and lime are added in the flocculation area of the two 22-L/s (500,000-gpd) solids contact clarifiers.

The clarifiers are square with circular sludge removal mechanisms. Prior to the clarifiers, water from a 14-L/s (220- gpm) "soda well" is pumped into the raw water stream. Hydraulic conditions cause an uneven split of this softer water between the two clarifiers.

Water flows through the clarifiers to a recarbonation basin, where the pH is lowered, and onto four dual media filters. From the filters, the finished water flows into the clearwell. Chlorine and fluoride are added to the water as it enters the clearwell. The three high-service pumps deliver finished water to the distribution system.

Figure 4-1. Plant 1 process flow diagram.



Major Unit Process Evaluation
Figure 4-2 illustrates the assessed capacity and projected performance of each of the plant's major unit processes in a performance potential graph. The vertical broken lines indicate the annual average flow of 70 L/s (1.6 mgd), the peak monthly flow of 131 L/s (3 mgd), and the design capacity of 307 L/s (7 mgd).

As Figure 4-2 shows, the raw water pumps, low-service pumps, filters, and high- service pumps are rated at the 307-L/s (7-mgd) plant design flow. Potential capacities of the pre-sedimentation basin and the clarifiers are rated at less than design.

The pre-sedimentation basin was derated because of short circuiting through the basin and no capability to add coagulant aids. Also, return of backwash water to the effluent end of the basin results in excessive turbidity levels in the raw water. The basin was rated above the peak monthly flow of the plant.

The clarifier/flocculator was rated at 136 L/s (3.1 mgd) with one unit in service and 272 L/s (6.2 mgd) with both in service. The corner sweeps on the sludge mechanisms have failed allowing excessive amounts of sludge to build up in the basin corners. Sloughing of the sludge coupled with inconsistent weir elevations has resulted in periodic solids loss. The clari-flocculators were derated because of these conditions.

Performance Assessment
Plant 1 is currently required to produce finished water with turbidity levels less than 1.0 NTU and with free chlorine at levels that will ensure less than 0.2 mg/L at all points in the distribution system. Fluoride is added to achieve a 0.9-1.1 mg/L residual in the finished water. A comparison of plant monitoring data with state requirements indicated the plant was operating in compliance with applicable regulations. A review of operating records, however, indicated numerous excursions of filter effluent turbidities above acceptable levels.

The SWTR will require plants to demonstrate by regular turbidity monitoring or constant recording turbidimeters, turbidity at less than 0.5 NTU greater than 95 percent of the time. Additionally, theoretical 3-log removal and/or inactivation of Giardia cysts and 4-log removal and/or inactivation of enteric viruses must be demonstrated.

Performance-Limiting Factors
The factors identified as having a major effect on performance on a long-term repetitive basis are summarized below in order of priority.

1. <u>Operator Application of Concepts and Testing to Process Control</u> - Operation: Operation of the plant is maintenance rather than process control driven. Priorities need to be established that allow process control to be integrated into the daily routine of the plant staff. This involves collecting additional process control data and interpreting the data to direct process control that optimizes plant performance.

2. <u>Process Control Testing</u> - Operation: The lack of process control testing has resulted in incomplete data being collected to determine the level of plant performance. In addition, it is probably masking periods of production of poor quality finished water. Items of particular concern are lack of turbidity testing of raw water and water from the clarifiers, and continuous monitoring of individual filter effluent. Plant data indicate that filter effluent "spikes" were occurring, but it was not possible to determine their severity or duration.

3. <u>Process Automation</u> - Design: There is a need for continuous monitoring and recording turbidimeters on the raw water, each filter, and the clearwell.

The factors identified as having either a minimal effect on a long-term repetitive basis or a major effect on a periodic basis were prioritized and are summarized below.

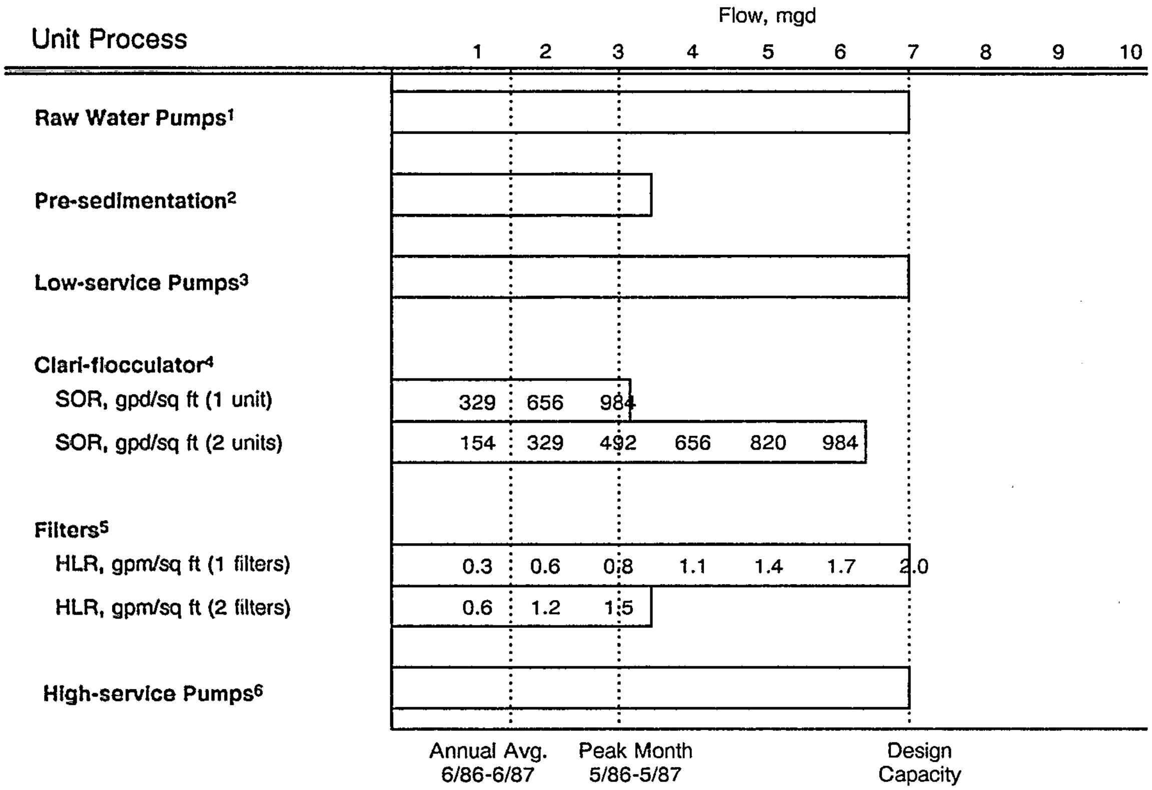
1. <u>Process Flexibility</u> - Design: More flexibility is necessary in types of chemicals added and points of chemical addition. At the time of the evaluation, alum and lime were added to the flocculation portion of the clarifier and polymer was added after the low-service pumps. There was no process available to feed a filter aid or flocculent aid. Flexibility to move the alum feed to a point with greater mixing could reduce the alum feed rate and may also allow the flocculator speed to be reduced to better optimize flocculation. The ability to add a filter aid would improve filter performance.

2. <u>Lack of Standby Units</u> - Design: There is no standby backwash pump. If the existing pump fails, the plant is out of operation until it can be repaired or replaced.

3. <u>Preliminary Treatment</u> - Design: Obvious problems exist with the pre-sedimentation basin, including no chemical feed (except carbon) to the basin, short circuiting, backwash water fouling of the intake area of the low-service pumps, and difficulty cleaning the pre-sedimentation basin.

4. <u>Staff Number</u> - Administration: The current major emphasis is on maintenance; more time must be spent on process control to improve performance. In addition, the superintendent is working extra shifts to keep the plant operating. At least two additional plant operators are necessary for both operations and maintenance activities to be adequately addressed.

Figure 4-2. Plant 1 performance potential graph.



[1] 7.8 mgd with individual pumps - assumes design capacity with continued operation.
[2] Assumes run 2 filters at 2 gpm/sq ft and backwash 2 filters at end of day.
[3] 7.8 mgd with individual pumps - assumes design capacity with continued operation.
[4] Rated at 800 gpd/sq ft for turbidity removal - use 1,000 gpd/sq ft for softening capacity (weir imbalance).
[5] Rated at 2 gpm/sq ft.
[6] 2.5 mgd with individual pumps - assumes design capacity with continued operation

5. Sedimentation - Design: The corners of the clarifiers need to be grouted to prevent buildup of sludge in the basins and the flow through the weirs needs to be balanced so that resulting hydraulic gradients do not impact the quality of the water from the clarifiers. The combination of un-level weirs and sludge accumulation in the basin corners has led to periodic solids loss in the effluent, which severally degrades plant performance.

6. Disinfection - Design: Short circuiting of finished water through the clearwell results in inadequate contact time for proper disinfection. This problem will be amplified with colder water and higher pHs.

7. Return Process Streams: Return of the backwash water to the pre-sedimentation basin near the low-service pumps' suction negatively impacts raw water quality.

In addition to the above major factors limiting performance, other factors were noted during the evaluation as having a minor effect on performance. Action taken to address these factors may not noticeably improve plant performance, but may improve the efficiency of plant operation:

- The pre-sedimentation basin is not designed to handle high turbidities caused by runoff and ice jams.
- Flash mixing of chemicals appears inadequate
- The ability to sample the sludge return and the sludge concentration within the clarifiers (top to bottom) is inadequate.

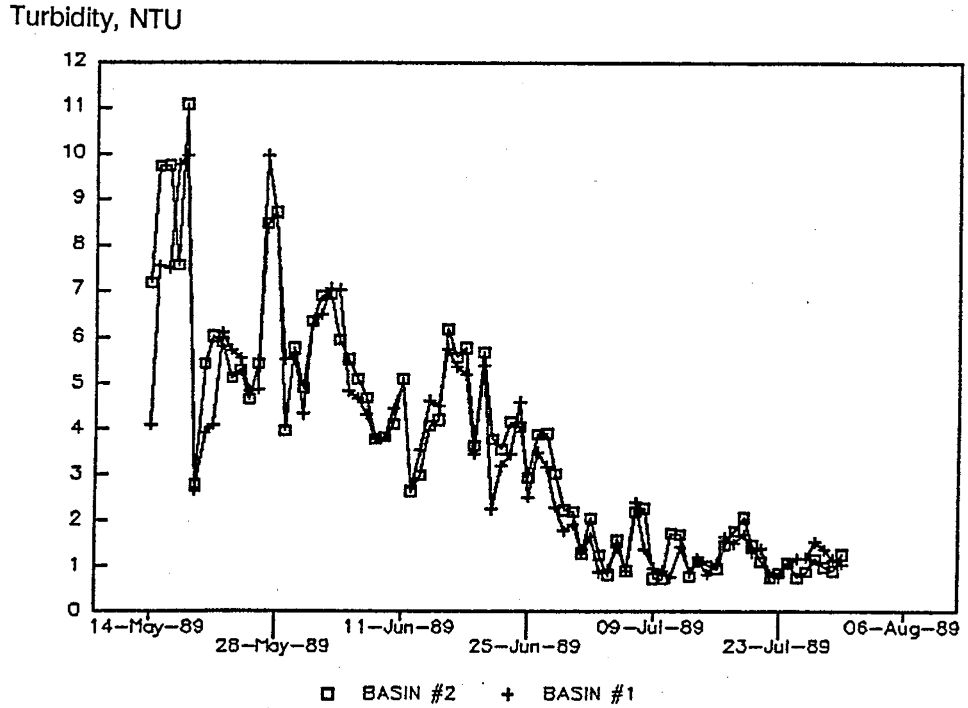
Projected Impact of a CCP

The CPE indicated that operator training through a CCP would be beneficial for improving process stability and finished water.

CCP Results

A CCP was initiated. Monitoring of the two reactor clarifiers during the CPE phase had revealed problems

Figure 4-3. Settled water turbidities from the reactor clarifiers at Plant 1.



with clarifier solids control. Thus, the CCP efforts began by expanding process control in the clarifiers. Each clarifier was taken out of service so that several feet of anaerobic lime sludge that had accumulated in the basins could be removed.

Figure 4-3 shows the finished water turbidity from the two clarifiers from the time the cleaning operation was completed in May until the CCP was concluded in August. The basins' settled water turbidities gradually improved and stabilized at 1 to 2 NTU; both basins exhibited equal performance. Activities that contributed to this consistent performance included controlled flow splitting, equalized chemical doses to each basin, and shutting off of a well that was contributing a disproportionate amount of flow to basin 2. The reactor clarifiers achieved this performance despite variable influent turbidities to the basins from the pre-sedimentation pond, as shown in Figure 4-4.

Most importantly, the improved reactor clarifier performance "carried over" to improve the consistency of turbidity removal by the filters. Figure 4-5 shows the overall plant finished water turbidity, which stabilized at less than 0.2 NTU since the end of June 1989, coinciding with stable performance from the contact clarifiers. The improved performance was achieved despite an increase in treated water volume and a gradual increase in turbidities from the pre-sedimentation basin during the last month of the CCP.

The CCP resulted in dramatic improvement of plant performance without major capital improvements. Process control and monitoring activities, coupled with several major process adjustments, improved and stabilized turbidity removal in the reactor clarifiers.

Figure 4-4. Effluent turbidity from the presedimentation pond for Plant 1.

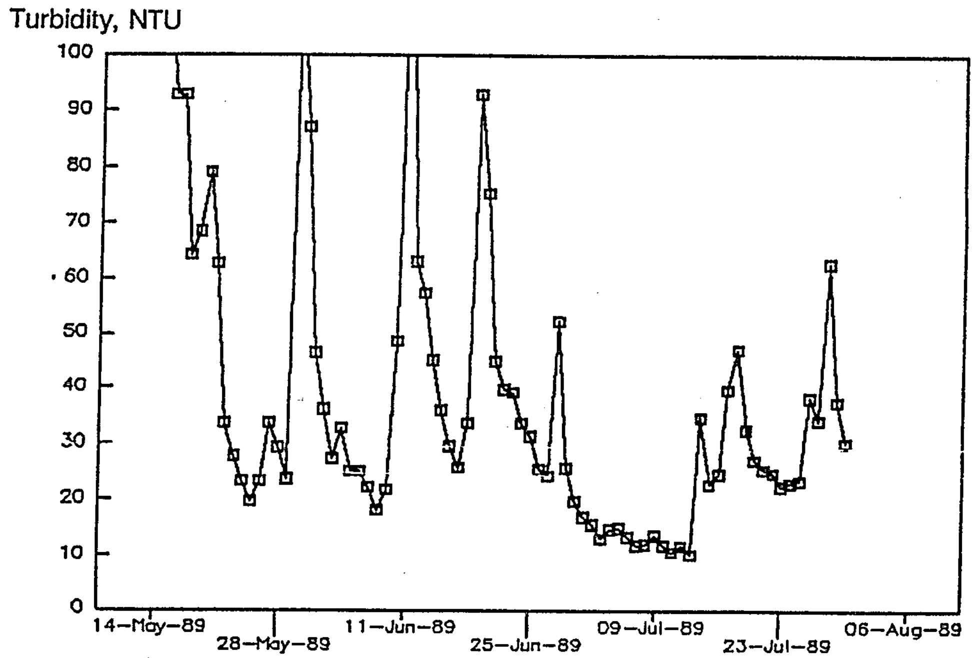
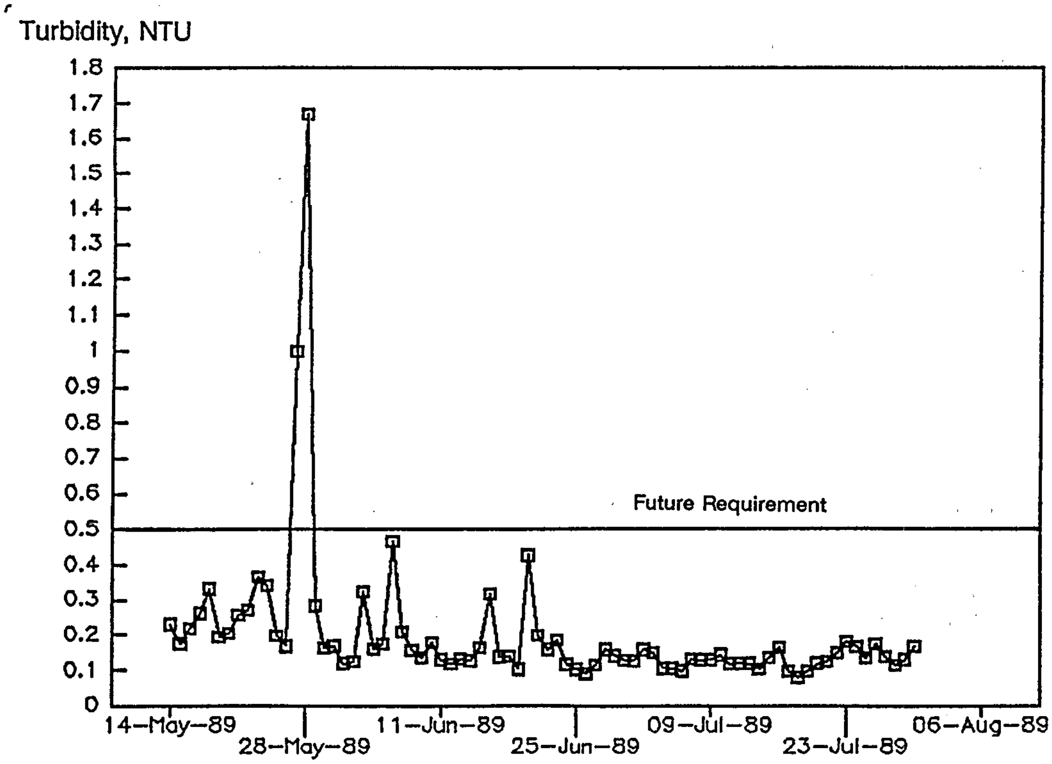


Figure 4-5. Finished water turbidity profile from Plant 1.



Plant 2

Facility Description

Plant 2, constructed in 1931 and expanded and upgraded in 1976, has approximately 1,000 service connections and no significant industrial water users. It consists of a conventional treatment process including flash mix, flocculation, sedimentation, and filtration, and no pre-sedimentation. Source water is provided by the nearby river.

Plant records for a 12-month period show daily water production to be 1.1-6.1 million L (0.3-1.6 mil gal). Flow records are obtained from the plant finished water meter and do not include water used for filter backwash. During the CPE, water was produced over an 8-hr day at an effluent flow rate of about 89 L/s (2 mgd); peak effluent flow was 131 L/s (3 mgd). Plant influent flow is not measured because the raw water meter is inoperable. Plant 2 includes the following unit processes (see Figure 4-6):

- Two vertical turbine raw water pumps rated at 76 and 69 L/s (1,200 and 1,100 gpm), and one 28-L/s (450-gpm) engine driven raw water pump
- Chemical addition of alum, polymer, and lime with in-line mechanical flash mix for the alum
- Two 206,430-L (54,540-gal) parallel flocculation basins with two variable speed turbine mixtures in parallel
- Two 666,160-L (176,000-gal) sedimentation basins with tube settlers over half their surface area
- Three 3.4-m x 4.9-m (11-ft x 16-ft) mixed media filters with Leopold underdrains
- Gas chlorination system
- 204,390-L (50,400-gal) clearwell
- Two centrifugal high-service pumps rated at 72 and 94 L/s (1,150 and 1,500 gpm), and one standby natural gas driven vertical turbine pump rated at 27 L/s (425 gpm)

Water flows by gravity to a wet well through either a shallow culvert near the bank of the river or through a second pipe extending toward the center of the river at an unknown distance and depth. The vertical turbine pumps deliver water to the plant from the wet well. The turbine pump supplies water from the surface intake. A float control in the clearwell initiates the raw water pumps.

Alum is added to the raw water prior to an in-line mechanical rapid mixer; lime and polymer are added downstream of the mixer prior to the flocculation basins. Chemical addition is not flow paced, although the influent flow varies because raw water pumps are initiated and terminated several times a day. After chemical addition, the water flows to two parallel flocculation basins with two parallel- operating variable speed turbine flocculators. Subsequently, water flows to two sedimentation basins equipped with tube settlers. During the evaluation, flow did not appear evenly split between the two flocculation/sedimentation treatment trains, and the clarifier weirs were uneven.

Sludge is manually removed from the sedimentation basins approximately once a year.Following sedimentation, the water flows through a weir to three mixed media filters with Leopold underdrains. Powdered activated carbon is added once a day to the water prior to filtration. Filtration rates are automatically adjusted by filter water level floats that control the filter effluent valves. At the time of the evaluation, one filter was out of service because of an inoperable effluent control valve. Another filter effluent control valve was malfunctioning and was observed to readjust the flow rate by over 69 L/s (1,100 gpm) repeatedly within a few minutes.

The filters are normally backwashed once a day; the process is initiated manually but at automatically timed intervals and includes surface washing. The backwash rate can be set as high as 189 L/s (3,000 gpm).

Filtered water is disinfected with chlorine and is stored in the clearwell. The three high-service pumps deliver the water to the distribution system.

Spent filter backwash water flows by gravity to a sedimentation basin, which overflows to the raw water wet well. Each backwash sedimentation basin has the capacity for one backwash before excessive solids overflow the effluent weirs and return to the raw water wet well. The backwash sedimentation basins are normally cleaned once a year.

Sludge from the flocculation, sedimentation basins, and backwash water sedimentation basins are pumped to two sand drying beds. The dried sludge is disposed of at the landfill.

Major Unit Process Evaluation

The performance potential graph is shown in Figure 4-7. The flows listed across the top of the graph are the maximum at which the plant can operate while remaining in compliance with applicable regulations. Neither the raw water pumps nor the high-service pumps were rated because the condition of the impellers and the actual pump output were not known.

The flash mix was rated at 131 L/s (3 mgd), where it can produce a G value of approximately 3,000 sec^{-1}. The in-line mechanical mixer would probably be limited by water velocity in the pipeline rather than mixing capability.

Figure 4-6. Plant 2 process flow diagram.

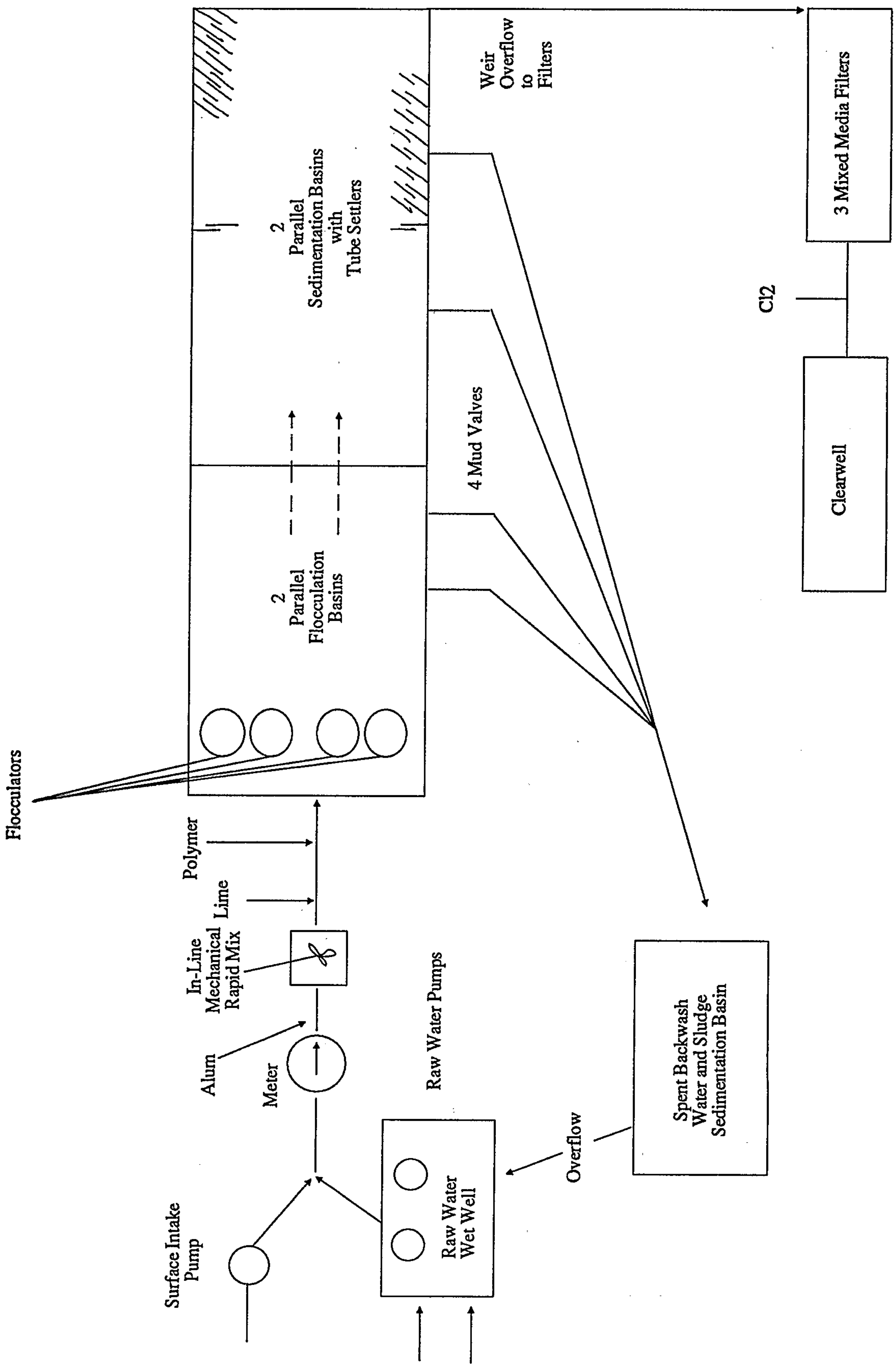
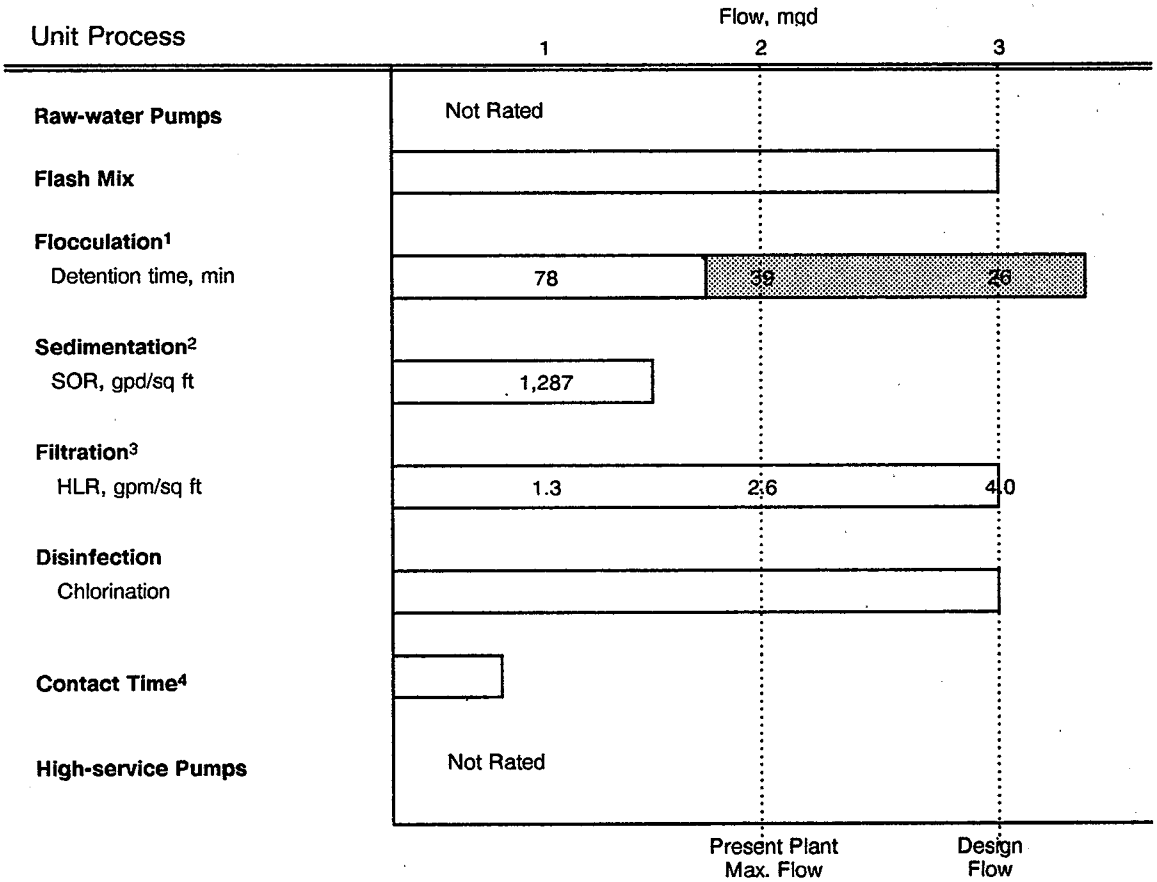


Figure 4-7. Plant 2 performance potential graph.



1 Rated at 45 min because of single stage.
2 Rated at 2,000 gpd/sq ft - may be able to use process control to increase capacity. Also rated on summer water quality, but may be able to direct filter in winter.
3 Rated at 4 gpm/sq ft - media and underdrain integrity.need to be verified to justify this rating.
4 Based on 2-hr detention time

The flocculation basins were rated below the plant design flow at 77 L/s (1.75 mgd) for a detention time of 45 minutes, because the flocculation basins are single-stage units. Altering the basins to provide multiple-stage flocculation would better control floc formation and justify increasing the basin capacity to 153 L/s (3.5 mgd).

The sedimentation basins were rated at 66 L/s (1.5 mgd), which results in a surface overflow rate of 81 $m^3/m^2/d$ (2,000 gpd/sq ft) (based on tube settler area). However, improved flocculation and process control could increase this rating. Direct filtration might be an option during winter months, which would decrease reliance on the sedimentation basins for solids settling.

The mixed media filters were rated at 131 L/s (3 mgd) for a loading rate of 234 $m^3/m^2/d$ (4 gpm/sq ft). With precise process control, the filters could operate successfully at up to 293 $m^3/m^2/d$ (5 gpm/sq ft); however, the media and underdrain integrity must be verified to justify either rate. If further evaluation indicates damage to the filter underdrain or support gravel, the filters would be a major performance-limiting factor.

The disinfection system was rated as two processes: chlorination capacity and contact time. The chlorination capacity rating of 131 L/s (3 mgd) indicates that the capacity of the feed unit is sufficient. The contact time, however, was rated at only 26 L/s (0.6 mgd), the maximum flow through the plant that would provide the recommended 2-hr detention time. The limited detention time provided at normal plant flows compounds the importance of effective performance of the other treatment processes for the removal of pathogens.

In summary, the performance potential graph indicates the plant should be operated at less than 66 L/s (1.5 mgd) during periods of high raw water turbidity. Flow rates above 66 L/s (1.5 mgd) may be possible without adversely affecting finished water quality; however, filter run times will probably be significantly reduced because of excessive solids loading, thereby reducing total plant capacity to 66 L/s (1.5 mgd).

During winter months, if raw water turbidities allow effective direct or in-line direct filtration, plant capacity may be able to increase to between 66 and 131 L/s (1.5 and 3.0 mgd), depending on whether or not flocculation is required for successful operation.

Performance Assessment

A review of the finished water quality monitoring data indicated the plant has been operating in compliance with the current turbidity Maximum Contaminant Level (MCL) of less than 1.0 NTU on a monthly average. The plant has, however, had periodic excursions above 1.0 NTU. The monitoring data also indicate the plant may have difficulty meeting the SWTR turbidity maximum of 0.5 NTU for 95 percent of the time (as measured every 4 hr of water production). Figures 4-8, 4-9, and 4-11 show effluent turbidities obtained through special studies. Figures 4-10 and 4-12 show turbidities from plant data.

Investigation of the filter media in the out-of-service filter bed revealed that the media was clean with no evidence of mudball formation. However, the evaluation team discovered numerous depressions of up to 10 cm (4 in) in the surface of the media, and by probing the filters found that support gravel had migrated and mounded. The operators mentioned that sand, anthracite, and garnet had been removed from the clearwell during cleaning. Measurement of the media pile that had been removed from the clearwell indicated that approximately 0.2 m^3 (7 cu ft) of filter media had passed through the support gravel. The migration of the support gravel, depressions in the surface of the filter bed, and the passing of 0.2 m^3 (7 cu ft) of media through the filter all indicate serious damage to the filter support gravel and media. Typically, this type of damage occurs when air is introduced into the backwash water.

Performance-Limiting Factors

The factors identified as having a major effect on performance on a long-term repetitive basis are summarized below in order of priority.

1. Operator Application of Concepts - Operation: Process control is needed so that operators respond directly to raw water quality changes. At the time of the evaluation, finished water quality was fluctuating drastically with periods of poor finished water production. Figures 4-8 through 4-11 show actual plant data indicating the variability in water quality and the extremely poor water produced, evidenced by the filtered water turbidity of 46 NTU from Filter 3 when Filter 1 was backwashed (figues 4-8 and 4-9). Plant operations staff need to vary coagulant and flocculant dosages and to change plant water flow rates when backwashing filters in response to raw water of variable quality.

2. Process Control Testing - Operation: Testing to monitor the treatment process is inadequate to detect problem areas and indicate necessary adjustments. This lack of testing allows periods of extremely poor water to go undetected and uncorrected as shown in Figure 4-12. At a minimum, additional jar testing and turbidity measurements of the raw water, sedimentation basin effluent, and filter effluent will be required to indicate appropriate plant chemical dosages and flow rate adjustments.

3. Maintenance: Preventive maintenance is lacking at the plant. The plant equipment is maintained on a crisis basis and plant performance is directly compromised. Major treatment components were out of service during the evaluation and have evidently not been repaired for up to several years. Examples of equipment in need of repair or out of service include the raw water meter, filter effluent control valves, raw water pump, and alum feeder flocculator paddles.

4. Staff Number - Administration: The present staffing level does not allow the water plant to be adequately operated or maintained. A minimum of two additional staff members are needed to sufficiently cover the utility needs. With adequate staff, one operator could focus on plant process control and other utility employees could specialize in either water or wastewater treatment.

5. Familiarity with Plant Needs - Administration: Plant administration needs to become more familiar with the requirements of the plant. Better understanding of the plant's requirements would help garner the administrative support necessary to operate and maintain the plant properly.

6. Filtration - Design: A limited evaluation of the filters revealed potentially serious problems in the support gravel. Depending on the outcome of a subsequent detailed evaluation of filter integrity, the filters may be found adequate to 131 L/s (3 mgd). However, if the filters are found deficient, they would probably have to be repaired before the plant could produce consistent high quality finished water on a continuous basis.

Factors identified as having either a minimal effect on a routine basis, or a major effect on a periodic basis are summarized below.

1. Pay - Administration: The extremely low pay scale and lack of employee incentives will make it

Figure 4-8. Filter 3 turbidity profile, June 8, 1988 – Plant 2.

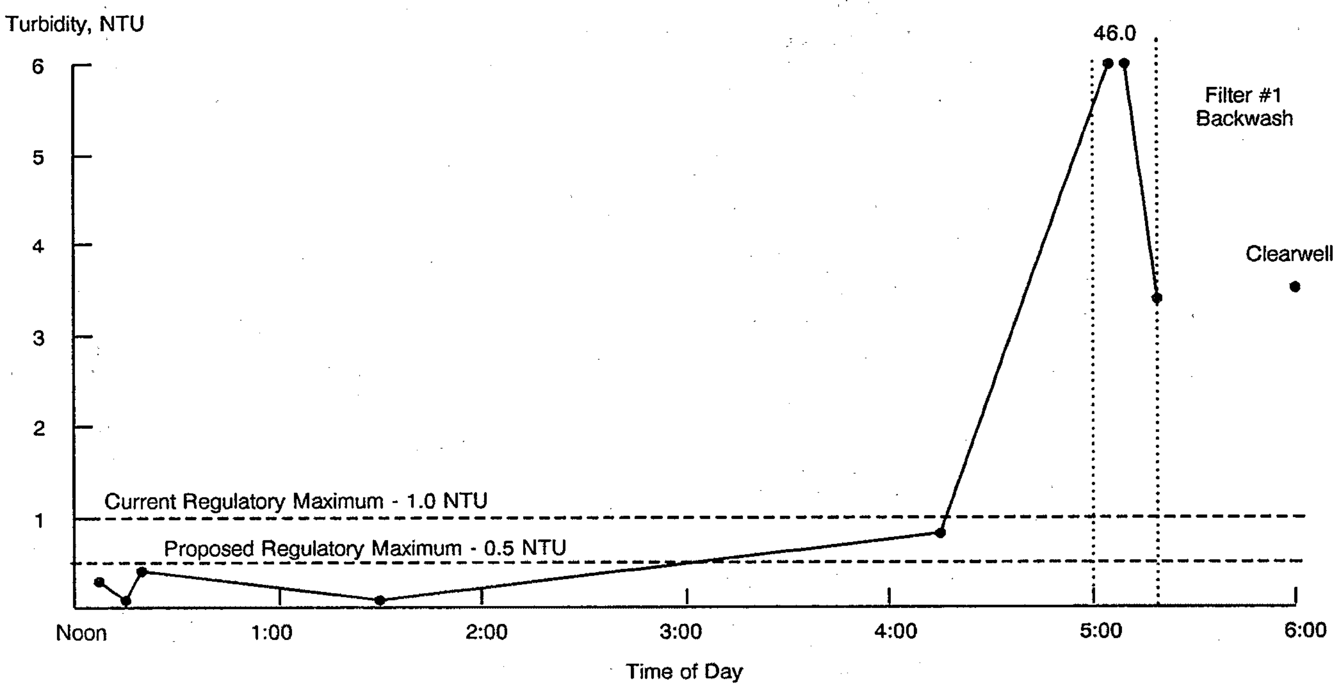


Figure 4-9. Filter 1 turbidity profile, June 8, 1988 – Plant 2.

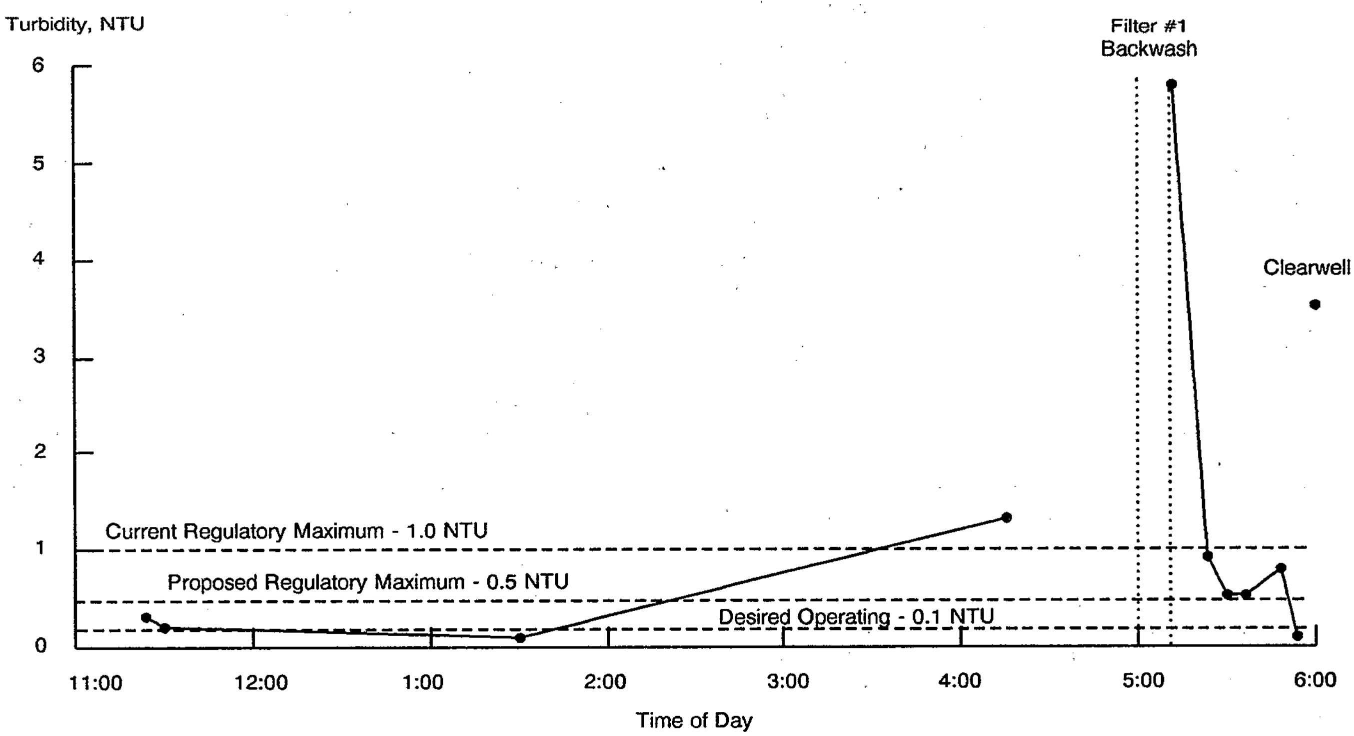


Figure 4-10. Plant 2 performance.

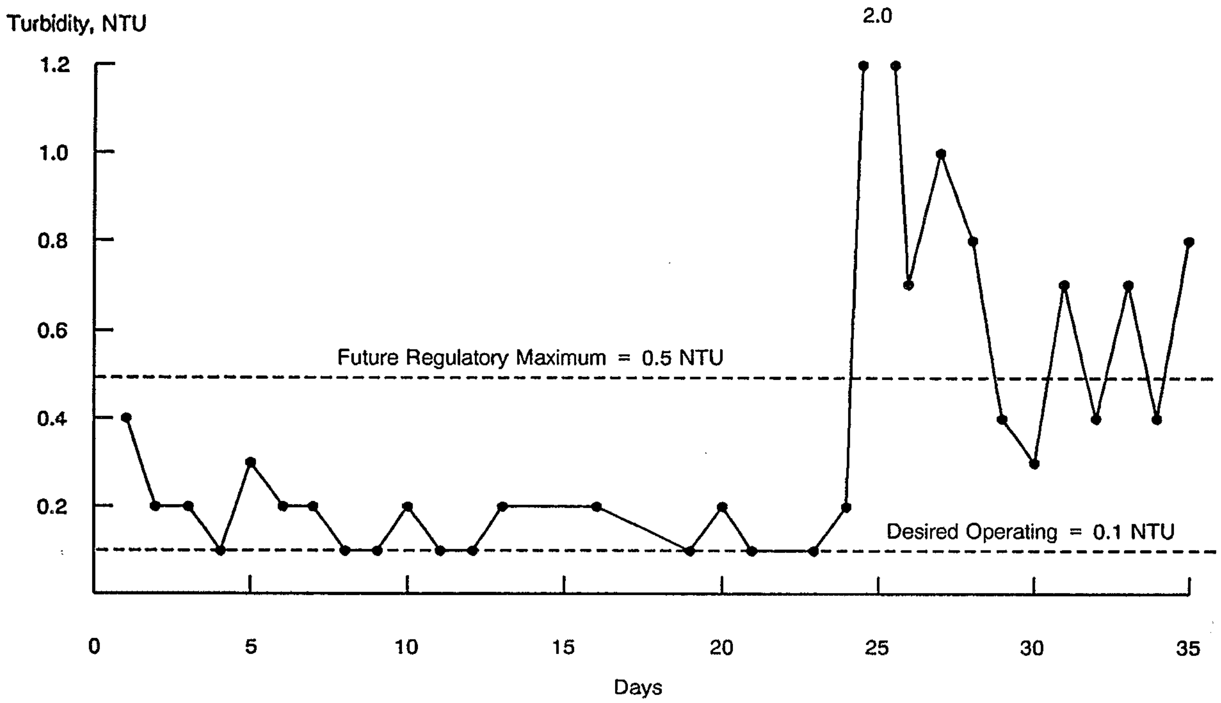


Figure 4-11. Filter effluent turbidities profile, June 8, 1988 – Plant 2.

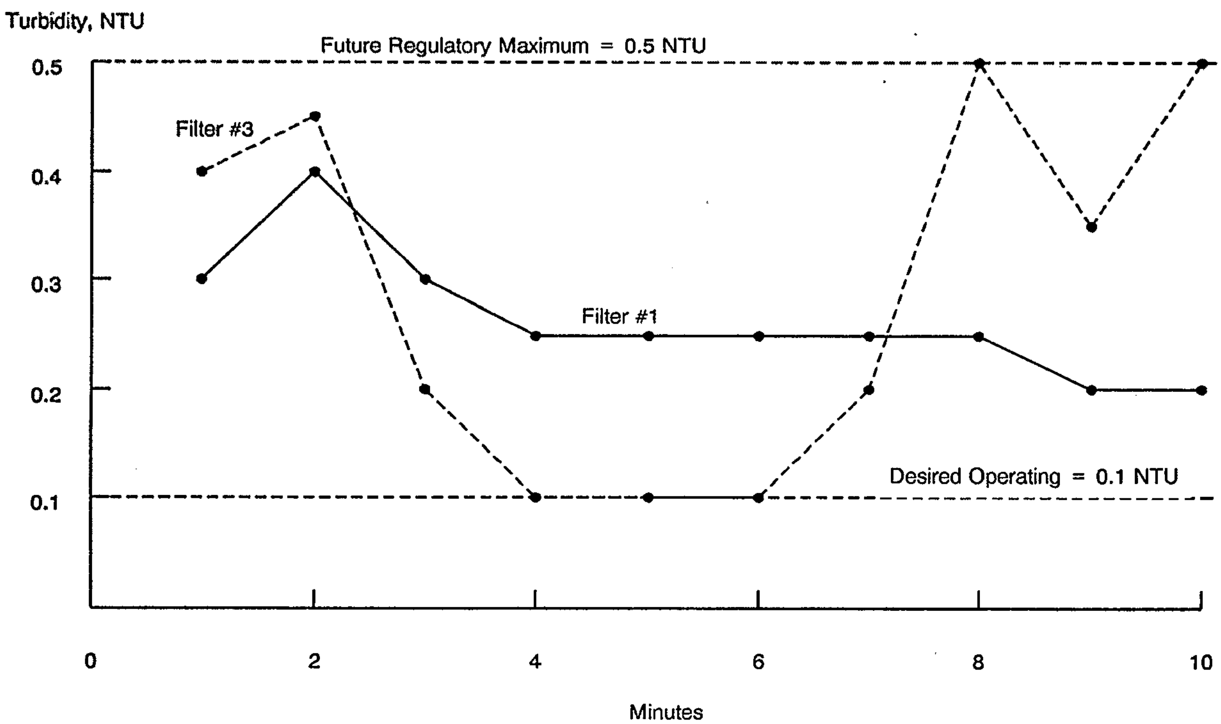
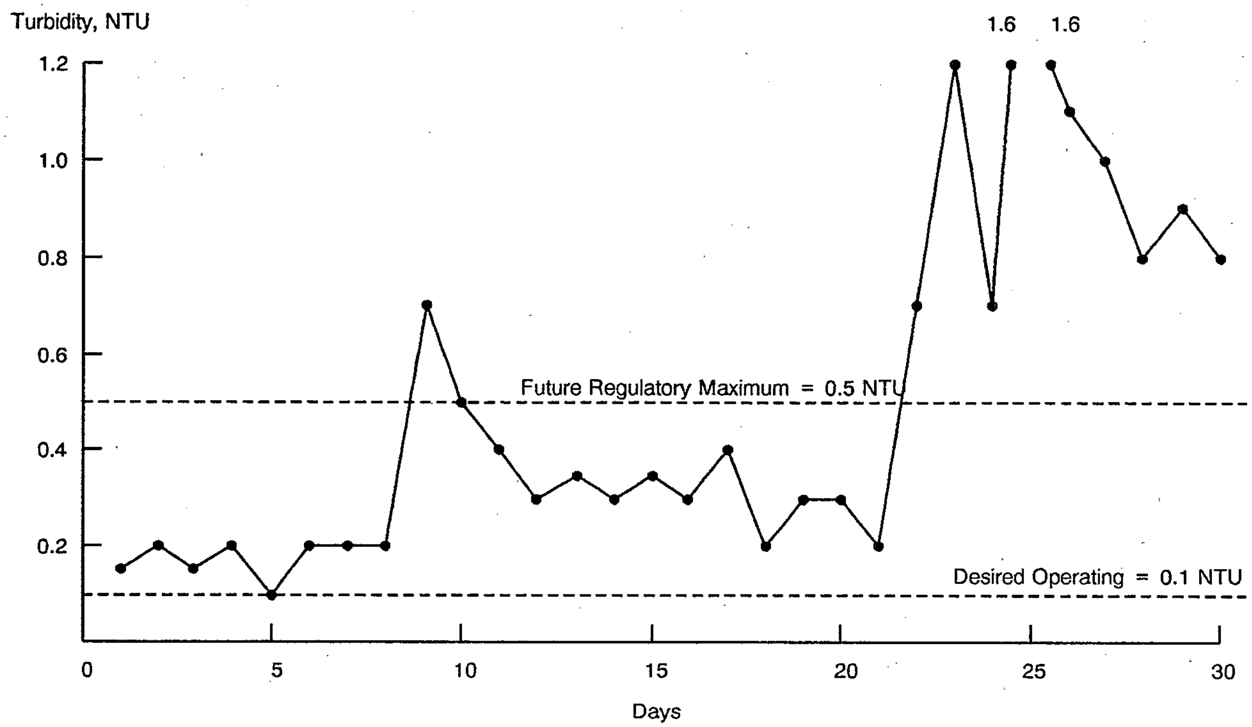


Figure 4-12. Plant 2 performance – May 1988.



difficult to retain present employees and to attract additional qualified help.

2. Turbidity/Pre-sedimentation - Design: Excessive turbidity levels during portions of the year and fluctuations during high demand periods have degraded effluent quality. Pre-sedimentation would minimize turbidity fluctuations and result in a more consistent raw water quality. Continuing operations without a pre-sedimentation basin may require reducing plant flow rates during high turbidity periods.

3. Sedimentation - Design: Surface overflow rates at flows above 66 L/s (1.5 mgd) may not allow adequate settling of the sludge. Poor settling can cause excessive solids loading to the filters and subsequently degrade filter efficiency. Uneven overflow weirs also cause poor distribution of water within the sedimentation basin, further impairing settling. Manual sludge removal twice a year may be inadequate to prevent solids carryover from the sedimentation basins. This practice is also operator intensive.

4. Hydraulic Loading - Design: Fluctuations in plant flows due to cycling of constant-speed, raw water pumps during high demand periods require additional operator attention to maintain finished water quality. An influent flow control valve would allow plant flow rates to be adjusted more gradually and set at various rates.

5. Disinfection - Design: The lack of a standby chlorinator, mixing, proportional feed capability, contact time, and automatic switchover could result in inadequate disinfection on a periodic basis.

6. Process Automation - Design: Effluent turbidimeters with recorders on each filter effluent would be beneficial to monitor water quality. Without such continuous monitoring, an operator would have to take frequent measurements (i.e., hourly) to monitor plant performance.

7. Chemical Feed - Design: The carbon feeder should be returned to service to replace manual addition. The capability to add two polymers would be desirable, with additional flexibility in chemical feed points. A backup alum feeder is also needed.

8. Flocculation Basins - Design: The single-stage flocculation basin makes control of proper floc formation difficult. The retention time is adequate and minor modifications may allow two-stage operation with variable energy input in each stage.

9. Process Controllability - Design: Chemical feeders should be flow paced or manually adjusted to

complement and control raw water quality changes.

10. Standby Units - Design: No standby units are available for critical process components, including backwash pump, alum feeder, and chlorinator.

11. Working Conditions - Administration: Conditions at the water plant discourage staff from spending time at the plant and encourage neglect. Provision of a comfortable climate controlled working area would improve operator morale.

In addition to the above major factors limiting performance, other factors were noted during the evaluation as having a minor effect. Action taken to address these factors may not noticeably improve plant performance, but may improve efficiency in plant operation:

- Preliminary treatment: Grit in the raw water wet well and the lack of screens on the intake piping produce operational problems because of silt and debris accumulation.

- Flow proportioning to units: Raw water flow to the sedimentation basins was not evenly proportioned. Operators can control the distribution of flow to the units by frequently adjusting valves located in the sedimentation basin influent piping.

Projected Impact of a CCP

Results of the CPE indicate performance to be severely limited by a number of administrative, design, maintenance, and operations factors. Every major unit process was identified as a performance-limiting factor. The evaluation team reached a consensus that significant improvements in water quality could likely be achieved with a CCP, but that major capital expenditures may also be required for the plant to meet the proposed finished water quality criteria.

Many of the unit process limitations described in the performance potential graph could be eliminated if the plant were to be operated at a lower capacity than the present summer water demand, which appears excessive. Water conservation measures and lowered water demands together with a CCP were recommended.

Plant 3

Facility Description

Plant 3 is owned and operated by the city. Constructed in 1950 and expanded and upgraded in 1975 and 1976, it currently serves approximately 5,000 people with no significant industrial water users. The plant uses a conventional treatment process consisting of flash mix, flocculation, sedimentation, and filtration.

Plant records for a 12-month period indicate that the average amount of water treated daily was 41 L/s (0.94 mgd), with a minimum of 22 L/s (0.5 mgd) and a maximum of 114 L/s (2.6 mgd). These daily flows were pumped through the plant in less than 24 hr and therefore do not indicate the operational capacity of the plant. It is typically operated at three standard rates - 69, 101, or 202 L/s (1,100, 1,600, or 3,200 gpm) - for less than 24 hr. Plant 3 includes the following unit processes (see Figure 4-13):

- Three vertical turbine raw water pumps: two 25-hp, 110-L/s (1,750-gpm) and one 15-hp, 63-L/s (1,000-gpm)
- Chemical addition (alum and polymer) with an in-line mixer
- 302,800-L (80,000-gal) flocculation basin with a variable speed vertical mixing unit
- Two sedimentation basins (each 4.1 m x 18.3 m, 3.7-m deep [13.5 ft x 60 ft, 12-ft deep])
- Three mixed media rapid sand filters with Leopold underdrains
- Gas chlorination system
- 246,000-L (65,000-gal) clearwell
- Four vertical turbine finished-water pumps: two 200-hp, 94-L/s (1,500-gpm), one 100-hp, 38-L/s (600-gpm), and one 50-hp, 22-L/s (350 gpm)

Raw water flows by gravity through three 46-cm (18-in) diameter perforated pipes located beneath the source creek into a raw water wet well. The three raw water pumps deliver water from the wet well to the flocculation basin.

Alum and polymer are added to the flow prior to the flash mix. The plant's in-line mechanical flash mixer was not in use at the time of the site visit because of maintenance problems; therefore, the only chemical mixing was caused by turbulence in the line at nearby elbows.

After chemical addition, the water flows into the single-stage flocculation basin with a variable speed vertical mixing unit that supplies up to a G value of 70 sec^{-1}. Following flocculation, the water flows by gravity into two parallel sedimentation basins equipped with tube settlers. During the evaluation, the flow was not evenly split between the two sedimentation basins.

Following sedimentation, the water flows to three mixed media filters with Leopold underdrains. The filters appeared to be in good condition, but some chemical residue had accumulated on the anthracite. These filters are typically washed at about 189 L/s (3,800 gpm), which corresponds to 972 $m^3/m^2/d$ (16.6 gpm/sq ft). Washing typically occurs at the end of the day so that the filters start clean the following morning.

The filtered water is disinfected with chlorine, then flows into the clearwell, where the four high-service pumps are available.

Sludge from the sedimentation basins and backwash water from the filters are directed to two earthen sludge settling ponds. At the time of the evaluation, the plant was discharging overflow from the ponds to the creek without a National Pollutant Discharge Elimination System (NPDES) permit.

Major Unit Process Evaluation

The performance potential graph is shown in Figure 4-14. As Figure 4-14 shows, the potential capacities of the raw water pumps, high-service pumps, and filters were rated at the 219-L/s (5-mgd) plant design flow. The flocculation basin, sedimentation basins, and the disinfection system were rated at less than plant design flow. The single-stage flocculation basin was derated because control of floc formation is more difficult with a single-stage than with a multiple-stage flocculation system. The sedimentation basins are limited by a high surface overflow rate, which can allow solids to be carried over to the filters. The disinfection system was not considered adequate at flow rates above 166 L/s (3.8 mgd), because the clearwell and transmission lines provide inadequate detention times at these rates.

The sludge settling ponds were not rated but were determined inadequate at current flows, unless the plant obtains an NPDES permit to allow discharge to the creek. Without operational changes such as more frequent cleaning of the ponds, the effluent quality in the ponds may not meet typical permit requirements (i.e., 30 mg/L total suspended solids and 1.0 mg/L total dissolved aluminum).

Figure 4-14 indicates that the plant should be operated at less than 101 L/s (2.3 mgd), if possible. Short periods of increased flow may be possible without adversely affecting finished water quality; however, filter run times will probably be reduced because of excessive solids loading. The plant may be operated more hours at the 101 L/s (1,600 gpm)

Figure 4-13. Process flow diagram of Plant 3.

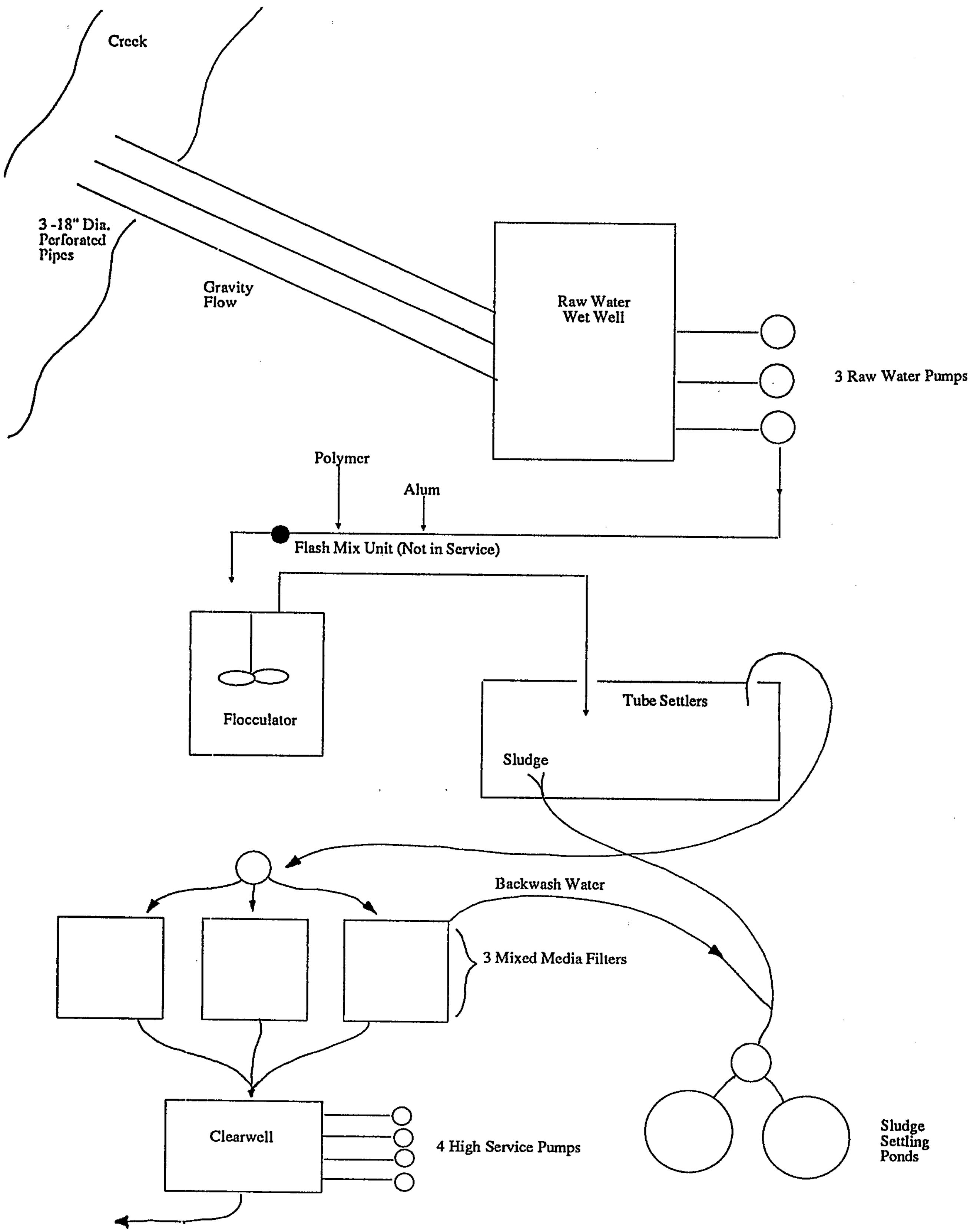
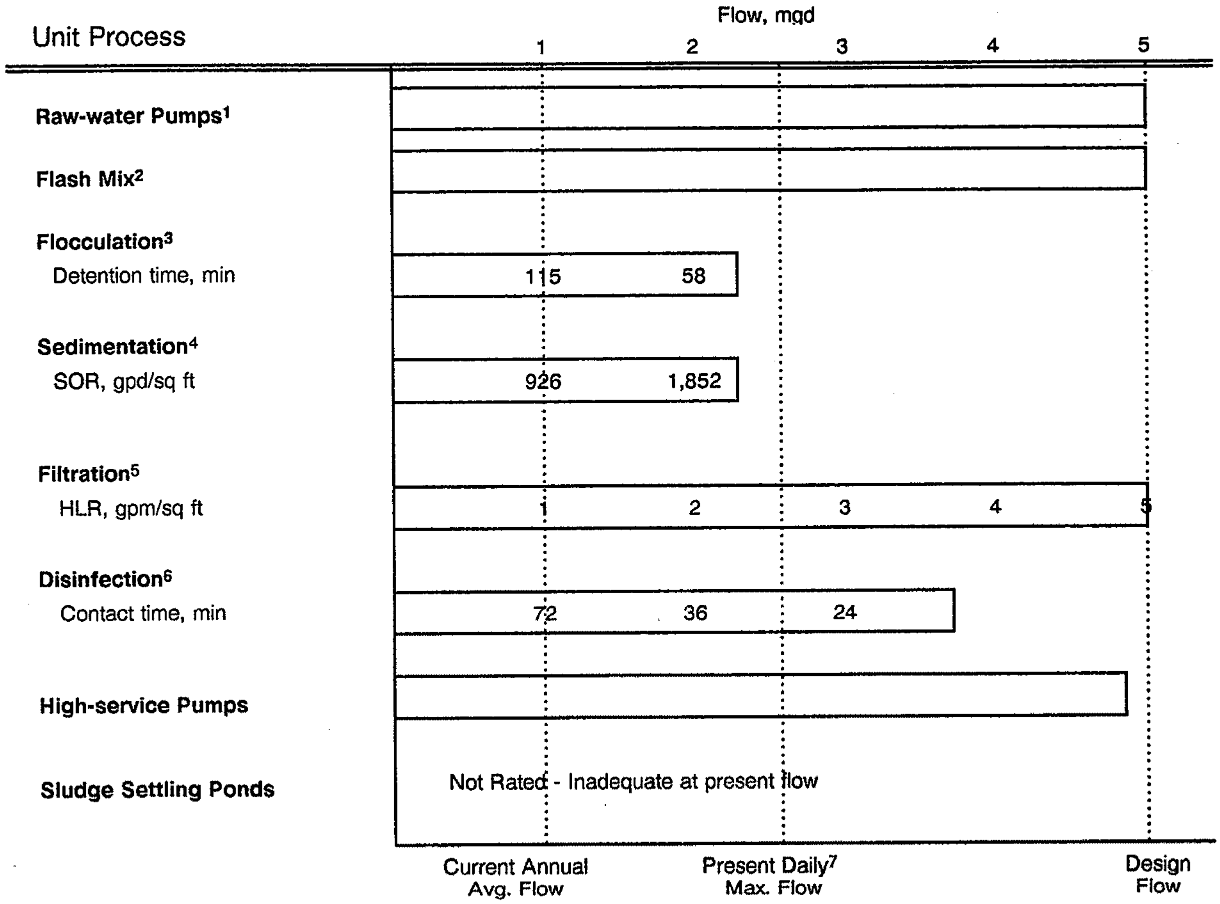


Figure 4-14. Plant 3 performance potential graph.



[1] Peak flow that plant can treat at worst water quality.
[2] Out of service.
[3] Based on detention time of 45 min and single stage.
[4] Based on 2,000 gpd/sq ft.
[5] Based on 5 gpm/sq ft.
[6] Based on allowing 2 min of contact time in clwarwell and 18 min of contact time in 2,500 ft Of 18-in transmissin line.
[7] Not based on 24 hr/day, so actual flows are higher

rate to overcome the limitation of the flocculation/sedimentation basins. Also, when raw water turbidities are low the plant may be operated in a direct filtration mode, which eliminates the need for sedimentation.

Performance Assessment

The city is currently required to produce finished water with turbidity levels less than 1.0 NTU on a monthly average and with free chlorine at levels that will ensure a chlorine residual in excess of 0.2 mg/L at all points in the distribution system. A review of monitoring data indicated that the plant was operating in compliance with the applicable regulations.

In the SWTR, the minimum requirements for finished water turbidity are much more stringent. Plants need to produce finished water with a turbidity less than 0.5 NTU more than 95 percent of the time, as measured by regular daily monitoring or constant recording turbidimeters. Additionally, the plant needs to demonstrate theoretical 3-log removal and/or inactivation of Giardia cysts and 4-log removal and/or inactivation of enteric viruses. In order to meet these regulations, surface water treatment plants need to optimize process controls to minimize or eliminate "spikes" of turbidity in the finished water at critical times, such as immediately after backwash.

Performance-Limiting Factors

The following factor was identified as having a major effect on performance on a long-term repetitive basis.

1. Sludge Treatment - Unit Design Adequacy: The sludge holding ponds are currently discharging to the creek, but the plant has no permit to allow this

discharge. A letter from the Permits Section of the Water Quality Bureau states that the plant must apply for a permit, which will require certain effluent limitations. Permit limitations may require major modifications to the plant. Failure to obtain a permit and to meet permit limitations could result in sizeable fines being levied against the town.

Factors identified as having either a minimal effect on a routine basis, or a major effect on a periodic basis were prioritized and are summarized below.

1. Sedimentation - Unit Design Adequacy: The surface overflow rate and weirs limit the performance of the sedimentation basin. If the plant were operated at a rate in excess of 101 L/s (2.3 mgd), the resulting high surface overflow rate would not allow for adequate settling. Excessive solids would be carried over to the filters, thereby degrading filtration performance.

2. Flocculation - Unit Design Adequacy: The single-stage flocculation basin makes control of proper floc formation difficult. Controlling plant flows at rates below 101 L/s (1,600 gpm) may allow additional detention time to compensate for the lack of a multiple-stage unit.

3. Lack of Standby Units - Unit Design Adequacy: There are no standby units for adding chlorine or alum. Failure of either of these chemical feeders would result in unacceptable finished water quality, which may require the plant to shut down. In addition, there is no spare backwash pump, although, in an emergency, the distribution system could provide limited backwash.

4. Application of Concepts and Testing to Process Control - Operation: The plant performance could be improved during periods of variable raw water quality by application of a thorough process control program. For example, more frequent jar testing would provide data on which to base chemical feed points. By monitoring turbidity from the sedimentation basins several times each day, chemical doses could be adjusted to optimize sedimentation basin performance.

   It would also be good practice to monitor the turbidity of water from each of the filters. At the present time, a daily turbidity value is being recorded for water from the clearwell. This measurement may mask higher turbidities coming out of the filters. Significant breakthrough may be occurring that would not be detected by the present monitoring practice. With continuous monitoring and recording of the turbidity of each filter effluent, the increase in turbidity following backwash could be observed along with the length of time the elevated turbidity occurs. This would indicate whether or not chemical addition has been optimized.

   The use of the flash mix unit, especially during the times of the year when direct filtration can be utilized, would probably reduce chemical usage. Also, additional experimentation with polymer products could result in the selection of more effective coagulant/flocculent aids.

5. Policies - Administration: Administrative policy limits the frequency with which the raw water intake can be backwashed. As a result, the intake pipes can accumulate a significant amount of silt before backwashing, thus reducing the plant's intake capability. More frequent backwashing would eliminate these periodic limitations in raw water supply.

6. Chemical Feed Facilities - Unit Design Adequacy: Inability to feed a filter aid and/or flocculant aid could result in poor plant performance during periods of variable raw water quality.

7. Alternate Power - Unit Design Adequacy: There is no standby power capability at the plant. Therefore, water would not be supplied to the distribution system during a power outage.

8. Hydraulic - Unit Design Adequacy: Low stream flows and upstream water use have resulted in periods when no raw water is available to be pumped into the plant. Studies are presently underway to incorporate in-stream or off- stream storage to alleviate this problem.

In addition to the major factors limiting performance discussed above, other minor performance-limiting factors were noted during the evaluation. Action taken to address these factors may not noticeably improve plant performance, but may improve efficiency in plant operation:

- The lack of adequate disinfection could be a problem when operating the plant above 166 L/s (3.8 mgd) because of the potential for short circuiting of the clearwell and the limited detention time provided in the transmission mains.

- The lack of automatic continuous turbidity monitoring and recording on the raw and finished water from each filter requires the operations staff to obtain this information manually on a periodic basis. Not only does this require an additional time commitment from the operators, but periodic information is not as effective as a continuous record.

- The pay of the chief operator/superintendent is approximately the same as the shift operators.

This pay differential does not recognize the chief operator's additional responsibility.

- It is very difficult to sample the sludge discharge lines from the sedimentation basins.

- Additional process control testing should be done to provide more of a basis for process control decisions. Examples of further testing would include more frequent analysis of raw water turbidity and alkalinity, along with measurements of turbidities of the water leaving each sedimentation basin and filter.

Projected Impact of a CCP

Results of the CPE indicated that plant performance, based on daily measurements of turbidity from the clearwell and a filter turbidity profile conducted during the evaluation, was in compliance with applicable drinking water regulations. The plant monitoring data also showed very consistent plant performance for the 12-month period evaluated. As a result, a CCP was not recommended at Plant 3.

Plant 4

Facility Description

Plant 4 is owned and operated by the county water and sewer district. It was constructed in 1970 and serves approximately 81 connections, including the school. It is a packaged, conventional plant and its processes include pre-sedimentation, flocculation, sedimentation, and filtration.

A stream fed largely by return flows from the local irrigation district, supplies the plant. Historically, the creek flowed only intermittently, but the importation of irrigation water with subsequent water losses to creek drainage have significantly increased stream flows. These artificially increased stream flows, coupled with naturally erosive soils, have caused a severe sedimentation and turbidity problem in the creek.

Plant flow records indicate an average daily water production of 0.4 L/s (10,000 gpd) in the winter and 2.6 L/s (60,000 gpd) in the summer. Flow records, obtained from the plant effluent meter, do not include water used for filter backwash.

The CPE did not determine the accuracy of the effluent flow meter, but the inconsistency of readings taken over the day indicated a problem exists. The influent flow rate is measured by a rectangular weir located just prior to the flocculation basin.

At the time of the site visit, the influent flow rate was 3.8 L/s (60 gpm). The plant operates at this rate for various hours per day depending on demand. Plant 4 (see Figure 4-15) includes the following unit processes:

- Manually-operated, 2-hp centrifugal raw water pump
- 22.7 million-L (6 mil gal) earthen pre-sedimentation basin
- 1.5-hp, 3.8-L/s (60-gpm) turbine-type settled water pump
- Chemical addition of alum and polymer without flash mixing; both alum and polymer are mixed in batches in 189-L and 114-L (50-gal and 30-gal) tanks, respectively
- 1.2-m x 1.2-m (3.8-ft x 4-ft), 2,290-L (605-gal) flocculation chamber with a constant-speed, vertical paddle wheel
- 0.9-m x 1.6-m (3-ft x 5.4-ft), 2,290-L (605-gal) sedimentation chamber with 6-degree tube settlers
- 0.9-m x 1.2-m (3.1-ft x 4.1-ft) mixed media filter with perforated pipe underdrain system
- 1.5-hp, 3.8-L/s (60-gpm)filtered water pump (to clearwell)
- 5-hp, 14-L/s (220-gpm) centrifugal backwash pump
- Chlorination system consisting of a calcium hypochlorinator; solutions are made as needed in 189-L (50-gal) batches
- 45,420-L (12,000-gal) clearwell
- Two high-service centrifugal pumps: one 7.5-hp, 5-L/s (80-gpm), and one 3-hp, capacity unknown, backup

Raw water is pumped through a 10-cm (4-in) line from the creek to the pre- sedimentation basin. The 1.5-hp turbine pump delivers water from the pre-sedimentation basin through a 5-cm (2-in) line to the plant. This pump is started automatically by a float control in the clearwell and the flow rate is regulated by a float-controlled valve in the chemical mix chamber.

Alum and polymer are added in line to the raw water prior to the chemical mix chamber. The manufacturer originally designed this basin for the addition of calcite to stabilize the raw water. Some mixing, but no flash mixing, is provided both in the line and through the chamber. After chemical addition, the water flows over a rectangular weir and into a single-stage flocculation basin with a detention time of 10 minutes at both design and operating flows. The flocculator is a constant-speed (12 rpm), vertical paddle wheel type.

Following flocculation, the water flows into the settling chamber equipped with 6-degree horizontal tube settlers. Settled water flows over a weir onto a mixed media filter equipped with a perforated pipe underdrain. The filter operates on a constant rate/variable head basis; a float-controlled effluent valve regulates flow rate. Design filtration rate is 293 $m^3/m^2/d$ (5 gpm/sq ft); the operating filtration rate was determined to be 281 $m^3/m^2/d$ (4.8 gpm/sq ft). Water is pumped out of the filter to the clearwell.

Backwash is initiated manually or automatically by headloss across the filter; the filter is not equipped with a surface wash. The backwash flow rate of 13.9 L/s (220 gpm) corresponds to a wash rate of 978 $m^3/m^2/d$ (16.7 gpm/sq ft). Filter backwash water flows by gravity to an earthen storage pond located northwest of the plant, adjacent to the stream. Sludge from the tube settlers is removed with the backwash cycle.

Filtered water is disinfected with a calcium hypochlorite solution within the clearwell and pumped approximately 2.6 km (1.6 mi) to the town reservoir

Figure 4-15. Plant 4 process flow diagram.

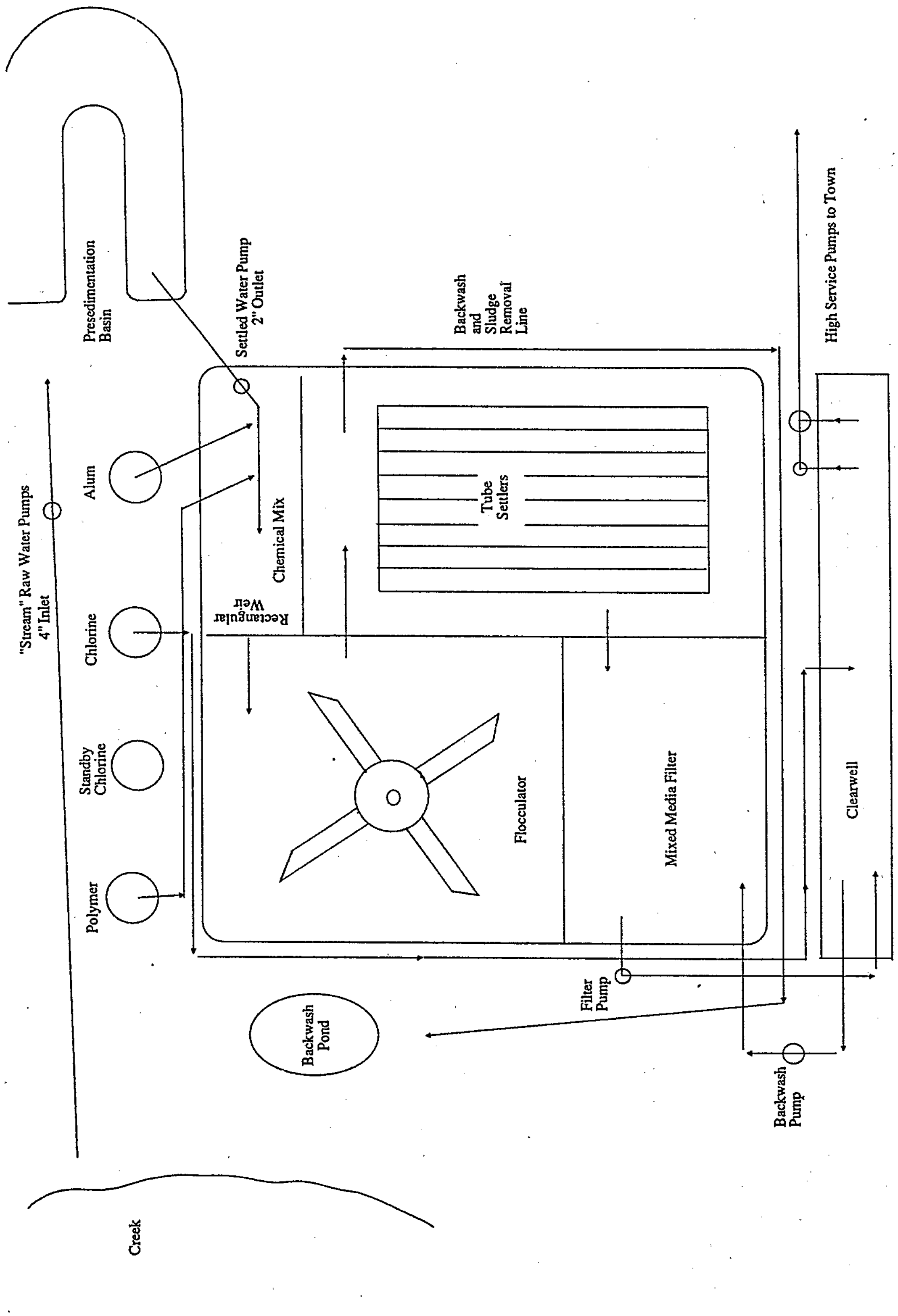
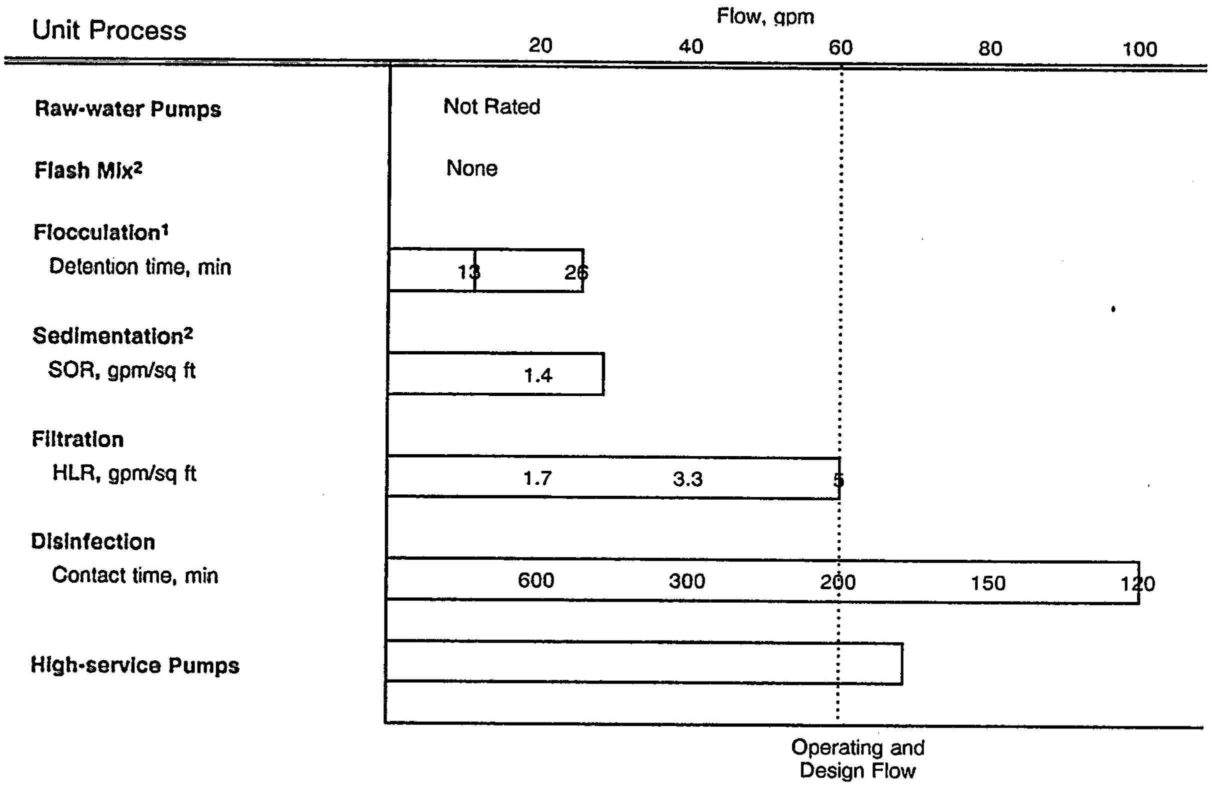


Figure 4-16. Plant 4 performance potential graph.



[1] 45-min HDT for sweep floc; 22.5-min HDT for direct filtration.
[2] Based on SOR = 2 gpm/sq ft.

(capacity of 50,000 gal [189,250 L) through a 10-cm (4-in) line.

Major Unit Process Evaluation

The performance potential graph is shown in Figure 4-16. The slashed vertical line on the graph represents both the design and operating flow rate of 3.8 L/s (60 gpm).

As seen in Figure 4-16, the raw water pumps were not rated because actual pump output was not known. The high-service pumps were rated at 4.4 L/s (70 gpm), slightly above the design flow. The flocculation basin was rated at 0.8 L/s (13 gpm) when operated in the sweep mode of coagulation and at 1.6 L/s (26 gpm) when operated in the direct filtration mode. The rated flow was doubled for direct filtration because shorter flocculation times are acceptable in this operational mode. The flocculation basin was derated because it is a single-stage unit and only provides 10 minutes of detention time at a 3.8 L/s (60 gpm) flow rate. Single-stage flocculation and short detention times make formation of an adequate floc more difficult.

The sedimentation basin was rated at 1.8 L/s (28 gpm) or 117 $m^3/m^2/d$ (2.0 gpm/sq ft) surface overflow rate (SOR) based on the capability of the tube settler to produce a clear water with the existing raw water conditions. The design surface overflow rate of 251 $m^3/m^2/d$ (4.28 gpm/sq ft) is too high given the raw water conditions and has resulted in excessive carryover of solids to the filter.

The mixed media filter was rated at the design flow of 3.8 L/s (60 gpm), which corresponds to a loading rate of 293 $m^3/m^2/d$ (5 gpm/sq ft). The backwash rate was also rated at design, for up to 1,171 $m^3/m^2/d$ (20 gpm/sq ft). The condition of the media must be restored (mudballs eliminated) and the support gravel and underdrain integrity must be verified to justify this rating. The backwash cycle must be extended and surface wash facilities should be added or the filter will again become a major limiting factor at this plant.

Disinfection contact time was rated at 2.0 hr at flows of up to 6.2 L/s (98 gpm). This rating was justified because of the long transmission line to town and the 189,250-L (50,000-gal) storage reservoir.

The performance potential graph indicates that the plant capacity is limited by the flocculation and sedimentation unit processes. To achieve acceptable finished water quality, the plant capacity may have to be limited to about 1.9 L/s (30 gpm) and operated for longer periods of time to produce the daily amount required.

Performance Assessment

A review of the finished water quality monitoring data submitted to the State indicate that the plant is operating at the current MCL for turbidity, 1.0 NTU, on a monthly average. However, much of this data was collected from the storage reservoir located in town, 2.6 km (1.6 mi) from the plant. Sampling at this point violates the regulations and intent of the law. Unreported records of turbidity data taken directly from the filter reveal that numerous excursions above the 1.0 NTU occurred on a regular basis for several months. These data indicate the plant will have difficulty meeting the SWTR turbidity MCL of 0.5 NTU for 95 percent of the time. Figures 4-17, 4-18 and 4-20 depict turbidity data from plant records, while Figurs 4-19 shows turbidity data generated from special CPE studies.

Inspection of the filter revealed a heavy layer of chemical floc on the media surface and numerous mudballs within the anthracite. The depths of media were found to be adequate; however, probing of the media indicated the support gravel varied by as much as a couple of inches in some areas of the filter. In the past 18 years of operation, the filter media has "solidified" to a concrete-like state twice, the last time about 5 years ago.

Media removal necessitated the use of a jackhammer. Recently, the clearwell and in-town reservoir were both cleaned for the first time. Four 189-L (50-gal) barrels of media and sediment were removed from the clearwell and a considerable amount of sediment was removed from the finished water storage reservoir in town.

Inspection of the automatic backwash cycle indicated that the backwash time was inadequate to clean the filter media. This, coupled with the lack of a surface wash, has allowed the filter to accumulate mudballs. The inadequate backwash not only results in costly replacement of the media, but also makes production of an acceptable finished water quality impossible.

Performance-Limiting Factors

The factors identified as having a major effect on performance on a long-term repetitive basis are summarized below in order of priority:

1. Water Treatment Understanding - Operation: The operator is newly hired and, while enthusiastic and willing to learn, has had no training or background in the science of water treatment.

2. Process Control Testing - Operation: Testing to monitor the effectiveness of the treatment process is inadequate. The available data clearly substantiates turbidity MCL violations. (See Figures 4-17 through 4-20.) During certain times, unacceptable water is supplied to the public, exposing users to an unacceptable risk of contracting waterborne diseases. At a minimum, turbidities should be monitored in the plant influent, sedimentation basin effluent, and filter effluent several times each day. Jar testing should be done daily or at least when raw water conditions change, to fine-tune chemical dosages. Continuous-recording, in-line turbidimeters would be very beneficial in providing information for optimizing process control.

3. Plant Coverage - Administration: The operator makes one brief visit to the plant each day, which is not adequate to perform proper process control testing, experimentation, and adjustments. Addition of continuous-recording turbidimeters and appropriate alarms could reduce the time spent at the plant, but a minimum of 2 hr each day will still be required for process control testing.

4. Flocculation - Design: The plant design only allows for single-stage flocculation and the detention time is too short to allow optimum floc formation before water flows to the sedimentation chamber. The effect of flocculation may be reduced if the plant could be run in the direct filtration mode. However, the plant flow rate may need to be reduced to overcome flocculation deficiency.

Factors identified as having either a minimal effect on a routine basis or a major effect on a periodic basis were prioritized and are summarized below.

1. Laboratory Space and Equipment - Design: The operator has no equipment other than a turbidimeter to perform the necessary tests to determine raw and finished water quality. The accuracy of the meter cannot even be verified, because of a lack of equipment. There is no jar testing or other equipment and supplies for process control testing.

2. Operator Pay - Administration: The operator pay is too low to compensate the operator for the number of hours necessary to run the plant properly. This pay does not offer an incentive for keeping qualified operational personnel or for providing adequate plant coverage.

3. Alarm Systems - Design: Because of a lack of an alarm system, particularly on the finished water turbidity, unacceptable water has been pumped into the distribution system on many occasions. Without alarm systems and with minimal plant

Figure 4-17. Plant 4 turbidity profile.

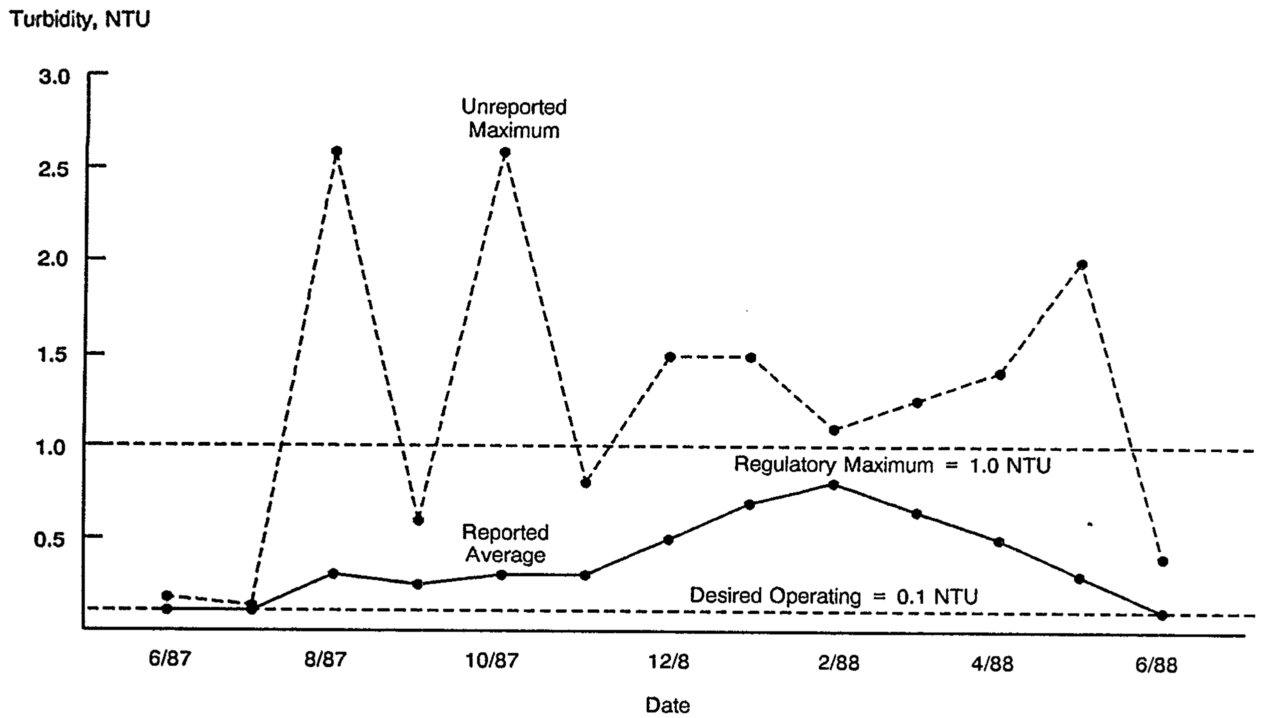


Figure 4-18. Plant 4 turbidity profile, August 1987.

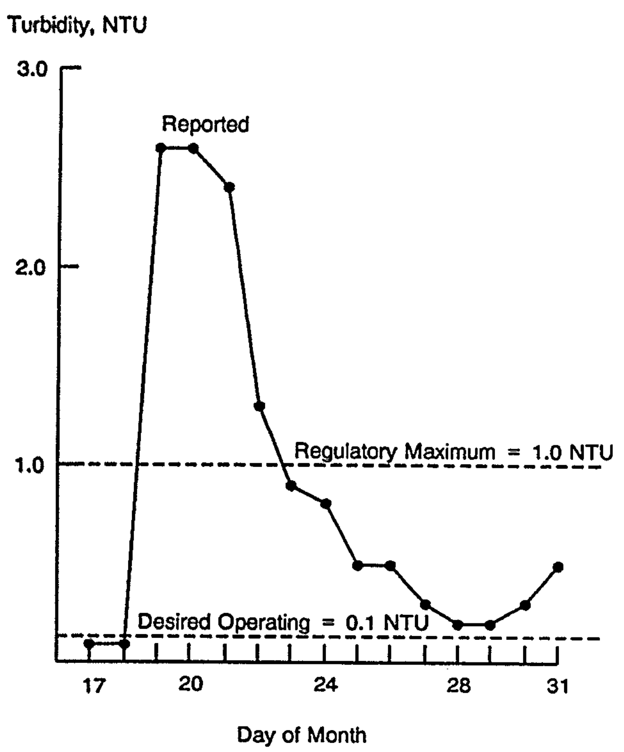


Figure 4-19. Plant 4 turbidity profile before and immediately following backwash.

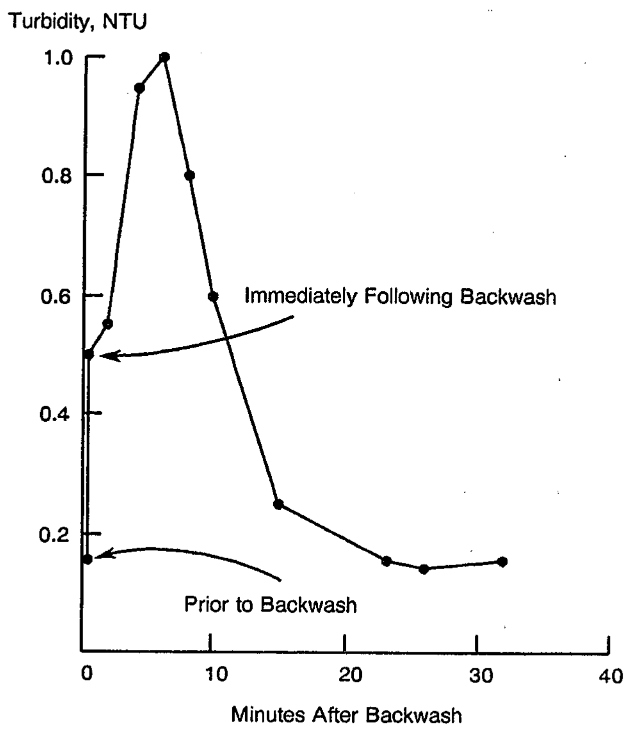
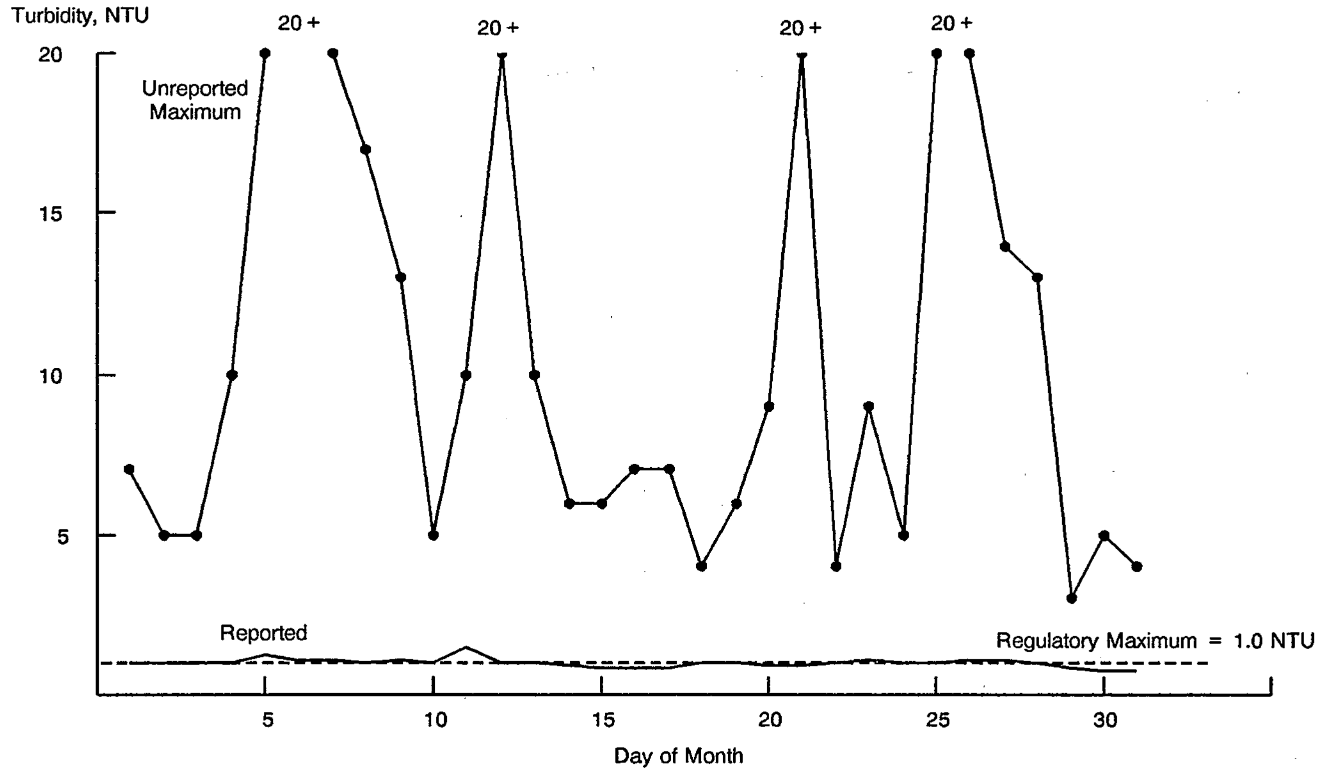


Figure 4-20. Plant 4 turbidity profile , January, 1988.



coverage, the operator is not aware of the water quality being supplied to the town.

4. Staff Number - Administration: The district needs to have a backup operator, so that the plant manager can leave town for business or personal reasons without leaving the plant unmanned.

5. Flash Mix - Design: Lack of a flash mix unit will limit coagulation effectiveness and increase the chemical requirement, particularly if the plant is run in the direct filtration mode.

6. Sedimentation - Design: The surface loading rate within the sedimentation chamber is too high to allow floc to settle prior to flowing to the filter. Better settling would improve or lengthen filter runs. Operation in the direct filtration mode would eliminate the sedimentation basin as a potential problem since the floc that is produced is filterable, but not settleable.

In addition to the above major factors limiting performance, other factors identified as having a minor effect were noted during the evaluation. Action taken to address these factors may not noticeably improve plant performance, but may improve the efficiency of plant operation:

- Lack of a preventive maintenance program may result in excessive equipment downtime, which could be significant since there are no backup systems.
- Lack of filter surface wash may be contributing to the inefficient washing of the filter.
- Lack of standby units for key equipment could cause periods of plant downtime.

Projected Impact of a CCP

Results of the CPE indicated performance was limited by a number of factors in operation, administration, and design. The evaluation team judged that a CCP could help the plant make significant improvements in finished water quality. However, design limitations may require the plant to operate at a reduced rate to produce an acceptable finished water quality. In addition, since many of the limiting factors are in the areas of administration and design, some minor capital improvements must be made and greater administrative support to the plant (i.e., higher operator salary) must be provided to significantly improve plant performance.

Plant 5

Facility Description

Plant 5 is a direct filtration plant that was installed in 1978 to replace an older pressure filter. At the time of the CPE, the system had a total of 1,122 connections. Water for the plant is supplied from the southeast end of a multiple use lake located about 29 km (18 mi) to the northwest.

The plant's water treatment processes include coagulant chemical feed (alum and polymer), flocculation in a reaction basin, optional pre-chlorination and non- ionic polymer filter aid feed, filtration through four dual media filters, post-chlorination, and gravity flow from the plant to storage and distribution. The plant was designed for a flow rate of 131 L/s (3 mgd). Plant flow records for a 12-month period indicated an average daily flow of 26 L/s (0.6 mgd). Average monthly flows during the same period were 12-50 L/s (0.28 and 1.16 mgd). Plant 5 (see Figure 4-21) includes the following unit processes:

- Two 100-hp, 125-L/s (1,980-gpm), vertical turbine raw water pumps
- 36-cm (14-in) propeller influent flow meter at the plant
- Chemical addition of alum and cationic polymer without flash mixing
- Three-compartment "reaction" basin that allows mixing and detention time for flocculation, 6.1 m (20 ft) in diameter, with a water depth of 2.3 m (7.6 ft)
- Four dual media filters, each 3.5 m (11.5 ft) square and 2.4 m (7.75 ft) deep, with heater/lateral-type underdrains
- Two 60-hp, 167-L/s (2,650-gpm) vertical turbine backwash pumps
- 10-hp, 7-L/s (112-gpm) vertical turbine surface wash pump
- Two 378,500-L (100,000-gal) hypalon-lined backwash water storage basins
- Two submersible backwash water recycle pumps
- Gas chlorination system
- Two 3.8 million-L (1 mil-gal) steel ground level reservoirs

Water is pumped to the plant through a pair of 30-cm (12-in) transmission mains. One pump is used at a time and the pumps automatically alternate each time one of them stops. The pumping rate through the plant was measured at approximately 136 L/s (3.1 mgd), at the time of the visit. This is the "normal" plant flow rate and remains constant.

The influent flow meter was found to measure almost 13 percent less flow than was calculated to be entering the clearwell. Meters typically measure less flow with age, so the meter may need to be recalibrated.

A valve controls the flow to the plant during startup of the raw water pumps. An orifice plate is located downstream of the valve to regulate pressure for optimum operation.

Alum and a cationic coagulant polymer are added to the influent after the orifice plate. Typical feed rates were 5-10 mg/L for alum and 0.1 mg/L for the cationic polymer. No flash mixing is provided; however, moving the chemical feed points to the orifice plate would probably result in a hydraulic flash mix. At low alum feed rates in a direct filtration plant, some type of flash mixer must be provided.

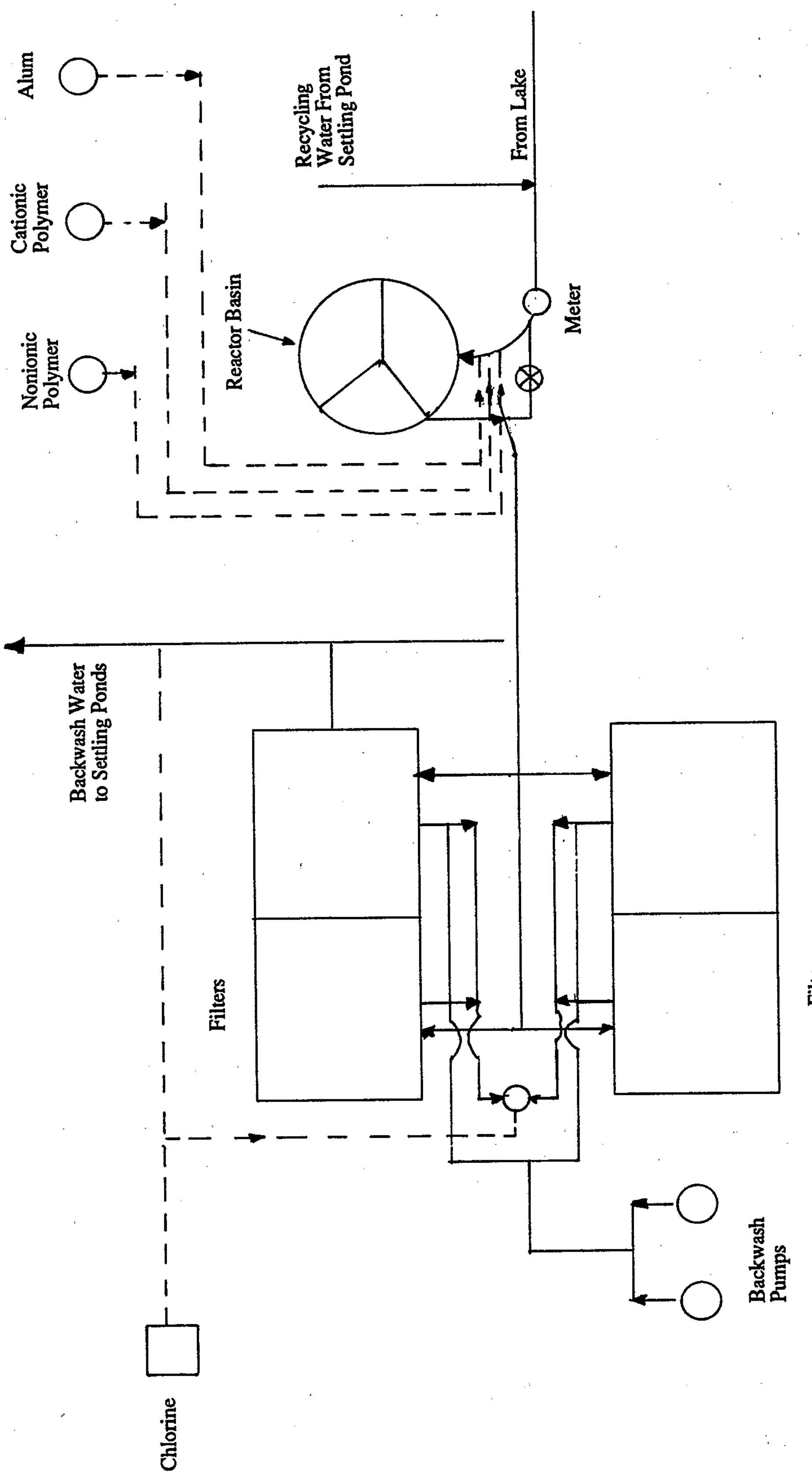
The three compartment reaction basin allows some flocculation to occur before filtration. Flow of the water through the baffled compartments provides hydraulic "agitation" of the water to promote floc formation. No outside energy is input to the water. The reaction basis has apparently been designed to decrease turbulence as flow proceeds through the compartments. Approximately 8 minutes of detention time are provided in the reaction basin at the normal flow rate.

Chlorine and a non-ionic polymer can be added just ahead of the filters, but chlorine normally is added only after filtration. The non-ionic polymer, Serapan, is added ahead of the filters during some periods of the year, for example, in winter when turbidities are low.

Water then enters an open influent channel where it is distributed to the dual media filters. Flow through the filters is regulated by effluent valves. As the headloss across the filter builds up, the effluent valve gradually opens to counteract this increase. Since the influent flow to each filter cannot be equally split, the flow rate through each filter is unknown. 61 cm (24 in) of 0.90-mm effective size anthracite and 15 cm (6 in) of 0.45- to 0.55-mm effective size silica sand lie above the 53 cm (21 in) of layered support gravel. A header/lateral piping underdrain system is located at the bottoms of the aluminum filter boxes. The filtration rate under normal plant flow conditions is 234 $m^3/m^2/d$ (4 gpm/sq ft).

One interesting feature of the filters is the design of the discharge header. The header profile rises in elevation just before the water is discharged into the clearwell. This discharge pipe then terminates just

Figure 4-21. Plant 5 process flow diagram.



above the floor of the clearwell, creating a negative head in the discharge header from the filters. The intensity of the negative head depends on the amount of headloss across the filters, the plant flow rate, and the depth of water in the clearwell. A plug can be removed from the top of the tee fitting, thus eliminating the negative head condition. It is not known what effect this negative head condition has on the filter operation, but its effects should be evaluated.

Backwash is initiated by adjustable headloss controls. The two 60-hp pumps each provide 167 L/s (2,650 gpm) of backwash water from the clearwell at 21 m (70 ft) of head. A rotating arm surface wash system helps break up sediment at the surface of the filters during backwash. The 10-hp surface washwater pump can provide 7 L/s (112 gpm) at 79 m (260 ft) of head.

The spent plant backwash water is stored in the two hypalon-lined basins adjacent to the plant. After settling overnight, the decant water is recycled back into the plant by two submersible pumps. The valve described previously holds the flow rate through the plant constant during recycle of the backwash water.

The production of the backwash pumps was restricted by a butterfly valve to about 118 L/s (1,870 gpm) each to prevent excessive media loss and disruption during backwash. This represents a backwash rate of only about 820 $m^3/m^2/d$ (14 gpm/sq ft); the backwash pumps are capable of pumping as much as 167 L/s (2,650 gpm), or 1,171 $m^3/m^2/d$ (20 gpm/sq ft). Dual media filters are typically backwashed at 878-1,171 $m^3/m^2/d$ (15-20 gpm/sq ft).

Major Unit Process Evaluation

The performance potential graph is shown in Figure 4-22. The raw water pumps appear to be capable of pumping at the plant design capacity of 131 L/s (3 mgd). During the plant evaluation, the plant flow rate was measured by drawing down the clearwell and measuring the average rate at which it filled with time. This rate was measured at 136 L/s (3.1 mgd)).

The reaction basin was not a typical design and, therefore, was rated in terms of detention time provided. A detention time in flocculation basins of at least 20 minutes normally is desirable to permit adequate floc formation in cold water conditions. (The reaction rates of the coagulants are slowed considerably in cold water.) To provide a 20-minute detention time, the plant flow rate would have to be decreased to 57 L/s (1.3 mgd). Achievement of this rate would require the raw water pumps to be restricted in their output during the winter months.

During warm water conditions, the flow rate theoretically can be increased because reaction rates of the coagulant chemicals are higher. The typical minimum flocculation time for warm water, which appears in the design standards, is 10 minutes. To provide 10 minutes, the plant flow rate would have to be reduced to 114 L/s (2.6 mgd). Further evaluation would be required to determine the actual detention times necessary for successful flocculation.

The filters are the weakest major process. The most significant factor affecting filter performance is air binding. Air binding (accumulations of air within the filters) has been a problem since the plant was constructed. It is believed that the air coming into the plant from the lake is very high in dissolved gases. As water flows into the plant from the transmission pipe, the pressure on the water is relieved, allowing the dissolved gases to escape. The air accumulations are so serious that the filters have to be allowed to "rest" for several minutes prior to backwashing to allow the gases to escape, so that they will not disrupt the support gravel and filter media during backwash. Based upon the uneven surface of the top of the media in one filter, it is possible that accumulations have disrupted the support gravel in the past. If disruption of the support gravel has occurred, it would need to be removed from the filter(s) and replaced. Further investigation is needed to evaluate this potential problem before taking such drastic action.

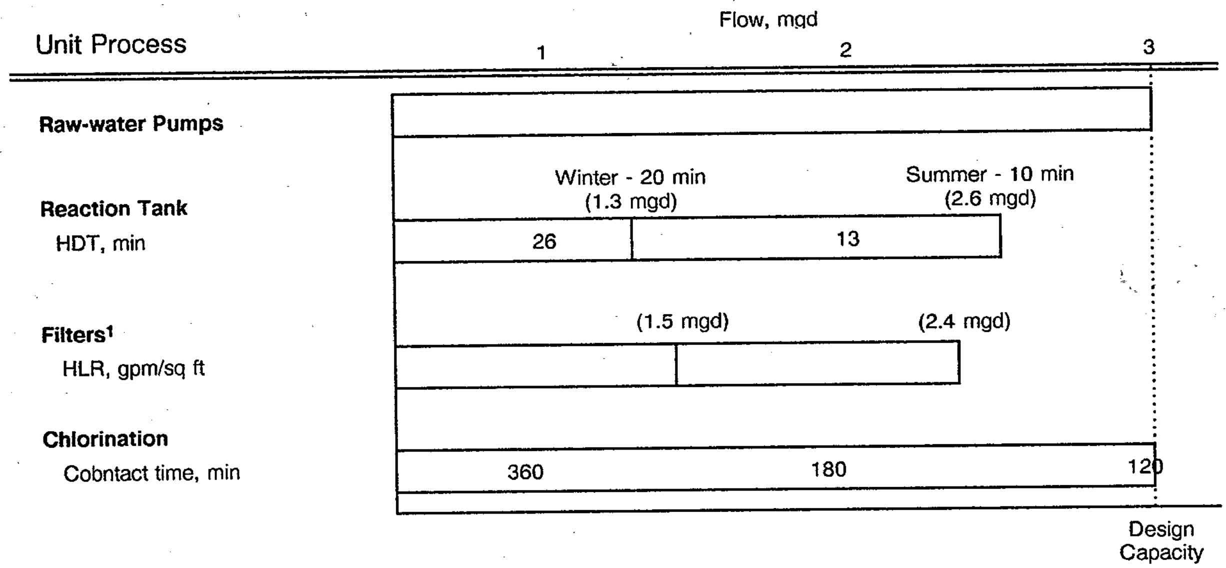
During air binding, the effective filtration rate through the filters is increased because the water must flow around the air bubbles. The net area of the filters is therefore reduced, resulting in an increase in effective filtration rate. The only way to reduce the filtration rate is to either eliminate the air binding problem, or to reduce the plant flow rate. The plant is now operating at, or slightly above, the design filtration rate of 234 $m^3/m^2/d$ (4 gpm/sq ft) or 136 L/s (3.09 mgd). Because about 20 percent of the finished water must be used for backwash water, the effective filtration rate is reduced to 187 $m^3/m^2/d$ (3.2 gpm/sq ft) or 107 L/s (2.44 mgd). After observing the amount of air released from the filters, the evaluation team estimated that the effective filtration rate of the filters may have to be reduced to about 117 $m^3/m^2/d$ (2 gpm/sq ft) or 67 L/s (1.52 mgd).

The automatic filter backwash cycles (headloss initiated) did not appear to be long enough to properly clean the filters. The water was still dirty as the backwash cycle ended. Improper cleaning of the filters can lead to poor treatment and short filter runs.

Performance Assessment

Finished water quality data from the past year indicated that the plant was operating within the 1.0-NTU standard for finished water turbidity, although incoming turbidities are extremely variable. Winter turbidities are often less than 5 NTU, and usually less than 10 NTU, while spring and summer turbidities can vary widely, even within a given day. Prevailing westerly winds often stir up sediment in the relatively shallow lake, resulting in raw water turbidities of 50-280 NTU. Monthly average turbidities are reported

Figure 4-22. Plant 5 performance potential graph.



[1] Flow reduced to 2.44 mgd to account for 20 percent of the production being used for backwash water. The flow may have to be reduced even further (to approximately 1.5 mgd) because of air binding.

typically at 0.5 NTU or less, but turbidities of 0.5-0.6 NTU range were reported for a few months.

Finished water quality data is taken from the plant potable water system, which pumps water from the clearwell. Readings are typically taken at about 9 a.m. after the plant has been shut down overnight. Figure 4-23 shows, under current operating conditions, the number of days each month that Plant 5 would be in violation of the SWTR effluent turbidity standard, which will require that finished water turbidity be 0.5 NTU or less at least 95 percent of the time.

Inspection of Filter 2 after dewatering did not detect the presence of any mudballs; there was, however, deep penetration of the floc into the anthracite. This in itself is not necessarily indicative of a problem, but a variation of about 5 cm (2 in) in the elevation of the top of the anthracite media indicates a potentially serious problem with the condition of the support gravel.

The presence of filter sand and anthracite in the clearwell also indicates a potential problem. This material was cleaned out of the clearwell previously but has since accumulated. If the support gravel were in proper condition, the filter sand and anthracite layers would not break through to the underdrains. Readings taken after backwash of Filter 2 during the site visit indicated that the filter effluent turbidity exceeded 1.0 NTU. This is of concern both for the present standard of 1.0 NTU and the proposed 0.5-NTU standard. These data are presented in a graph in Figure 4-24.

Over the past several years, the State has completed microscopic particulate examinations (MPEs) of the finished water to determine the effectiveness of the filtration process. These have shown that the finished water contains a large amount of particles (algae, insect eggs, etc.), which indicates that, at times, the filters are not operating well.

Performance-Limiting Factors

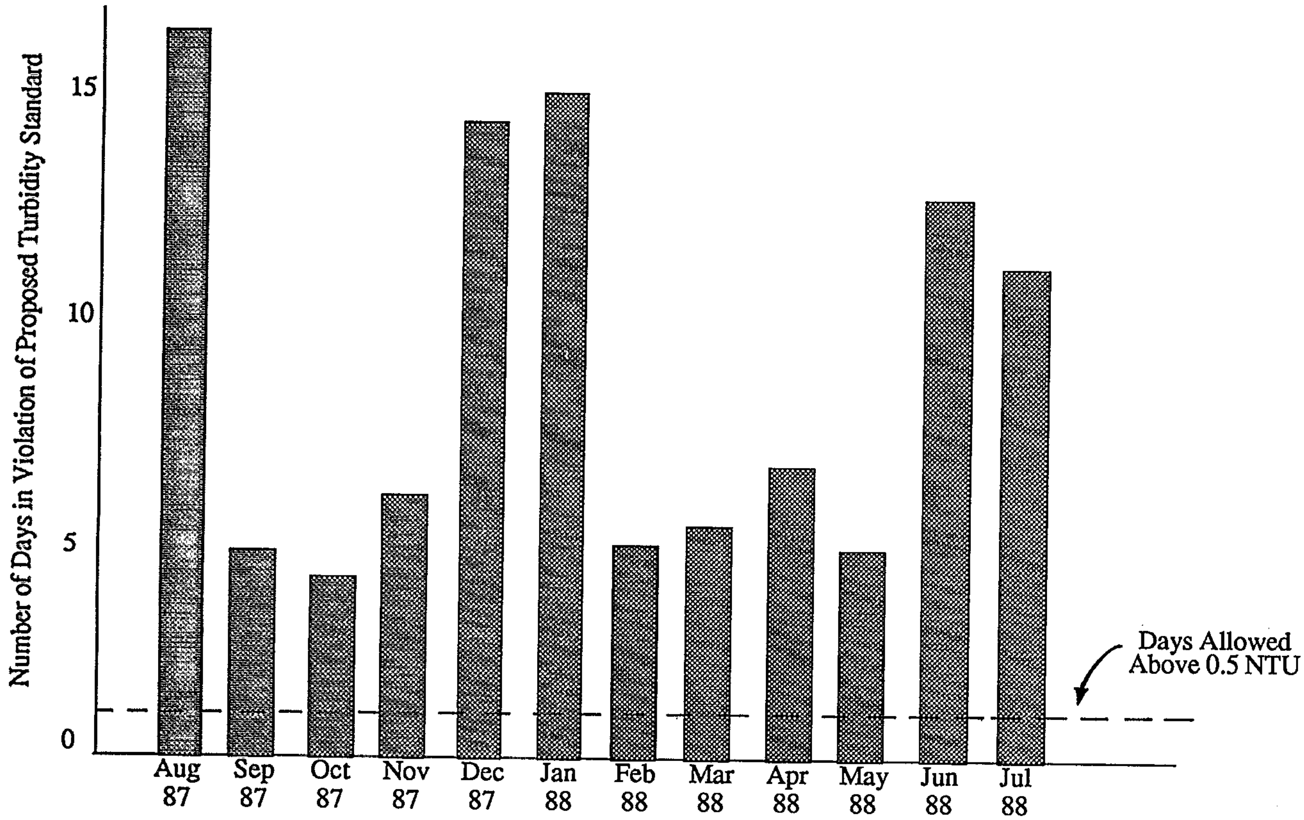
The factors identified as having a major effect on performance on a long-term repetitive basis are summarized below in order of priority:

1. Operator Application of Concepts - Operation: Varying raw water quality requires changes in chemical feed rates and plant flow rates to maintain acceptable finished water quality. The plant had no organized process control program to provide information to base operational decisions upon. Although the operators had a good understanding of water treatment, they were not applying that knowledge fully.

2. Process Control Testing - Operation: Proper operation of a direct filtration plant requires regular process control testing so that chemical doses can be optimized. Jar testing, followed by filtration through Whatman #40 paper filters, is a reasonable simulation of the direct filtration process. This regular testing was not being done at the plant.

3. Filtration - Design: Turbidity measurements taken at the time of the evaluation and MPE testing

Figure 4-23. Plant 5 potential for SWTR compliance.



done by the State demonstrate that the filters do have a performance problem. The presence of filter media in the clearwell indicates that the support gravel may have been damaged in the past. If the support gravel is in fact damaged, replacement to the media will be necessary. Filter capacity and finished water quality is being affected by severe air binding. Periods of high turbidity also require frequent backwashing, which further reduces plant capacity. If the support gravel is in good condition, then the filters could be rated as a lower priority factor and the filtration rate decreased because of the air binding problem and backwash water requirements.

Factors identified as having either a minimal effect on a routine basis, or a major effect on a periodic basis were prioritized and are summarized below.

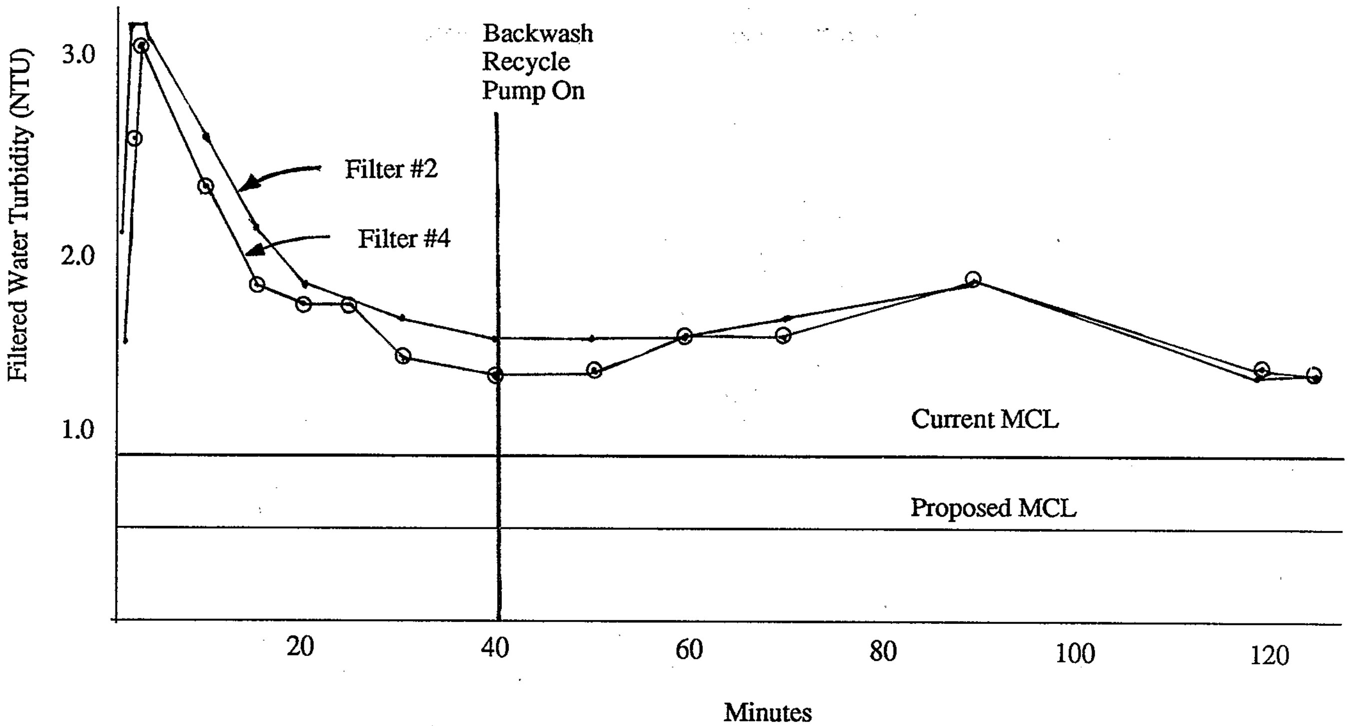
1. <u>Turbidity</u> - Design: The turbidity of the raw water often exceeds that normally recommended for the direct filtration treatment mode. During periods of high turbidity, it may be necessary to reduce plant flow rates to produce an acceptable finished water. Nearly constant backwashing may also be necessary because of the solids load to the filter, which will reduce the effective plant capacity.

2. <u>Plant Coverage</u> - Administration: The plant is not attended on weekends and the operators are often away from the plant during weekdays performing other duties. As a result, periods of poor finished water quality could go undetected.

3. <u>Lack of Standby Units</u> - Design: There are no standby alum and polymer feed units. Failure of one of the units would severely affect plant performance.

4. <u>Automated Process Monitoring</u> - Design: A lack of continuous monitoring turbidimeters on the raw water quality at the lake pumping station and on the effluent line from each filter makes plant operation more difficult. Turbidity monitoring on the raw water would allow increases in raw water turbidity to be anticipated, so that treatment could likely be improved. Monitoring of the filter effluent quality would provide information necessary to

Figure 4-24. Finished water turbidity profile after backwash of filter 2 - Plant 5.



adjust chemical feed rates and, therefore, optimize filter performance.

5. Reactor Basin - Design: The reactor basin may provide inadequate detention time to allow chemicals to react and flocculate during cold water conditions. As a result, the plant flow may have to be reduced substantially during the winter.

6. Inoperability Due to Weather - Design: As discovered during the summer of 1985, drought can severely impact the availability of water from the lake. The raw water intake is located in a shallow corner of the lake and considerable attention has been given to relocating the intake to a deeper portion of the lake. An engineering study has been completed that evaluates the alternatives for another intake location.

In addition to the above major factors limiting performance, other minor factors were noted during the evaluation. Action taken to address these factors may not noticeably improve plant performance, but may improve the efficiency of plant operation:

- Funding the operation of the wastewater system through water revenues is not a good practice. Each utility should be self sufficient.
- Better communication of priorities to the plant staff and better teamwork among staff members could improve plant performance.
- Return of spent backwash water to the influent can result in increased raw water turbidities and a change in raw water chemical characteristics.
- The alum and cationic polymer feed points provide no flash mix of the chemicals. Movement of the chemical feed points to just prior to the orifice plate would provide better mixing.

Projected Impact of a CCP

It was projected that a CCP would help Plant 5 achieve better performance. Results of the CPE indicated that the plant was limited by a number of factors, primarily in operation and design. Because of the design limitations, the plant would need to reduce its operating rate to produce an acceptable finished water quality. Some capital investment could be necessary, depending upon the condition of the filters.

It was recommended that the city continue its efforts to construct a new water intake on the lake. The new intake would appear to improve the quality of the raw water, as well as the reliability of the water source.

CCP Results

A CCP was initiated, at which time the plant flow rate was reduced so that design-related limitations could be addressed. During the initial site visit, the CCP team developed a daily data sheet and implemented a procedure describing process control testing. In addition, procedures were developed for calibrating chemical feeders and calculating chemical dosages so that chemical feed rates could be accurately applied. Special studies were implemented to determine the effect of operating the plant at a reduced flow rate and operating the filters without a negative pressure.

At the conclusion of the first visit, the plant was operated at 69 L/s (1,100 gpm) rather than at 132 L/s (2,100 gpm) and a plug was removed from the filter effluent header to release the negative pressure from the filter. Chemical feed rates were not changed. The CCP team developed an action list and assigned tasks to the operating staff and administrators with due dates to ensure activity continued until the next site visit.

During an additional two site visits and weekly phone consultation sessions, the CCP team explained the conduct and interpretation of the jar test/filter paper procedure to the operating staff. This, coupled with activities from the first site visit, launched full implementation of the process control program, including evaluating raw water quality and making a determination of the correct coagulant and filter aid feed rates.

The only physical change to the plant was the relocation of the feed points for alum and cationic polymer addition to take advantage of a hydraulic flash mix at an orifice plate located in the influent piping. City administrators were also convinced to allow time for the operating staff to remain at the plant so that they could conduct process control testing and make plant adjustments.

Figure 4-25 shows the significant improvement in plant performance achieved by Plant 5 during the conduct of the CCP. Plant operation improved after reducing the plant flow rate and eliminating the negative pressure on the filter bottoms in April, but performance remained erratic until process control, including chemical adjustments, was implemented in July. After July, plant finished water turbidities remained very consistent at about 0.1 to 0.2 NTU through the duration of the project, even though raw water turbidities varied widely (Figure 4-26). Plant finished water quality remained below 0.3 NTU even when the raw water turbidities reached 70 NTU, because the operating staff consistently monitored varying raw water quality and responded by changing chemical feed rates.

Plant performance was especially impressive since influent turbidities frequently exceeded values thought to be treatable with direct filtration (e.g., less than 50 NTU). Another indication of improved performance was that filter effluent turbidity following a backwash did not exceed 0.3 NTU and returned to 0.15 NTU within minutes after the wash.

The CCP proved that the plant could achieve compliance with SWTR turbidity requirements without major capital improvements. City administrators had planned on spending an estimated $1,000,000 on construction of sedimentation basin facilities and related improvements. After the CCP, they decided to delay any construction until water demands required the plant to be operated at higher rates. The plant staff developed increased confidence that excellent quality water could be produced despite high raw water turbidities, and they developed a level of pride that did not allow them to accept marginal finished water quality. In addition, the jar test/filter paper procedure proved to be a valuable process control tool that allowed accurate selection of coagulant doses.

Figure 4-25. Finished water turbidities during CCP for Plant 5.

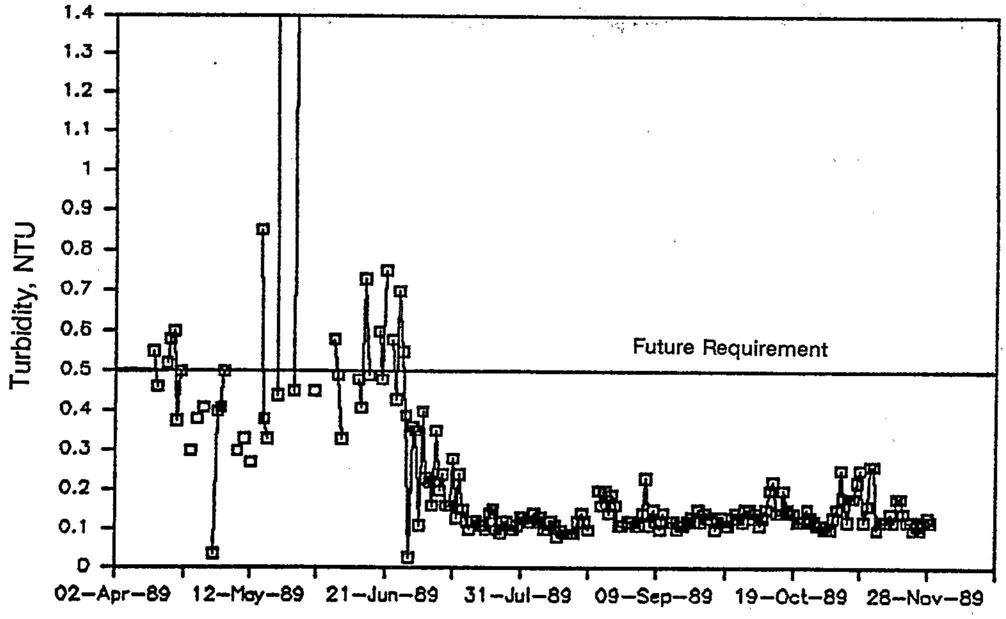
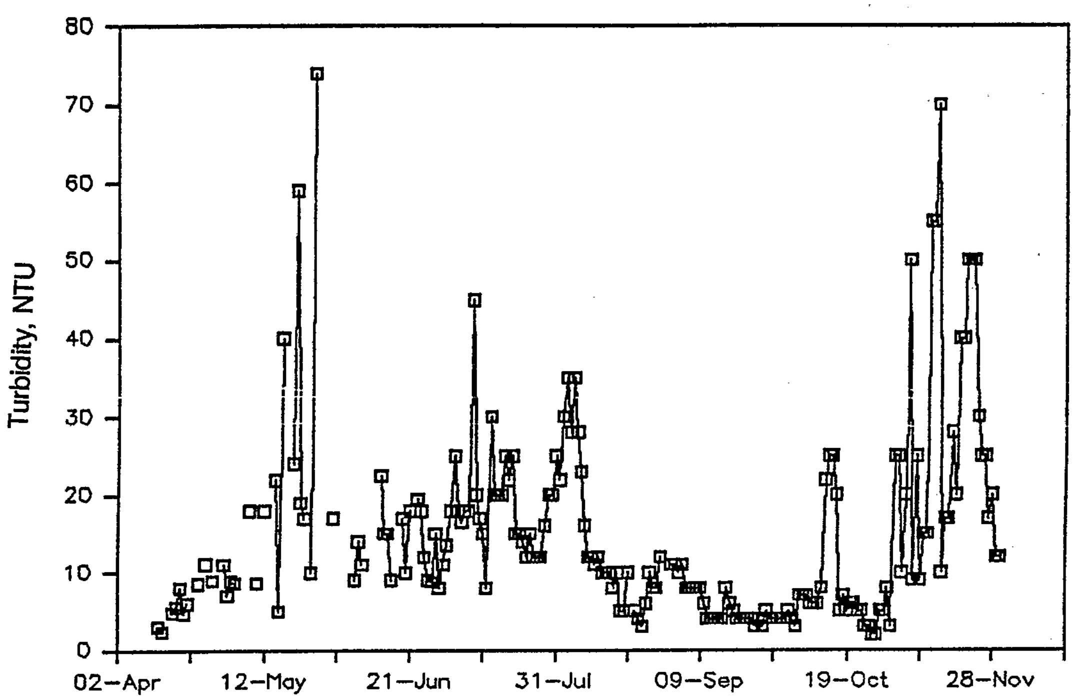


Figure 4-26. Raw water turbidities during CCP for Plant 5.



Plant 6

Facility Description

Plant 6 was built in 1916, and underwent major modifications in 1923 and 1960. To date the plant serves approximately 5,000 people, with no significant industrial users. The plant's water source is the nearby river. The plant is a 175-L/s (4-mgd) lime softening facility with pre-sedimentation, rapid mix and flocculation (in a solids contact unit), filtration, and disinfection. The maximum quantity of water produced over a 12-month period was 1,182 L/s (4.15 mgd) and the lowest was 17 L/s (0.39 mgd). Plant flow is measured by a raw water meter ahead of the solids contact unit, and by a master meter following the high-service pumps.

The city is currently under a compliance schedule from the State to curtail the discharge of untreated sludge into the river. The city has applied for funds for the construction of sludge handling facilities and for other plant modifications. Plant 6 consists of the following unit processes (see Figure 4- 27):

- Four split-case centrifugal raw water pumps: two 69 L/s (1,800 gpm) and two 50 L/s (800 gpm)
- Pre-sedimentation basin divided into five sections, total volume of about 3.8 million L (1 mil gal)
- Three non-clog centrifugal pumps (one 63-L/s [1,000-gpm] and two 94-L/s [1,500-gpm]) as intermediate pumps for transferring water from the pre-sedimentation basin to the solids contact unit
- Chemical addition of liquid cationic coagulant, alum, filter aid, polyphosphate, lime, soda water, carbon dioxide, activated carbon, and gaseous chlorine
- Solids contact unit with a total surface area of 144 m^2 (1,555 sq ft) and a 3.1-m (10-ft) depth. A mechanical 10-hp rapid mix unit is located in the solids contact unit.
- Recarbonation chamber to reduce pH after softening
- Seven single media sand filters with a total surface area of 167 m^2 (1,800 sq ft): three in the plant addition with surface area of 33 m^2 (360 sq ft) each, and four in the old plant with surface area of 17 m^2 (180 sq ft)
- Two chlorinators
- 487,130-L (128,700-gal) clearwell
- Four vertical turbine high-service pumps: three 88-L/s (1,400 gpm) and one 63-L/s (1,000 gpm)

Raw water is pumped from the river to the pre-sedimentation basin. Two of the raw water pumps are located in the basement of the plant and two are located in a pumping station north of the plant. A hand-cleaned basket strainer provides preliminary screening for the two raw water pumps located in the plant basement. The five separate chambers in the pre-sedimentation basin are normally run in series, but may be run in series, parallel, or any combination. Sludge is removed from the basin manually, and when the pre-sedimentation basin is cleaned the sludge is discharged directly to the river. From the pre-sedimentation basin, water is pumped by the three intermediate pumps to the solids contact unit. Chlorine may be added ahead of the solids contact unit, if necessary.

In the solids contact unit, alum, polymer, lime, soda water, and activated carbon are added for softening, turbidity removal, and taste and odor control. Flocculation and rapid mixing both take place in the contact unit. From the solids contact unit, water flows by gravity to the recarbonation chamber, where carbon dioxide generated onsite by burning natural gas is added to reduce pH after softening. Polyphosphates are added prior to filtration.

The design filtration rate is 117 $m^3/m^2/d$ (2 gpm/sq ft). Filtration rates are controlled by an effluent regulator on the basis of flow and headloss. The filters are backwashed with finished water from the clearwell pumped by one 189-L/s (3,000-gpm) backwash pump. Backwash water flow is measured by a Venturi meter and totalized at the main instrument control panel.

Filtered water is disinfected with chlorine dosed at a feed rate of 1-2 ppm. Disinfected water then flows to the clearwell. The clearwell detention time is 46 minutes at a plant flow of 175 L/s (4 mgd).

The three high-service pumps deliver the water to the distribution system.

There are no facilities available for the disposal of sludge. Sludge generated from cleaning the pre-sedimentation basins, solids contact unit, and the spent filter backwash water is piped untreated to the river.

Major Unit Process Evaluation

The performance potential graph is shown in Figure 4-28. The raw water pumps were rated at 208 L/s (4.75 mgd), based on information from a previous engineering study. The pre-sedimentation basin was rated at 175 L/s (4 mgd) assuming that a coagulant aid could be added prior to the basin. At 175 L/s (4 mgd), the basin has a detention time greater than the 3-hr minimum recommended by the Ten State Standards.

Figure 4-27. Plant 6 process flow diagram.

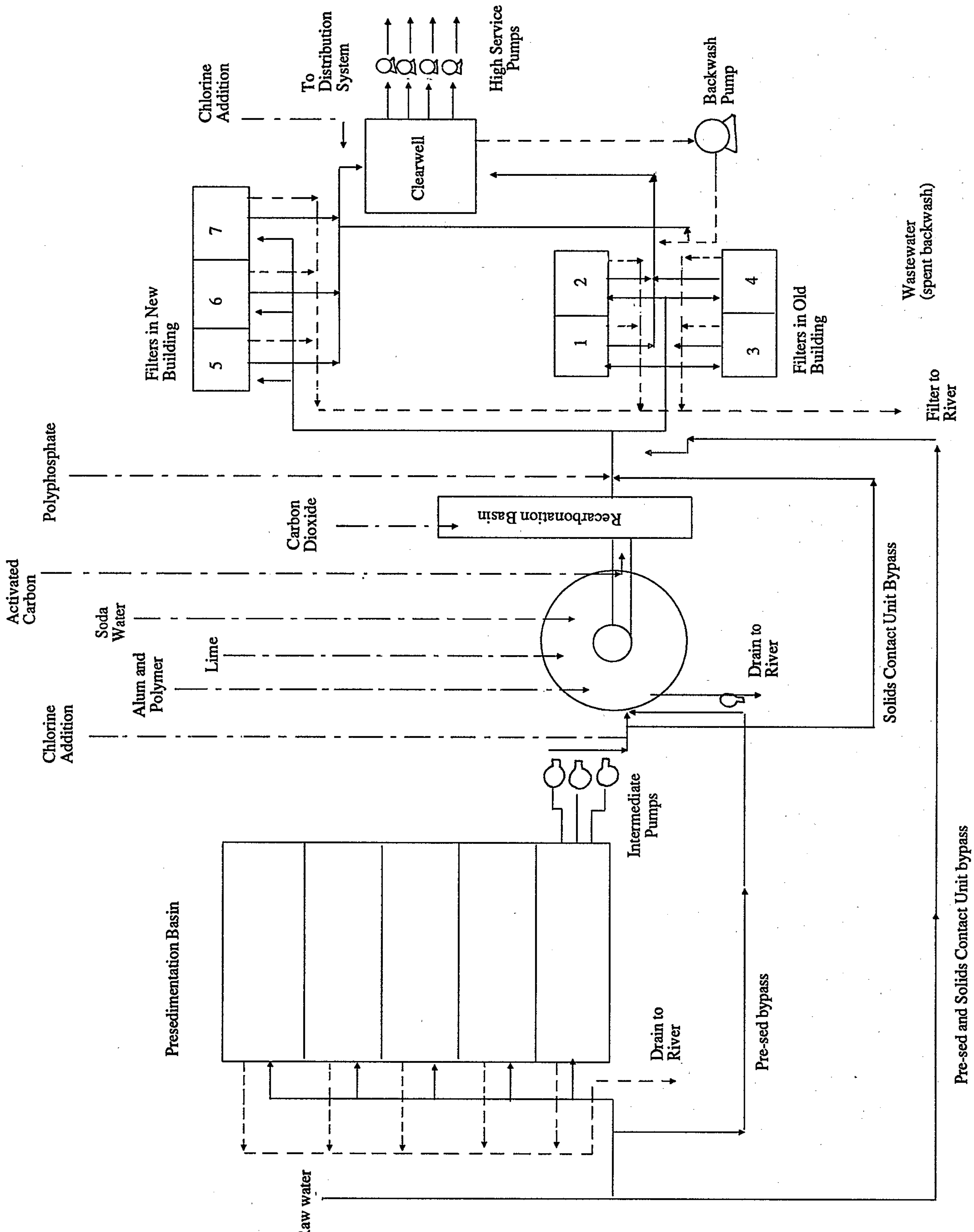
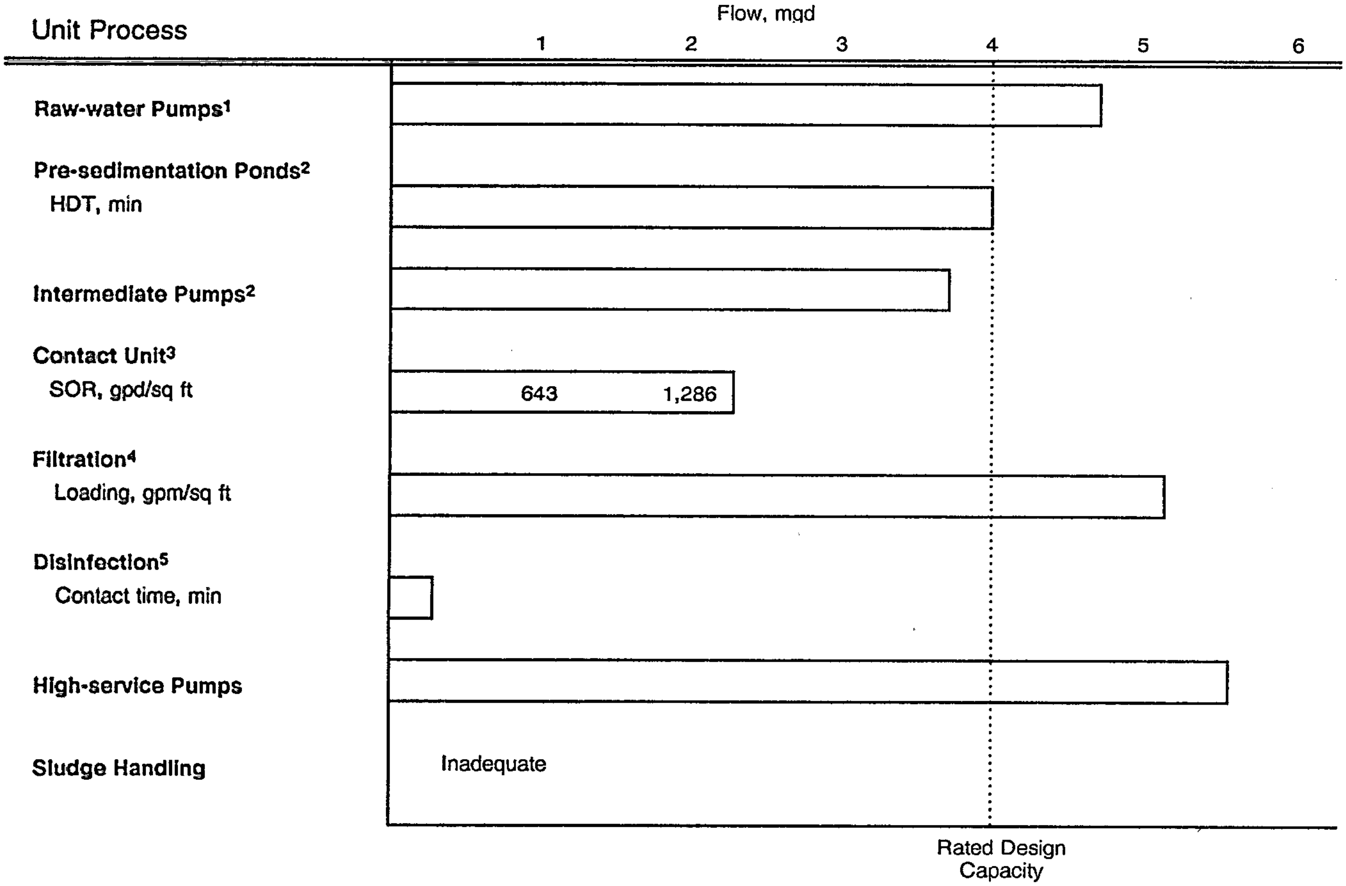


Figure 4-28. Plant 6 performance potential graph.



[1] Based on previous master plan study.
[2] Based on addition of coagulant aids - detention greater than 3 hr minimum in Ten State Standards.
[3] Based on 1,440 gpd/sq ft.
[4] Based on 2 gpm/sq ft and assumes filter aid with labor-intensive backwash.
[5] Based on 120-min contact time and total clearwell volume.

The intermediate pumps were rated at 167 L/s (3.8 mgd), slightly less than the 175-L/s (4-mgd) design capacity, based on a previous study. Based on a surface overflow rate of 58 $m^3/m^2/d$ (1 gpm/sq ft), the solids contact unit was rated at 96 L/s (2.2 mgd), well below the plant design capacity.

The filters were rated at 228 L/s (5.2 mgd) based on a filtration rate of 117 $m^3/m^2/d$ (2 gpm/sq ft). This rating assumes successful use of a filter aid and hand-raking of the filters during backwash.

Because the clearwell has such a small volume in relation to total plant production, the disinfection contact time was rated at only 8.8 L/s (0.2 mgd). Current design standards require a minimum disinfection contact time of 2 hr, but the clearwell provides only 46 minutes at 175 L/s (4 mgd). When the plant produces water with a turbidity greater than 1.0 NTU, the chlorine contact time must be adequate to ensure disinfection of any pathogenic organisms that may have passed through the plant's previous treatment steps.

The high-service pumps are rated at 241 L/s (5.5 mgd).In summary, the solids contact unit limits plant capacity to 96 L/s (2.2 mgd) during periods of high turbidity. An operational rate greater than 96 L/s (2.2 mgd) may result in increased solids carryover from the solids contact unit to the filters, with a subsequent decrease in filter performance and overall plant performance. Also, if bypass of the solids contact unit becomes necessary, provisions must be made to add coagulants prior to filtration.

Performance Assessment

Finished water quality monitoring data indicated that the plant had been operating in compliance with the current turbidity MCL of less than 1.0 NTU on a monthly average. However, the MCL had been exceeded on days within certain months. The highest finished water turbidities were noted at a time when the solids contact unit was being bypassed for cleaning. Plant records indicated that no coagulant aids were added at times when the solids contact unit was bypassed, an unacceptable practice.

Figures 4-29 through 4-31 show selected plant operating data. The data shown in these figures suggest that the plant will experience difficulty in complying with the SWTR, which establishes a MCL for turbidity of 0.5 NTU for 95 percent of the time.

Performance-Limiting Factors

The factors identified as having a major effect on performance on a long-term repetitive basis are summarized below and listed in order of priority.

1. Operator Applications of Concepts and Testing to Process Control - Operation: The operators had a good understanding of water treatment but were not applying that knowledge fully. For example, direct filtration without chemical pretreatment can result in a significant health risk to the consumers. The Filter 6 effluent turbidity plot presented in Figure 4- 30 is from a special CPE study and indicates that the coagulation process has not been optimized.

2. Disinfection - Design: The limited volume of the clearwell results in inadequate chlorine contact time, which in turn limits the time the chlorine has to act on pathogenic organisms that may have passed through the previous treatment process. There was also an inadequate free chlorine residual in the finished water leaving the plant.

3. Sludge Disposal - Design: No sludge disposal facilities exist to treat the sludge generated in the water treatment process. The city is in violation of the State Clean Water Act because of the discharge of sludge to the river and has hired a consultant to evaluate the problem and design a remedy.

Factors identified as having either a minimal effect on a routine basis, or a major effect on a periodic basis were prioritized and are summarized below.

1. Process Flexibility - Design: There are no provisions for chemical feed to the pre-sedimentation basin or to the filter influent. Addition of these chemical feed points would allow operators to better control finished water quality.

2. Process Control Testing - Operation: The absence of or the wrong type of process control testing results in improper operational control decisions. The solids contact unit should be monitored more

Figure 4-29. Plant 6 direct filtration results, February 1988.

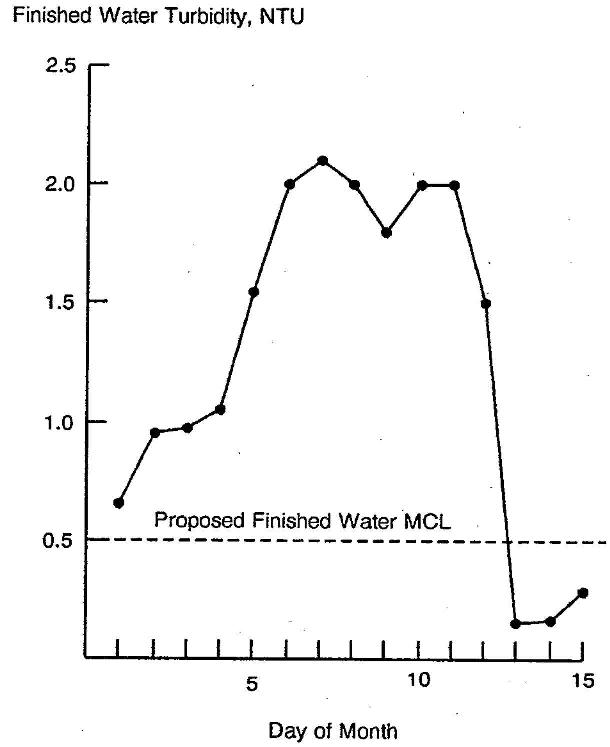


Figure 4-30. Plant 6 effluent turbidity after backwash, September 21, 1988.

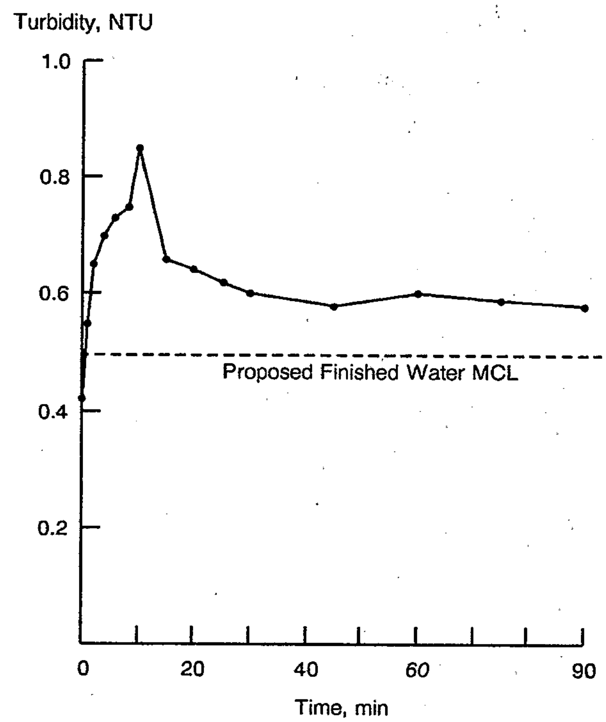
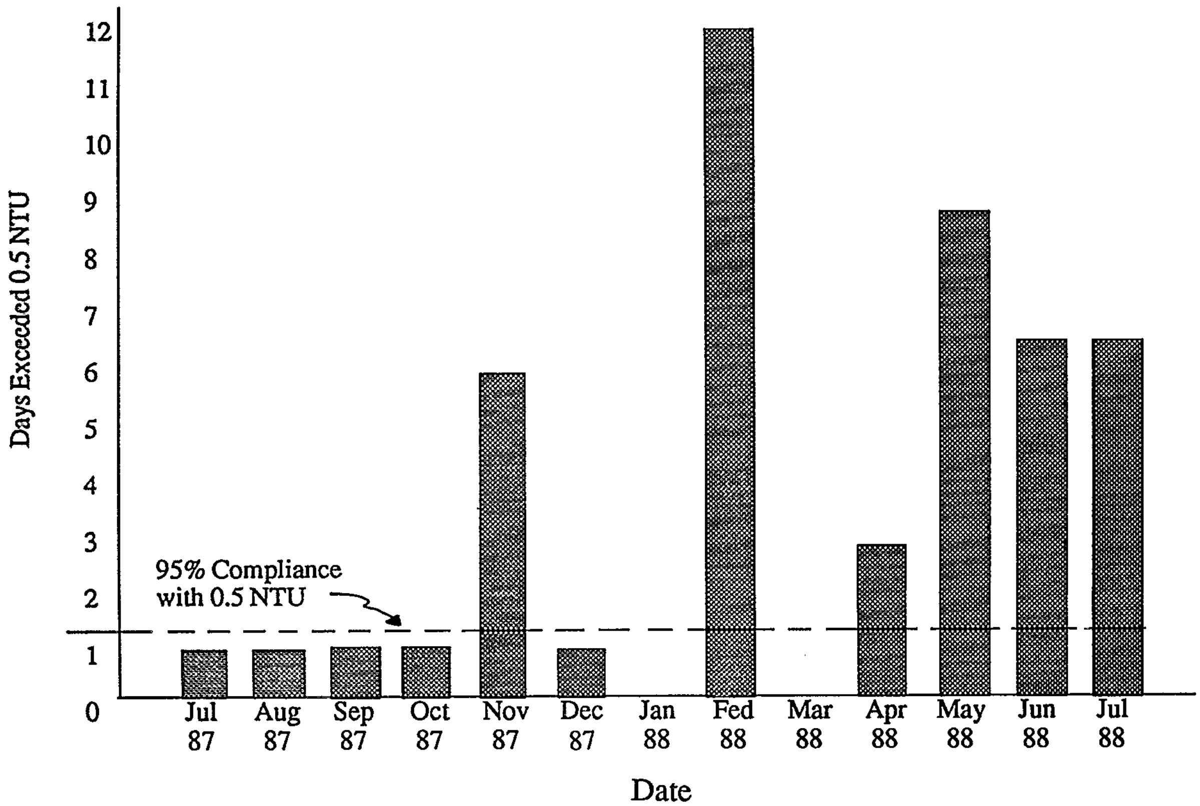


Figure 4-31. Plant 6 turbidity.



thoroughly and more frequently. Sample taps and continuous monitoring turbidimeters should be installed on each filter effluent so that discrete changes in filter performance may be observed before substandard quality water is produced. Process control activities should be integrated into the daily routine of operation.

3. Solids Contact Unit - Design: The solids contact unit severely limits flow during peak periods when the surface overflow rate becomes excessive, and results in a high solids loading to the filters.

4. Planning and Guidance - Administration: More emphasis should be placed on ongoing capital improvement and replacement of equipment. Long-term reliability of the plant has been jeopardized by a reluctance to make necessary expenditures. Administration should develop an integrated approach to setting goals, not only for maintenance and process control, but also for meeting minimum finished water quality goals and sludge discharge limitations.

In addition to the above major factors limiting performance, other factors identified as having a minor effect were noted during the evaluation. Overall, there is a heavy focus on maintenance at the expense of adequate process control. Action taken to address these factors may not noticeably improve plant performance, but may improve the efficiency of plant operation:

- The screens on the raw water pumps plug with moss at certain times of the year. Cleaning the screens is very labor intensive. Frequent plugging of the screens affects water quantity more than finished water quality.
- If filter aids are used to improve filter performance, it may be necessary to agitate the filters by hand during backwash to facilitate cleaning. This practice will be rather labor intensive.

Projected Impact of a CCP

The evaluation team believed that a CCP that addressed factors related to plant operation, such as operator application of concepts, process control testing, and flexibility could improve plant performance for the majority of the year. However, continuous compliance with proposed regulations for finished water turbidity and disinfection, and with existing NPDES permit limitations on sludge discharge to the river, would require design modifications as well.

Plant 7

Facility Description

Plant 7 is a conventional plant that treats water from a river for industrial and domestic use by the city. The peak day demand for a 12-month period was 202 L/s (4.6 mgd) based on plant records. Plant 7 includes the following unit processes (see Figure 4-32).

- Concrete river intake structure that houses manually cleaned bar screens, 1.9-cm (3/4-in) spacing.
- Three manually operated raw water pumps: one turbine - 126 L/s (2,000 gpm), and two centrifugal - 126 L/s (2,000 gpm) and 88 L/s (1,400 gpm)
- Three turbine pumps used to pump raw water directly to a large refinery; one 76 L/s (1,200 gpm) and two 126 L/s (2,000 gpm)
- 46-cm (18-in) Parshall flume used to monitor raw water influent flow
- Liquid alum feed pump with a backup dry alum feed system
- Polymer feed pump
- Fluoride feed system for sodium silica fluoride
- Six manually-cleaned, uncovered "hydraulic" flocculation basins ("mud basins"), each with a volume of approximately 81,400 L (21,500 gal)
- Two manually cleaned sedimentation basins, one covered and one uncovered. Each basin has a volume of approximately 2.8 million L (750,000 gal). Basin effluent is transferred to the filters through a 61-cm (24-in) pipe
- Two 8.5-m x 7.6-m (28-ft x 25-ft) mixed media filters
- Gas chlorination system
- Two filtered water "transfer" pumps controlled by an altitude valve that "transfer" filtered water to a standpipe or to the high-service pumps
- On-site standpipe with a capacity of approximately 94,625 L (25,000 gal)
- Five high-service centrifugal pumps: two 157 L/s (2,500 gpm), one 126 L/s (2,000 gpm), one 63 L/s (1,000 gpm), and 38 L/s (600 gpm)
- Sludge holding lagoon of approximately 3.4 million L (900,000 gal) capacity
- On-site storage of sludge from the holding lagoon

River water is drawn from the concrete intake structure located in the middle of the river through 41-, 36-, and 51-cm (16-, 14-, and 20-in) lines. The intake structure is modified during winter months to include a perforated culvert intake, which lessens the impact of pack ice. A portion of the raw water from the intake structure is pumped directly to a local refinery.

Raw water pumps located in a pump station adjacent to the plant deliver the desired volume of water for treatment. The operators indicated that the turbine pump is unable to achieve rated capacity output. The pumps discharge to a Parshall flume. At the time of the CPE, sodium silica fluoride and liquid alum were being added just upstream of the throat of the Parshall flume. The superintendent had only recently switched from dry to liquid alum. Historically, polymer had also been added at the flume location.

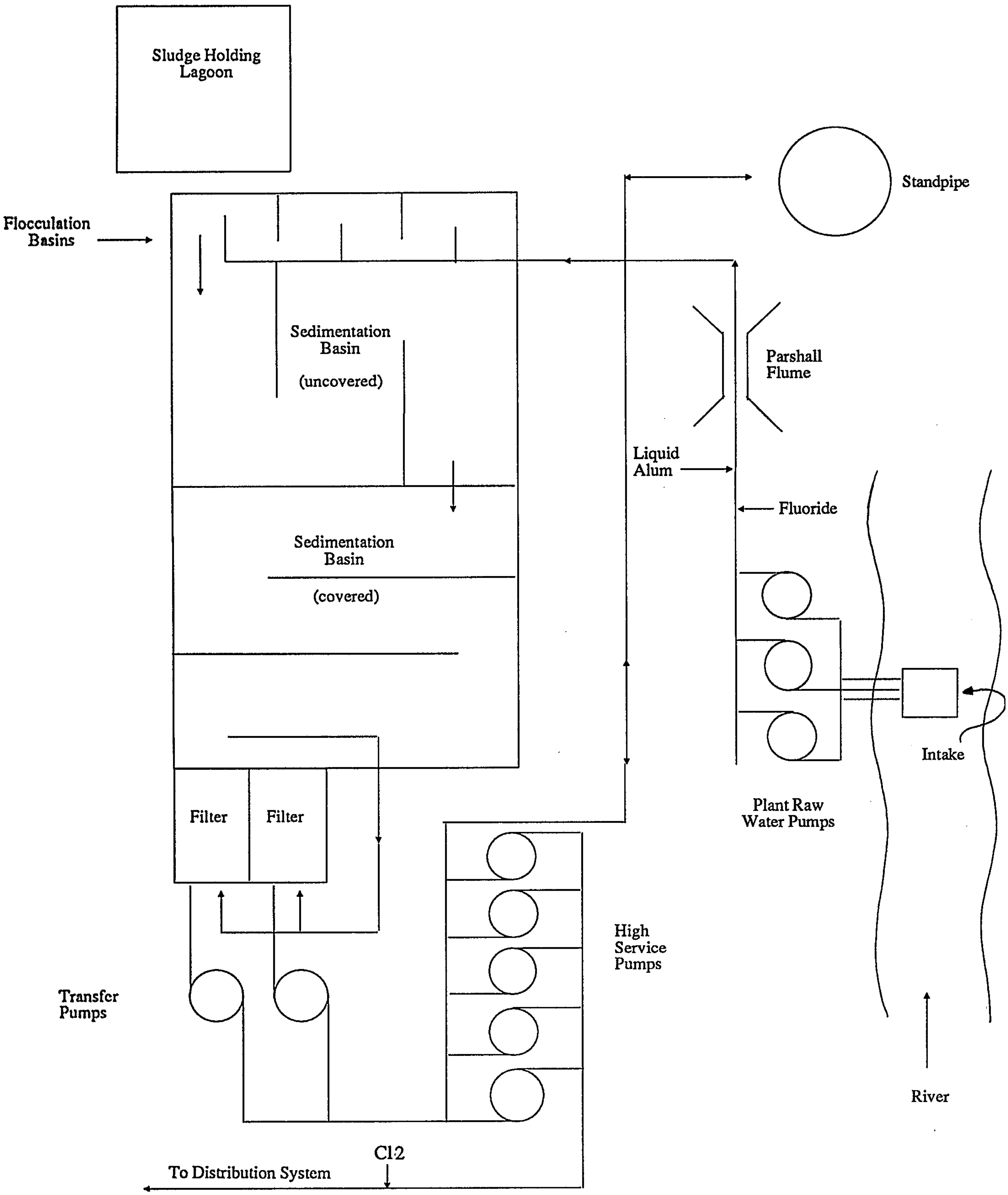
After the flume, the water flows to the "mud basins," a series of six tanks used for flocculation. The basins appeared to be functioning well even though the only energy impact was that generated hydraulically. The operators indicated that observing the floc formation in these basins was critical in adjusting the chemical dosages to the raw water. These basins are not used in the winter because of icing problems. The basins have noticeably deteriorating concrete, and a consultant had been retained to evaluate their structural integrity.

From the mud basins, water flows in series through two manually cleaned sedimentation basins. The first basin is uncovered and is used only during warm weather months. During winter operation, the covered basin is used for both flocculation and sedimentation. The basins are cleaned manually approximately six times each year, and the sludge is pumped to the earth sludge holding pond; 3-6 hr are required to clean the basins, and no routine sampling is done on them.

Effluent from the covered sedimentation basin is collected in a 61-cm (24-in) pipe and delivered to the mixed-media filters. The filtration rate is controlled by a transfer pump located at the discharge from each filter. The transfer pump discharges filtered water to the distribution headers of the high-service pumps and to an on-site standpipe. The transfer pumping rate is controlled by demand and by an altitude valve which receives a signal from a pressure sensor on the on-site standpipe. This filter control has been set to respond relatively slowly so as to minimize rapid fluctuations in filtration rate.

Backwash consists of a surface wash and gravity backwash using the water stored in the standpipe. At the time of the CPE, filter runs were approximately 10-20 days, and a dirty filter was started and stopped on a daily basis. Backwashing was intended to be

Figure 4-32. Plant 7 process flow diagram.



initiated when the headloss exceeded 2.4-2.7 m (8-9 ft) or the effluent turbidity exceeded 0.5 NTU. Backwash water was directed to the sludge holding pond.

After filtration, the plant effluent is chlorinated and pumped by the high- service pumps to the distribution system. The plant does not have a clearwell to allow contact time of the chlorine with the treated water, and the first consumer is located approximately 275 m (300 yd) from the plant site. The target chlorine residual is 0.7-0.8 mg/L.

Operators attempt to match water demand with high-service pumping. However, caution is used in turning on high-service pumps so as to avoid high pressure in the distribution system. Excessive system pressures have resulted in broken lines because of the existence of old pipes in the system. The 38-L/s (600-gpm) high-service pump was out of service at the time of the CPE.

Sludge from the sedimentation basins and the filter backwashes is stored in the unlined sludge storage lagoon from which it is dredged approximately every 2 years and stored in a ditch adjacent to the lagoon. Supernatant from the lagoons is pumped back to the head of the plant.

Dried sludge is removed from the ditch and stockpiled on the plant side. Present stockpile volumes have practically filled the available space, and alternative disposal options will be necessary in the foreseeable future.

Operation is almost totally manual. Pump settings, chemical dosage rates, and filter backwashing are all initiated manually by the plant operators. The plant is staffed 24 hr every day with four operators rotating shifts every 28 days. A relief operator is available.

Major Unit Process Evaluation
The performance potential graph is shown in Figure 4-33. The flocculation basins were rated based on a detention time of 40 minutes, which resulted in a capacity rating of approximately 206 L/s (4.7 mgd). The 40-minute detention time rating is relatively conservative but is justified because mechanical mixing is not provided. This rating is slightly higher than the current peak demand; therefore, the unit process is deemed satisfactory.

The sedimentation basins were rated on a hydraulic loading rate of 12 $m^3/m^2/d$ (300 gpd/sq ft) and a detention time of 5.4 hr because of the relatively poor outlet structure (e.g., a 61-cm [24-in] pipe) and the absence of mechanical sludge removal. Polymer addition was assumed in establishing this rating. Based on these criteria, the capability of the sedimentation basins was assessed as 263 L/s (6 mgd).

The mixed media filters were assessed based on a filtration rate of 293 $m^3/m^2/d$ (5 gpm/sq ft). At this rate, a potential capacity of 438 L/s (10 mgd) was projected for the existing filters.

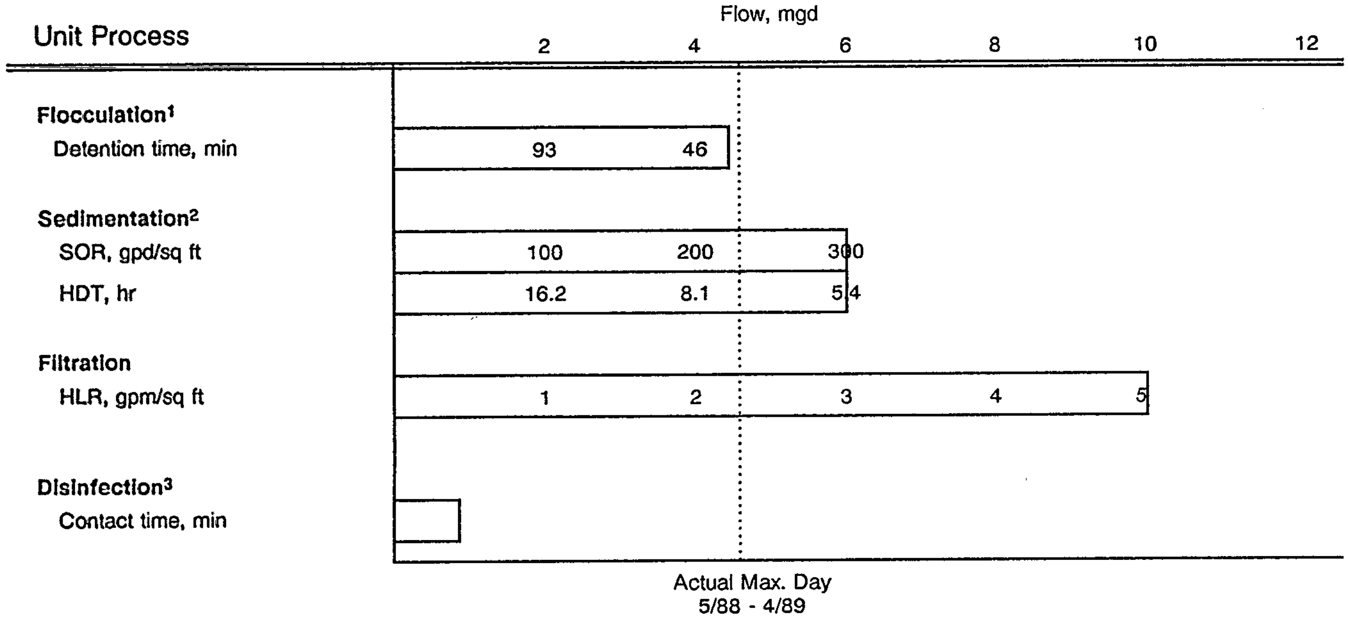
Disinfection capability was severely limited based on current state criteria of a 2-hr detention time after chlorination. A capacity of 11 L/s (0.25 mgd) was projected based on the 2-hr standard and the approximation that there are 274 m (300 yd) of 36-cm and 41-cm (14- and 16-in) pipes prior to the first system user. Despite revisions of existing regulations that may allow lower detention times, the absence of any clearwell or contact basin will remain a unit process limitation.

Except for the noted limitation in the disinfection process, unit processes were assessed adequate to meet the current peak demand of 202 L/s (4.6 mgd).

Performance Assessment
In general, the CPE indicated that a high quality water (e.g., turbidities less than 0.15 NTU) was produced. However, some difficulty with performance was indicated during winter operation. Figure 4-34, which shows a plot of filter turbidity and headloss vs. time, indicates an excessively long recovery time after backwash of Filter 1 (e.g., 36 hr until effluent turbidity stabilized). Ideally, performance stability would be achieved in less than 10 minutes. Also shown is a period of approximately 12 hr in which the turbidity exceeded the current state criteria of 1 NTU. Cold, low turbidity, low alkalinity water and use of only the covered sedimentation basin may have contributed in part to the noted difficulties. Greater operational control and perhaps additional chemical conditioning may be required to improve performance.

Another problem indicated on Figure 4-34 is the time of deteriorated performance before a filter backwash was implemented. Turbidities increased from the 0.1 NTU range to the 0.35 NTU range, and approximately 1 full day passed before the operators initiated backwash. Failure to backwash when turbidity begins to increase can allow significant breakthrough of particles, causing a potential health risk for the community. Figure 4-35 shows March 1989 turbidity data for Filter 2 with results similar to those in Figure 4-34. The performance problem indicated on Figure 4-35, however, is much more severe. Initial turbidities, after filter startup, exceeded the state requirements (1.0 NTU) for over a day. Additionally, backwashing was delayed for approximately 3.5 days from the time indicated by plant data. Proper chemical conditioning and closer attention to the need to backwash would have lessened the potential for health risk demonstrated by these data analyses.

Figure 4-33. Plant 7 performance potential graph.



[1] Flocculation basin rated at 40-min HDT because there is no mechanical mixing.
[2] Rated at 300 gpd/sq ft and 5.4 hr because there is a poor outlet and no sludge collection equipment. Assumes polymer use..
[3] Based on current State standard of 2-hr HDT. Assumed 300 yd of 14- and 16-in pipe to first user. Standards are being revised and lower detention times may be allowed for existing plants.

During the CPE, a special study on filter startup was conducted under spring runoff water conditions. During the study, Filter 1 was removed from service for backwashing and Filter 2 was placed in service. The results of this analysis showed that turbidities never exceeded 0.15 NTU during and after startup of Filter 2. The stability of the filter's performance was also demonstrated when the flow was increased dramatically over a short period of time and no increase in turbidity occurred. An additional evaluation of the surface of Filter 1 after backwash revealed no mudballs, indicating that the backwash procedure was adequate.

Performance-Limiting Factors

The following factor was identified as having a major adverse effect on performance on a long-term repetitive basis.

1. Disinfection - Design: A detention time of 2 hr is not available at the plant to ensure effective disinfection of the treated water prior to use. The new regulations that will be promulgated as a result of the SWTR and/or current state criteria may necessitate capital improvements in order to provide adequate disinfection capability. This factor was asterisked because the final rule and direction could not be established until the latter part of 1989.

Factors identified as having either a minimal effect on a routine basis, or a major effect on a periodic basis were prioritized and are summarized below:

1. Supervision/Staff Morale - Administrative: Communication between administrative personnel and the plant staff, and communication among the staff is limited and strained. As a result of the limited communication; data interpretation, initiative, maintenance efforts, proper process adjustments, understanding of standard operating procedures, and "cross training" of personnel are limited. The operators seem to function independently on each shift. This limited interaction is believed to be a major contributing factor to the poor operational decisions that resulted in the deteriorated filter performance documented in Figures 4-34 and 4-35. Administrative skills and operator attitude will have to be addressed to eliminate the impact of this factor.

2. Application of Concepts - Operation: Inability to apply proper concepts to optimize unit process performance was identified for several reasons. First the supervision/staff morale problem limits the capability of current personnel to learn from each other and, therefore, limits their capability to properly and consistently apply basic concepts to operational decisions. Also, the practice of

Figure 4-34. Turbidity and headloss profiles for filter 1 - Plant 7.

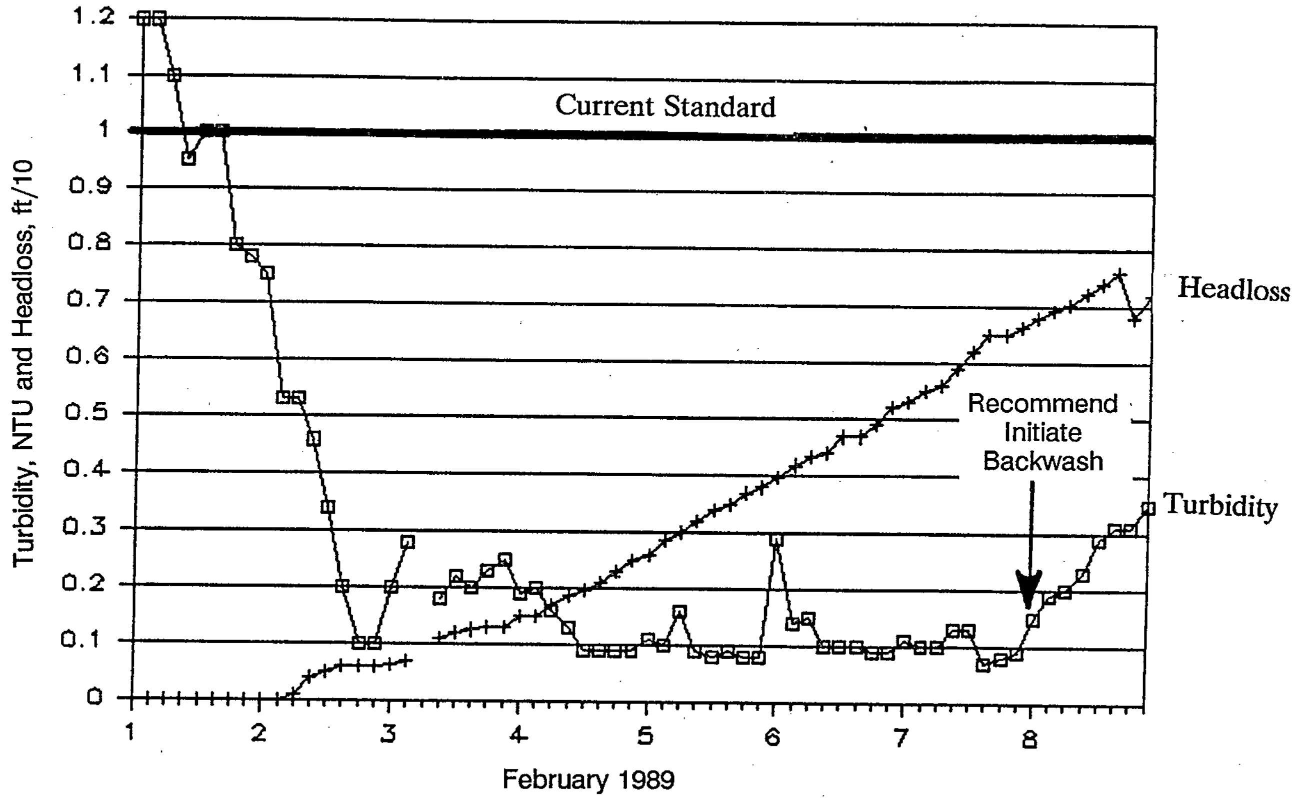
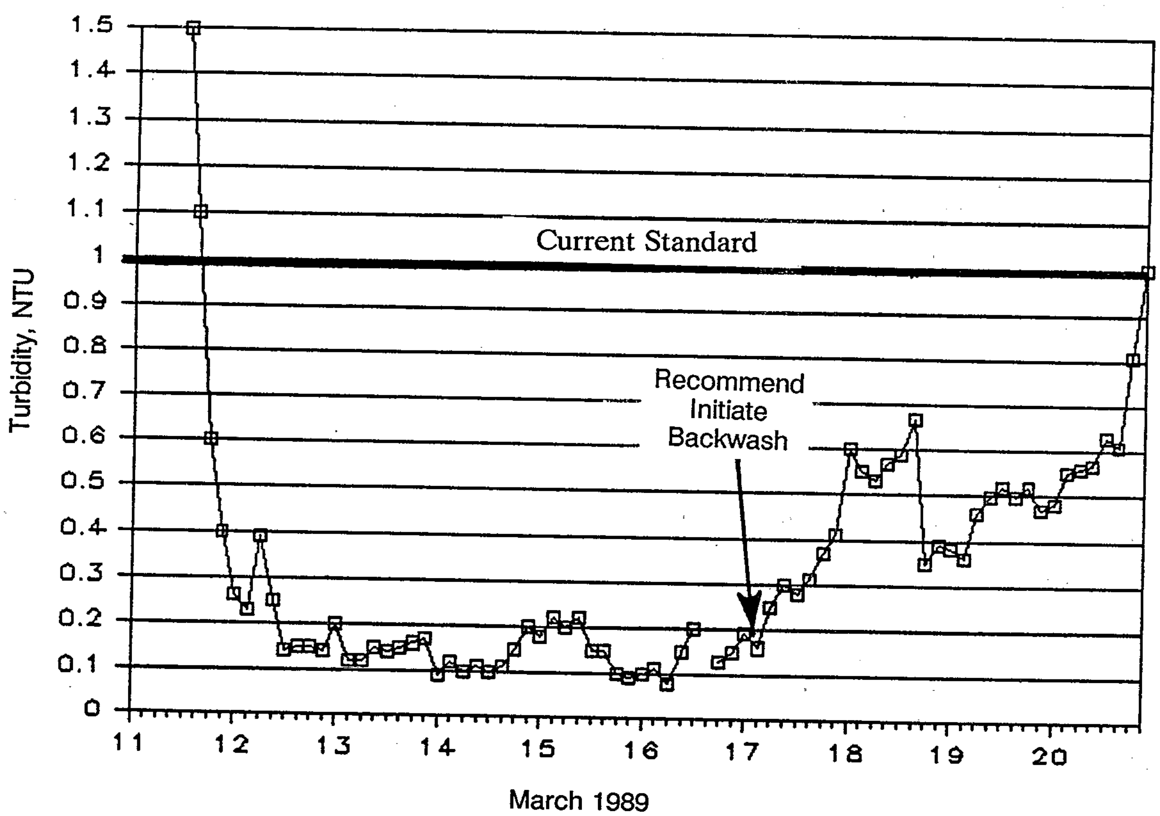


Figure 4-35. Turbidity profile for filter 2 - Plant 7.



routinely starting up a dirty filter and of occasionally "bumping" the filters with large changes in flow rate can and has resulted in turbidity spikes and the associated breakthrough of particles. Particle breakthrough represents a high potential health risk.

3. Policies - Administration: The implementation of very tight fiscal policies limits the expenditure of funds for necessary items. The lack of in-line turbidimeters for the two filters, an additional polymer feed pump, and use of polymer was assessed to be impacting plant performance. The CPE did not identify where these policies were originating. It was felt that improved communication would greatly assist in addressing this factor.

Chemical feed capability was identified as having a minor impact on performance. Moving the alum/coagulant feed point from its present location to the throat of the Parshall flume would allow a better rapid mix to occur and may result in lower chemical use. As a side benefit, the raw water sample could be taken in the chemical feed room, although the sample would contain fluoride.

Projected Impact of a CCP

Generally, the plant was producing a high quality treated water. As such, a CCP would not dramatically improve water quality. However, intangibles such as communication, operational concepts, and a "tight" fiscal policy represent deep-seated problems that may be difficult to address using past practices. From this point of view, an external facilitator may be necessary to impact the current situation.

In lieu of a CCP, it was recommended that the community pursue a correction effort to address the factors identified as limiting plant performance, recognizing that they will be difficult and time consuming to eliminate.

Plant 8

Facility Description

Plant 8, operated by the county sewer and water district, treats water from a nearby river for domestic use by the town and a local rural water system. The plant, which began operation in 1981, utilizes a solids contact clarification/filtration process. Extreme variations in turbidity exist in the river. During the winter, turbidity is generally below 30 NTU and can be as low as 10 NTU; however, during spring and summer, turbidity ranges from 40 NTU to as high as several thousand NTU as the result of storm events. Plant 8 includes the following unit processes (see Figure 4-36).

- 1.2-m (4-ft) diameter corrugated steel intake which extends below the river bottom. The steel intake pipe is perforated and packed with gravel in the area below the river bottom
- Wet well with two 16-L/s (250-gpm) submersible raw water pumps. The pumps are automatically operated from a level signal in the plant clearwell.
- 15-cm (6-in) diameter propeller meter for measuring the raw water flow rate
- 110-4,375 kg (240-9,645 lb)/d dry alum feeder
- 3-15 L (0.1-0.5 cu ft)/hr lime feeder
- 3-15 L (0.1-0.5 cu ft)/hr soda ash feeder
- Polymer feed system with a 170-L (45-gal) dilution tank and a 3.7-20.8 L (1- 5.5 gal)/hr feed pump
- Steel, 5.5-m (18-ft) diameter, 3.2-m (10.5-ft) deep solids contact unit with 45° tube settlers
- 1.3-6.8 L (0.34-1.8 gal)/hr polyphosphate feeder
- 11-kg (24-lb)/d carbon dioxide feed system and an associated in-line static mixer
- Steel 3.2-m (10.5-ft) diameter dual-media filter
- 9-kg (20 lb)/d gas chlorination system
- 56,000-L (14,800-gal) clearwell with baffled compartments
- Two 16-L/s (250-gpm) vertical turbine pumps which pump treated water to the distribution system and a storage tank
- Two sludge holding lagoons with a total capacity of approximately 658,200 L (173,900 gal)
- Spent backwash storage lagoon of approximately 2.1 million-L (556,170-gal) capacity

River water flows to the raw water pump wet well through a pipe that is located inside the corrugated steel intake structure. The original intake configuration consisted of an infiltration gallery located in the river; however, due to plugging of the gallery with sediment, the system was replaced in 1986 with the current intake pipe. The operator and board members indicated that the original infiltration gallery provided water of much lower turbidity than the current intake structure. However, as the gallery became plugged with sediment, raw water capacity was reduced to the extent that the board decided to replace the infiltration gallery with the present system.

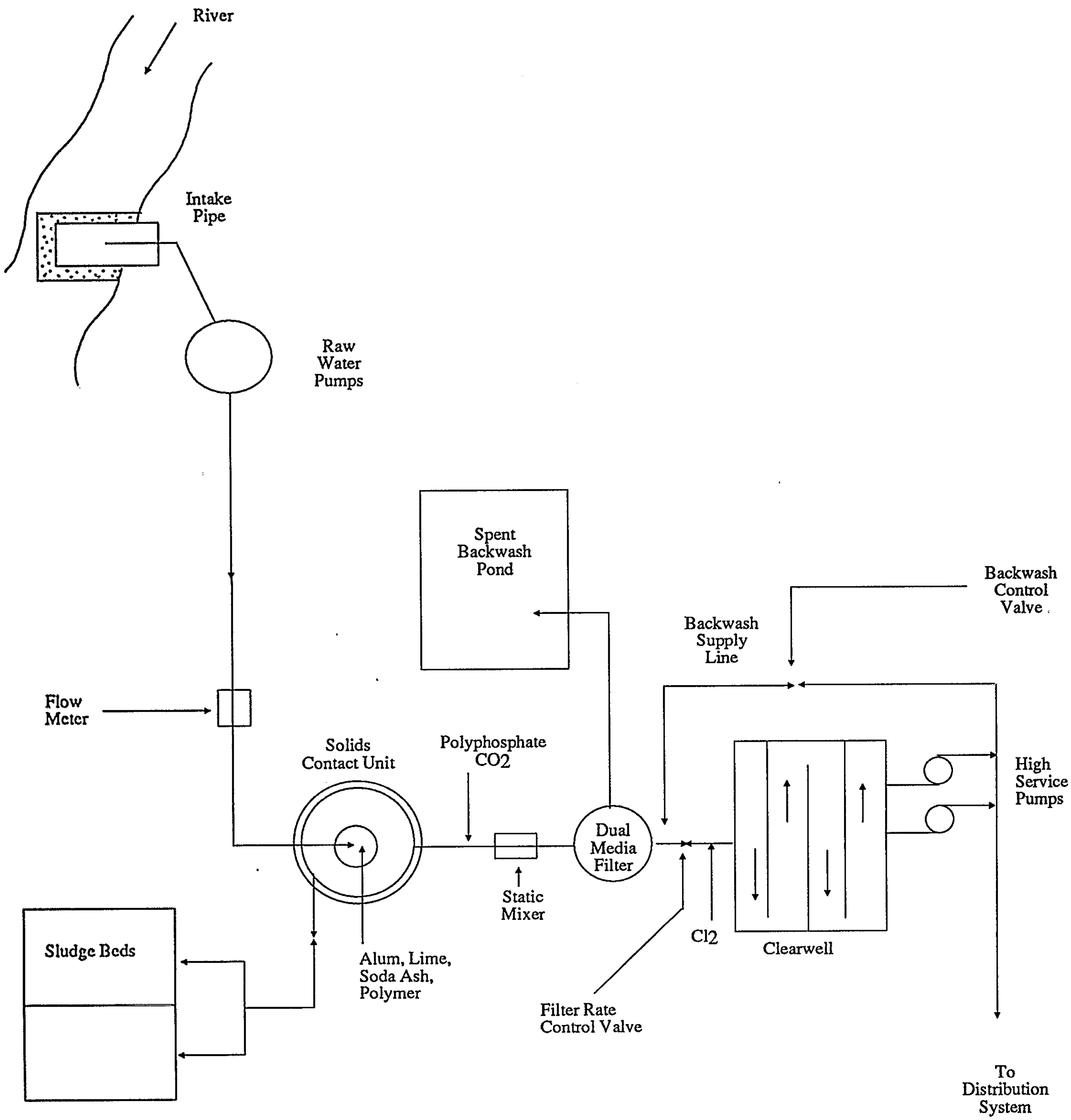
The two raw water pumps, located in a wet well adjacent to the river, each deliver the rated plant capacity. Pump operation is based on a level signal from the plant clearwell, and operation is alternated to maintain even run times on both units. The plant operator reported that a pump is typically operated at full capacity; however, a butterfly valve located in the plant can be used to reduce pump capacity. In an attempt to maintain a sludge blanket in the solids contact unit, the operator had throttled pump capacity to reduce flow to the unit. The operator felt that this experiment did not stabilize the process, and since that time the plant has operated at 16 L/s (250 gpm).

The raw water flow rate is indicated and totalized through a propeller meter located in the raw water line inside the plant building. Following the flow meter, raw water is directed into the solids contact unit. Components of this unit include an upflow mixing column with a turbine mixer, a downflow flocculation cone, and an upflow clarifier with tube settlers throughout the settling area.

Water treatment chemicals including alum, lime, soda ash, and polymer can be added into the mixing area. During the winter, when water hardness increases in the river, the operator can add lime and soda ash to the solids contact unit for softening. During the remainder of the year, alum and a polymer are typically used for turbidity removal. The operator reported that the plant was not operated in the softening mode last winter and that alum and a cationic polymer were used for coagulation during this period. At the time of the site visit, the operator indicated that 80 mg/L of alum and 2 mg/L of cationic polymer were being fed to the mixing tube.

A variable speed turbine mixer located on top of the mixing tube directs the incoming raw water upward through the tube and out into the flocculation cone. The mixing tube is open at the bottom, thus allowing the recirculation of flocculated water with the incoming raw water. The amount of recirculation depends on the speed of the turbine mixer. According to the operator, the turbine mixer speed has been operated throughout the entire range, without changing the performance characteristics of the solids contact unit

Figure 4-36. Plant 8 process flow diagram.



except at high speed. At high speeds, turbulent conditions in the unit degraded clarifier performance. The current practice is to operate the turbine at low to medium speed, and the turbine and sludge scraper continuously, even when the plant is not treating water.

Following the mixing tube, the conditioned water enters an inverted cone where flocculation occurs. At the bottom of the flocculation cone, water moves outward into the clarifier and, theoretically, through a developed sludge blanket. Water then flows upward through 45-degree tube settlers before overflowing a peripheral weir. The operator reported that he has had a difficult time controlling the sludge blanket in the solids contact unit. It appeared that sludge solids generated in the process are typically lost over the weir and deposited on the filter.

Excess sludge generated in the process can be directed to two sludge lagoons by opening a sludge blow-off valve. The operator indicated that sludge has never been removed from the two sludge lagoons since startup of the plant. Effluent from the solids contact unit flows onto a dual-media filter. If the plant is operating in the softening mode, carbon dioxide can be added for pH adjustment after the solids contact unit. Mixing is accomplished by an in-line static mixer. Polyphosphate can also be added at this location to control calcium carbonate buildup in the filter. Even though the plant was not operating in the softening mode during the site visit, polyphosphate was still fed to the solids contact unit effluent.

Water level in the filter is controlled by a modulating flow control valve. According to the operator and several board members, this control valve has never provided a constant-rate operating condition as intended by the original design. Until just recently, water level in the filter would fluctuate dramatically during a filter run, causing sudden, high magnitude flow rate changes through the filter. This condition has improved significantly since the plant operator and a board member fabricated an adjustment mechanism to control the travel distance of the valve seat.

Backwashing of the filter can be initiated by either filter headloss or filter effluent turbidity. The backwash supply water is provided by the pressurized distribution system including an elevated storage tank, and the backwash rate is controlled by a pressure reducing valve. Spent backwash water is directed to a storage lagoon located adjacent to the plant. The operator reported that spent backwash water seeps into the ground water and has never accumulated in the lagoon.

Treated water from the filter is chlorinated and directed to a baffled clearwell. The two vertical turbine pumps deliver treated water to the distribution system. Pump operation is based on a water level signal from the elevated storage tank. When operated in automatic mode, the plant may start and stop more than once daily with each start on a "dirty" filter. According to the operator, the clearwell is taken out of service once each year to remove accumulated sediment in the tank bottom.

Operation is usually by the automatic mode (i.e., storage tank elevation). During peak water usage periods in the summer months, the plant operates 12-14 hr each day at the design rate 16 L/s (250 gpm). Less operating time is required during the winter. The plant is staffed about 2-3 hr each day by one operator. Board members assist with plant maintenance and repair on an as-needed basis. The plant operator is also responsible for a booster pump station and distribution system serving the rural water members of the district. The operator and board members reported that maintaining this part of the system can be very time consuming because of frequent leaks that occur in areas of the rural distribution system.

Major Unit Process Evaluation

The performance potential graph is shown in Figure 4-37. Mixing, flocculation, and sedimentation processes all occur in the solids contact unit. Although flocculation is typically evaluated on the performance potential graph, it was not included here because the process occurs within the solids contact unit. Flocculation in solids contact units is enhanced by the recirculation of flocculated water through the mixing tube with the incoming raw water. The sedimentation component of the solids contact unit was rated at a surface overflow rate of 58 $m^3/m^2/d$ (1,421 gpd/sq ft), which is slightly less than the design rate. This rating is also based on incoming raw water turbidity levels of less than 500 NTU, which is typical for most of the year, and a relatively shallow depth of 3 m (10 ft). For occasions when turbidity is greater than 500 NTU, the sedimentation component was rated at a surface overflow rate of 32 $m^3/m^2/d$ (790 gpd/sq ft) or 8 L/s (125 gpm). At this turbidity level, control of the sludge blanket might be difficult and solids loss from the unit would begin to affect filter performance. The plant could overcome this limitation by operating at the lower flow rate of 8 L/s (125 gpm) over a longer period of the day.

The dual media filter was assessed based on a filtration rate of 176 $m^3/m^2/d$ (3 gpm/sq ft). At this rate, a potential capacity of 16 L/s (250 gpm) was projected for the existing filter. In some cases, dual-media filters have been rated over 176 $m^3/m^2/d$ (3 gpm/sq ft); however, because of the complex operations associated with the solids contact unit, a conservative filtration rate was selected. This rating also assumes that the existing effluent control valve limits extreme variations in water flow rate through the filter. Although the modifications made to the control valve appear to have significantly improved filter operation, adequate time was not available during the

Figure 4-37. Plant 8 performance potential graph.

Unit Process	Flow, gpm: 50	100	150	200	250 (Design Flow)	300
Solids Contact Unit[1]						
SOR, gpd/sq ft	316	632	947	1,263		
Filtration[2]						
HLR, gpm/sq ft	0.6	1.2	1.7	2.3	2.9	
Disinfection						
Contact time, hr	4.9	2.5	1.6	1.2	1.0	

[1] Capacity reduced to approximately 125 gpm when turbidity >500 NTU. Shallow, 10-ft deep clarifier limits capacity to <250 gpm when turbidity >500 NTU.
[2] Assumes adequate filter effluent control valve.

site visit to thoroughly evaluate the valve's effectiveness.

The chlorine contact basin was rated at 16 L/s (250 gpm) based on a hydraulic residence time of 1 hr. Disinfection capability is typically based on current State criteria of a 2-hr residence time after chlorination. The 1-hr residence time was allowed in this case because of the efficient baffling that exists in the contact basin.

At the present time, the plant operates at the 16 L/s (250 gpm) rate for about 12-14 hr/day during the peak demand period. The performance potential graph indicates that this peak demand can be met when raw turbidity is less than 500 NTU without significant changes in hours of operation. To meet the peak demand when turbidity is greater than 500 NTU, the plant would have to operate at a reduced rate of approximately 8 L/s (125 gpm) over a 24-hr period.

Performance Assessment

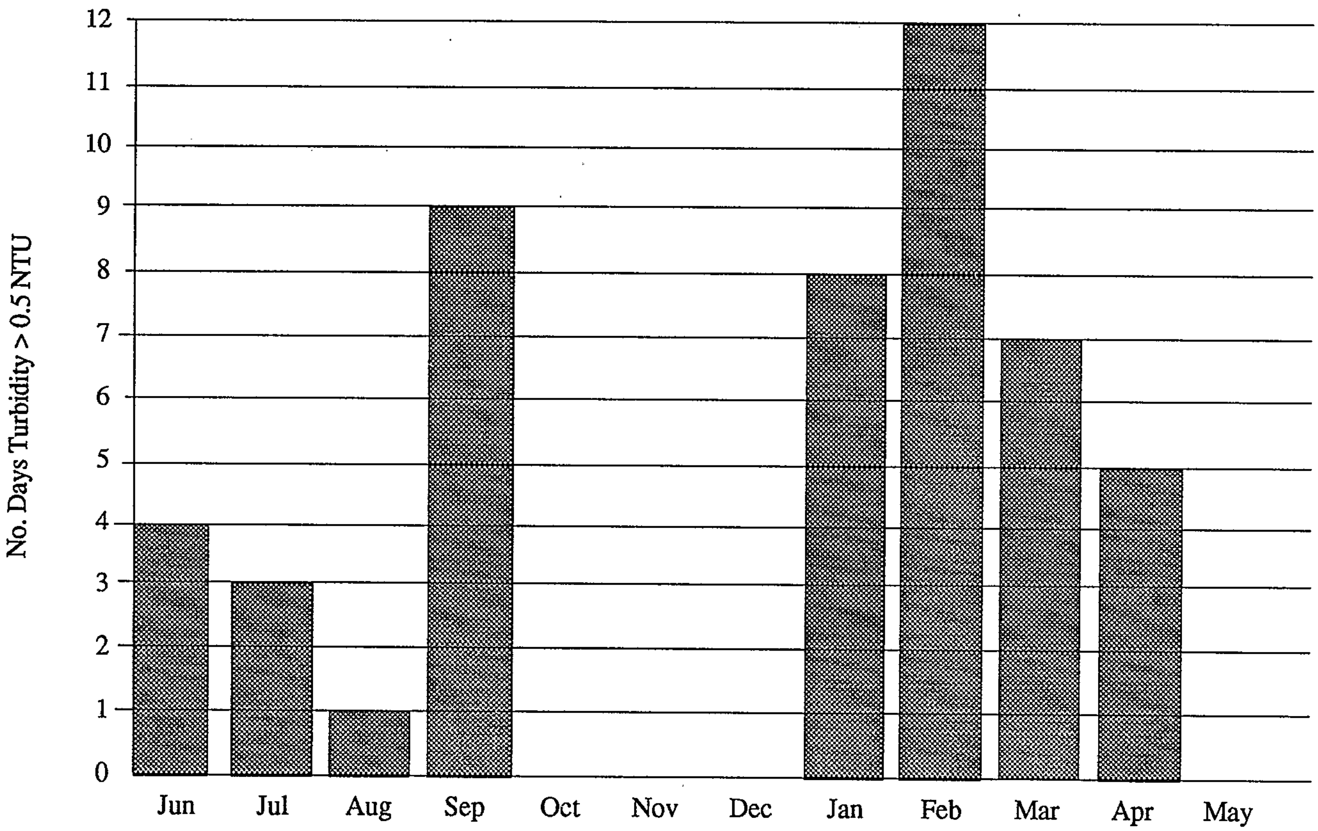
This plant has historically had operational problems associated with the operation of the solids contact unit. During the CPE site visit, the plant operator reported that maintaining a sludge blanket in the solids contact unit has been a problem since startup. Other operations-related information obtained during the site visit indicated that performance problems have been more common than indicated by plant monitoring reports. Figure 4-38 shows the number of days that treated water turbidity exceeded 0.5 NTU (the SWTR turbidity standard for treated surface water) for each month over the past year. This analysis indicated that performance problems have occurred on a frequent basis over the past year, and have been more severe during the winter months when low turbidity, cold water was treated by the plant.

During the CPE, a special study on filter startup under two different conditions was conducted. The first condition consisted of starting a dirty filter (i.e., a condition in which a backwash had not occurred before filter startup) and monitoring effluent turbidity. The operator indicated that this condition occurs routinely at the plant because of the automatic mode of operation. A graph of filter performance under this condition is shown in Figure 4-39. As shown, following filter startup effluent turbidity immediately increased to over 5 NTU and then gradually decreased to about 1.5 NTU after 20 minutes. Results of this test indicate that starting a dirty filter results in turbidity levels above the 0.5-NTU limit for an extended period of time and presents a significant danger of passing pathogenic organisms through the filter.

The second condition of the special study involved backwashing the filter and monitoring the effluent turbidity after it was placed in operation. As shown in Figure 4-40, turbidity after backwash increased immediately to a peak value of 13.5 NTU. About 25 minutes after the filter startup, the effluent turbidity decreased to the 0.5-NTU level. This condition also indicates the potential for pathogenic organisms to pass through the filter. Properly conditioned filters typically experience a turbidity spike of less than 0.2 NTU for less than 15 minutes.

Several problems associated with the backwash contributed to the subsequent poor performance of

Figure 4-38. Plant 8 performance.



the filter. When the backwash sequence was initiated, the surface wash valve did not open. According to the operator, the surface wash normally operates the entire length of the backwash period. The filter was washed for over 23 minutes, a much longer than normal duration for this function, without getting clean. Because of the dirty condition of the filter, the backwash rate was manually increased by adjusting the control valve, but never succeeded in cleaning the filter. Measurements of the rise rate in the filter at the beginning of the backwash indicated a backwash rate of approximately 645 $m^3/m^2/d$ (11 gpm/sq ft), less than the minimum recommended value of 878 $m^3/m^2/d$ (15 gpm/sq ft). Proper adjustment of the backwash control valve would allow an adequate backwash flow rate.

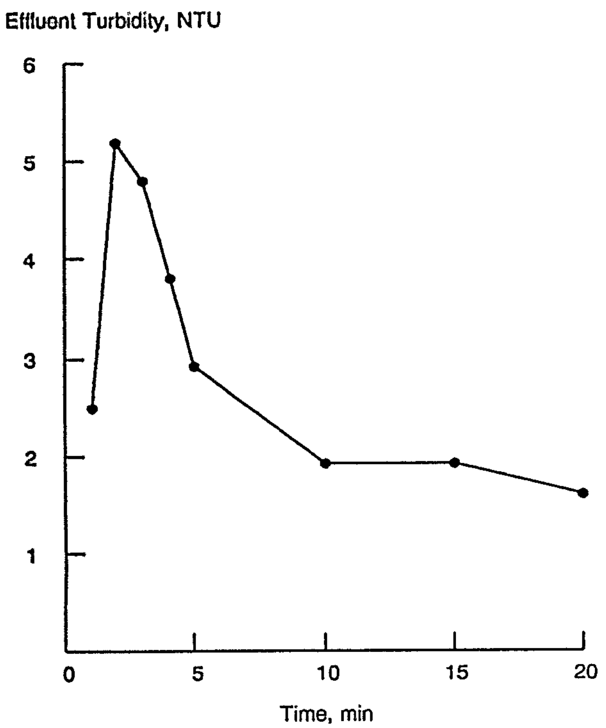
An additional factor that could have contributed to the plant's poor performance during the CPE site visit relates to the alum feed rate to the solids contact unit. The operator indicated that the alum feed rate to this unit was approximately 80 mg/L. Upon checking the alum feeder by weighing a sample of dry alum collected over a selected time period, it was determined that the actual alum feed rate was about 177 mg/L. Since the raw water turbidity was about 80 NTU at the time of the site visit, alum was probably being overfed at this dosage rate. Following further investigation into this problem, it was determined that the operator had exchanged the alum feeder with the lime feeder. This change was implemented so that the feeder with a vibrator could be used for lime addition. The operator was not aware that the new alum feeder had a 3.8-cm (1.5-in) feed screw instead of a 1.9-cm (3/4-in) feed screw, thus causing a higher-than-expected alum dosage.

Performance-Limiting Factors

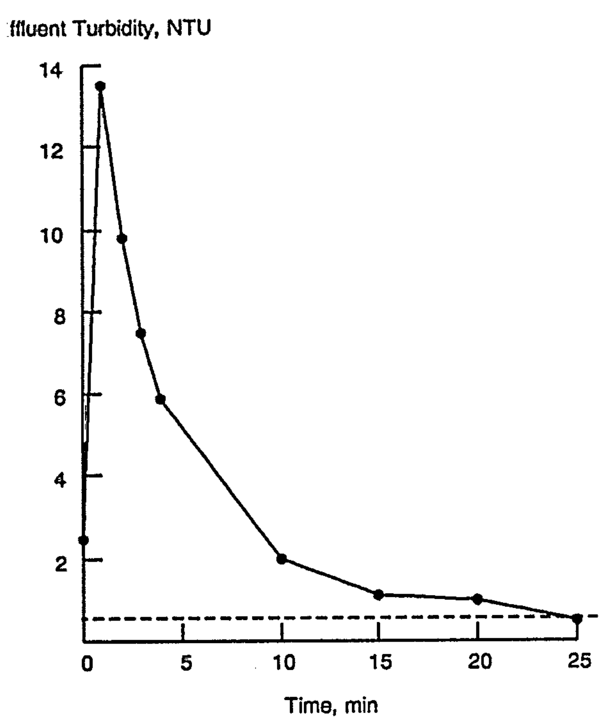
The factors identified as having a major effect on performance on a long-term repetitive basis were prioritized and are summarized below:

1. Water Treatment Understanding - Operation: Lack of operator understanding of water treatment has been a major cause of the performance problems experienced at the plant. The plant operator never received any formal training on operation of the plant. This situation is compounded by the fact that the solids contact process is complex and requires a high level of process control to achieve good performance. Examples of this lack of understanding include incorrect calculations of

Figure 4-39. Turbidity profile - dirty filter startup - Plant 8.



gure 4-40. Turbidity profile - filter startup after backwash - Plant 8.



alum and polymer feed dosages, startup of dirty filters, inadequate process control testing, and an inadequate filter backwashing procedure.

2. Process Control Testing - Operation: The current process control testing in effect at the plant is inadequate. The only process control testing currently done is periodic jar testing to determine chemical dosages. Jar testing should be completed whenever raw water quality changes significantly. Control of the solids contact unit requires daily monitoring of influent and effluent turbidity, sludge blanket concentration and location, and blowoff sludge volume and concentration. The plant does not have adequate testing equipment to perform many of these tests. Although a jar testing apparatus is available at the plant, it does not accurately simulate the flocculation and coagulation processes. Equipment necessary to monitor the solids contact unit includes a blanket finder and a centrifuge.

3. Plant Coverage - Administration: Paid coverage at the plant is presently 2- 3 hr/day, 7 days/week. If unanticipated problems develop at the plant or distribution system that require time beyond the routine amount, the operator and board members volunteer time to correct the situation. The operator's son currently acts as a backup operator; however, he has not received any formal training and is not certified in water treatment. Given the complex nature of the plant and the potential for extreme variations in raw water quality, coverage at the plant needs to be extended. Ideally, whenever the plant is in operation, an operator should be at the plant monitoring its performance. A minimum of 4 hr each day probably would be required to perform routine process control testing, data analysis, reporting, and preventive maintenance activities. Realistically, it would probably be difficult to staff the plant at all times that it is in operation because of the small size of the district. A possible compromise could include increasing plant coverage to a minimum of 4 hr/day, not including the distribution system, and adding an alarm/dialer system at the plant.

4. Insufficient Funding/Bonded Indebtedness - Administration: The district received a 40-year loan from the Farmer's Home Administration to fund the construction of the plant in 1981. Repayment of this loan requires approximately 50 percent of the district's revenues at the present time. Because of the small size of the district, approximately 46 town customers and 62 rural customers, and the large indebtedness, water rates are moderately high relative to other similar systems. Rates were recently increased to assist in rebuilding a reserve fund that was depleted when the new intake structure was installed. Even

with these moderately high rates, revenues are marginal to cover the cost of additional plant coverage and minor capital improvements.

Factors identified as having either a minimal effect on a routine basis, or a major effect on a periodic basis were prioritized and are summarized below.

1. Plant Staff, Number - Administration: The plant is staffed by one operator at the present time, and he provides coverage 7 days/week. Occasionally, the operator's son performs as a backup operator when the operator is not available. A trained, backup operator is needed at the plant to routinely relieve the regular operator. Several of the board members recognized this problem and expressed their concern with locating a person who would be willing to work on a part-time basis at the pay rate they could afford. The operator's son has expressed some interest in becoming certified in water treatment. Given his work experience at the plant, this option may be worth pursing by the district. Another option could involve utilizing an interested board member as the backup operator. Once trained and certified, the backup operator could provide plant coverage on alternating weekends and during vacations.

2. Alarm System - Design: An alarm and automatic plant shutdown capability are available when high turbidity is recorded from the filter. As is the case with any type of automation, this function has failed on occasion and high turbidity water was directed to the clearwell. This alarm function provides a necessary safeguard against contaminated water entering the distribution system and should be routinely checked and maintained. Because of the high degree of variability in the raw water source, it would be advantageous to have a similar high turbidity alarm and automatic plant shutdown capability for this source. This capability could warn the operator about a change in raw water turbidity and allow time to adjust chemical feed dosages.

3. Chemical Feed Facilities - Design: Because of the exchange made between the lime and alum feeders, the present alum feeder does not appear to have a satisfactory range to feed low dosages under certain water quality conditions. Since overfeeding alum can detrimentally affect plant performance, this problem will have to be corrected. The operator may want to investigate changing the feeders back to their original functions. If lime is to be fed in the future, a new shaker may be required.

4. Process Controllability - Design: Since startup of the plant, the filter effluent control valve has caused erratic control of the water level in the filter. This rapid change in filter water level causes particles to pass through the filter, thus affecting treated water quality. Recently, a throttling mechanism fabricated by the operator and a board member has limited these fluctuations in water level. With this modification completed, this factor moved to a lower priority; however, replacement of the valve should still be considered when funding is available.

5. Performance Monitoring - Operation: During the CPE site visit, performance monitoring records were reviewed, and some performance problems were occasionally noted. However, interviews and special studies conducted during the CPE revealed serious performance problems at the plant. Since records did not accurately reflect actual plant performance, regulatory agency reviews were not able to establish that a performance problem existed. Accurate reporting would probably have resulted in pressure from the regulatory agency and correction of some of the factors noted in this report.

6. Raw Water Turbidity - Design: As noted by the performance potential graph, raw water turbidity above 500 NTU is projected to limit plant capacity. High turbidity water typically occurs during the spring through fall, and only occasionally during this period as the result of runoff from storm events. The high turbidity problem can most realistically be handled through operational changes and minor expenditures for testing equipment and an alarm system. If the current peak demand remains the same, the plant may be able to treat high turbidity water by reducing the flow rate through the plant and operating for more hours during the day. If operational measures are not successful, there should be added flexibility to direct the raw water through a pre-sedimentation basin with chemical addition capability. A pre-sedimentation pond could be used as a backup water supply during short runoff events or used to lower raw water turbidity during longer storm events.

7. Sedimentation/Solids Contact Unit - Design: The solids contact unit's capability to treat water under a variety of conditions may be limited by its relatively shallow 3-m (10-ft) depth and high surface overflow rate. Under these conditions, maintaining a sludge blanket in the unit can be accomplished; however, considerable process control testing and possible adjustments to the plant flow rate are required. The short hydraulic residence time in the unit may limit the plant's capability to treat cold, low-turbidity water. Under cold water conditions, chemical reactions are slower and longer residence times are required. Longer residence times can be achieved by operating the plant at a lower rate for long periods of time.

A factor identified as having a minor effect on plant performance is the existing chemical feed arrangement, which limits the injection of alum, polymer, lime, and soda ash to the mixing tube in the solids contact unit. Under cold, low turbidity water conditions, it would be advantageous to add the coagulation chemicals ahead of the flow meter. This injection location would allow more intense mixing and slightly more detention time when treating cold, low turbidity water.

Projected Impact of a CCP

As indicated by the performance potential graph and factors limiting performance, this plant does have some design deficiencies. However, operational changes at the plant and administrative support could be used to overcome most of these deficiencies. As such, implementation of a CCP could demonstrate dramatic improvement in treated water quality. Before a CCP could be implemented, however, the district would have to commit to providing the additional staffing and coverage required to operate the plant and the expenditures necessary to purchase the necessary testing equipment.

Plant 9

Facility Description

Water is supplied to the city from four sources: a direct filtration plant and three ground-water wells that augment the water supply during summer months. The CPE was limited to the direct filtration plant, which treats water from an infiltration system for domestic and commercial use by the city. The peak day demand for a 12-month period was estimated at 74 L/s (1.7 mgd). Plant 9 includes the following unit processes (see Figure 4-41):

- Infiltration system consisting of perforated subsurface laterals that are connected to shallow caissons
- 8,330-L (2,200-gal) basin that serves as a sand trap
- In-line static mixer with two elements
- 30-m^2 (324-sq ft) monomedia (sand) travelling bridge automatic backwash filter
- Two polymer feed pumps: one for feeding neat polymer and one for feeding diluted polymer
- Gas chlorination system with two chlorinators, each 23-kg (50-lb)/d capacity
- On-site treated water reservoir, 33.5 m (110 ft) in diameter and 2-m (6.5-ft) deep (1.7 million L [462,000 gal])
- Propeller meter on the discharge line from the treated water reservoir
- On-site 12-m x 12-m x 2-m deep (40-ft x 40-ft x 6.5-ft) concrete backwash holding basin, which discharges to an irrigation ditch

Water from one of two creeks is diverted onto a hay field adjacent to the plant where the water percolates through several feet of soil to perforated laterals buried under the field. Water flows through the laterals to concrete caissons, which are fitted with metal covers. A line then carries the composite flow from the caissons to the direct filtration plant. Microscopic particulate examination of the infiltration system water has shown that it is directly impacted by the surface water and, therefore, should be considered a surface water source.

Raw water flows by gravity from the infiltration system to a sand trap basin in the plant. Cationic polymer is fed at the end of the basin after which the water flows through a control valve that regulates the amount of water treated in the plant. Any excess water from the infiltration system flows over a weir at the influent end of the sand trap basin to an irrigation return ditch. The control valve can operate automatically to shut down or start the plant, based on the water level in the finished water reservoir. At the time of the evaluation, the valve was being operated manually to maximize the depth of treated water in the finished water reservoir.

After passing the control valve, the water flows by gravity through an in-line static mixer and onto the automatic backwash filter. The filter was designed to operate at a filtration rate of 117 $m^3/m^2/d$ (2 gpm/sq ft), but was being operated at approximately 211 $m^3/m^2/d$ (3.6 gpm/sq ft) at the time of the CPE. The filter has approximately 28 cm (11 in) of sand media in 54 20-cm (8-in) sections.

The filter sections are separated by fiberglass dividers, which were warped at the top. Because of the warping, some sections were only 2.5-5 cm (1-2 in) wide at the top, while other sections were over 20 cm (8 in) wide at the top. This variation was caused by migration of the sand media from one section to another during backwash.

The filter can be backwashed automatically by headloss or by timer. During the evaluation, the filter was being washed automatically based on headloss, with little consideration given to filter effluent turbidity. When the filter is backwashed, a travelling bridge passes across the filter and washes each section. One pump on the bridge pumps water back up through the filter section and another pulls the spent backwash water from the top of each section through a shroud to a discharge channel adjacent to the filter. The backwash water flows by gravity to the backwash storage basin. Following filtration, the water is chlorinated prior to the filter level control weir and flows into the treated water reservoir. Effluent from the reservoir flows by gravity 8 km (5 miles) to town through parallel 20-cm (8-in) and 25-cm (10-in) transmission lines.

Sludge from filter backwashes is stored in the concrete backwash storage basin. Supernatant from the basin is discharged over a weir to an irrigation ditch. According to the operator, sludge is removed from the basin every 3-4 years by wheelbarrow and front-end loader and is spread on adjacent fields.

Operation is primarily manual except for filter backwashing. Plant operation, flow rates, and chemical dosage rates are all initiated manually by the plant operators. The two plant operators spend approximately 0.5-1 hr each day at the plant checking the operation of the plant. During that time, the plant is inspected to ensure equipment is operating properly; no significant process control activities are conducted. The operators are also responsible for the wastewater treatment plant, wastewater collection system, water distribution system, streets, parks, airport, swimming pool, and grave digging at the cemetery.

Figure 4-41. Plant 9 process flow diagram.

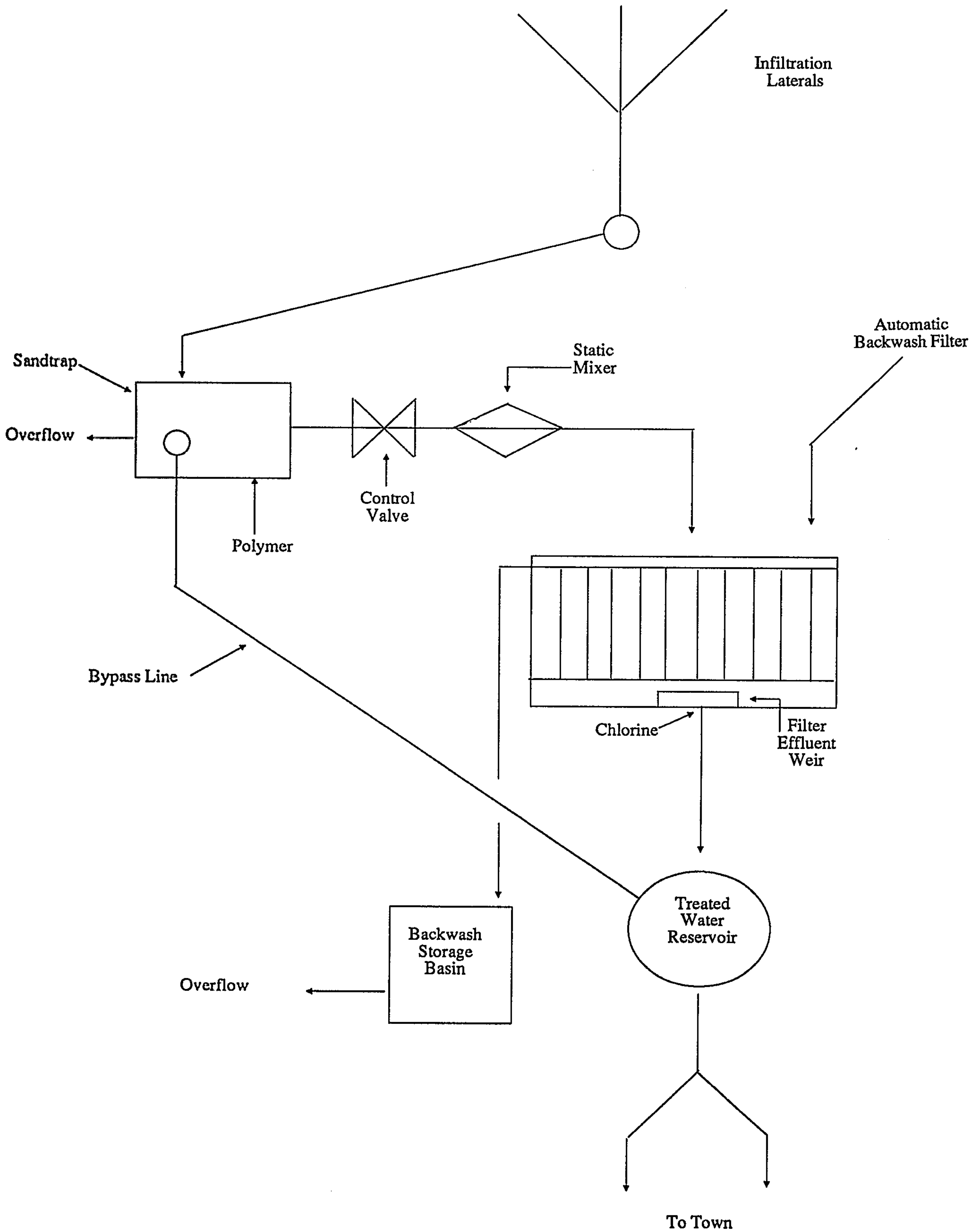
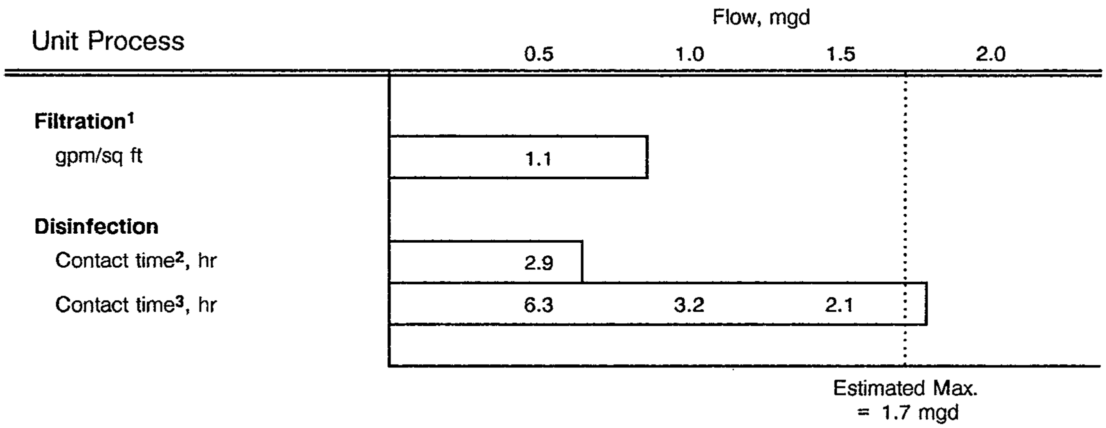


Figure 4-42. Plant 9 performance potential graph.



[1] Rated at 2 gpm/sq ft because there is only 11 in of sand medium.
[2] Based on current State standard of 2-hr HDT to first tap. Assumed 10 percent volume of clearwell and 0.75 mi of 8- and 10-in pipe to first user. HDT refers to time it takes water to travel from the plant to the first tap.
[2] Based on current State standard of 2-hr HDT to first tap. Assumed 10 percent volume of clearwell and 2.5 mi of 8- and 10-in pipe to first user in town.

During the evaluation, peak water use in the city was approximately five times greater than typical water use for a community with no large industrial users. This extensive use required the city to augment the surface water supply with three ground-water wells. Determining the cause of the excessive water use and taking measures to lower it to normal levels would allow the plant to operate at lower flow rates.

Major Unit Process Evaluation

The performance potential graph is shown in Figure 4-42. Peak day demand for the plant was estimated by measuring the depth of flow over the filter effluent weir and applying that flow on a 24-hr basis. This flow was then compared to projected plant capabilities. As Figure 4-42 shows, the monomedia sand filter was assessed at a potential capacity of 39 L/s (0.9 mgd) based on a filtration rate of 117 $m^3/m^2/d$ (2 gpm/sq ft). The filter capability was limited because a direct filter using 28 cm (11 in) of sand cannot be expected to provide consistent performance at rates higher than 117 $m^3/m^2/d$ (2 gpm/sq ft).

Disinfection capability was rated based on current state criteria of a 2-hr detention time after chlorination. As Figure 4-42 shows, two conditions were rated: detention time to the first tap downstream from the plant and to town. Disinfection detention time was adequate to town at flow rates up to 77 L/s (1.75 mgd). However, detention time to the first tap only resulted in a plant capacity of 33 L/s (0.75 mgd). Standards are being revised and different criteria may be used to allow lower minimum detention times for existing plants, which would likely rely on effective filtration.

Because of the limitation in the filtration process, the plant was assessed as inadequate to meet the projected peak demand. However, water use on a per capita basis was noted to be extremely high. Normal water use would result in daily water production of about 39 L/s (0.9 mgd), which the plant should be able to handle on a continuous basis.

Performance Assessment

A review of the operating records indicated that the raw water was of very good quality with peak turbidities of 0.7 NTU. Treated water was also of good quality with turbidities normally about 0.2 NTU and with a peak of 0.45 NTU. However, turbidity of very clear waters, such as the water from the infiltration system, is often not a good indication of bacteriological quality. In fact, previous state particulate tests revealed that the filter was not removing a significant number of particles from the raw water. The operating data revealed that only about 50 percent of the raw water turbidity was being removed. Plant data taken during periods of no chemical feed and some chemical feed indicated little difference between raw and treated water turbidity between the two.

During the CPE, a special study was conducted to determine the effect of backwashing the filter on treated water quality. The filter was backwashed and samples were collected as near as possible to the filter cell being washed and at the filter effluent weir. Figures 4-43 and 4-44 present the results of the study. As shown, at both sample points effluent turbidity increased significantly (to 5 and 7 NTU) during backwash and remained above the 0.5 NTU

Figure 4-43. Turbidity profile during and after backwash at filter effluent weir - Plant 9.

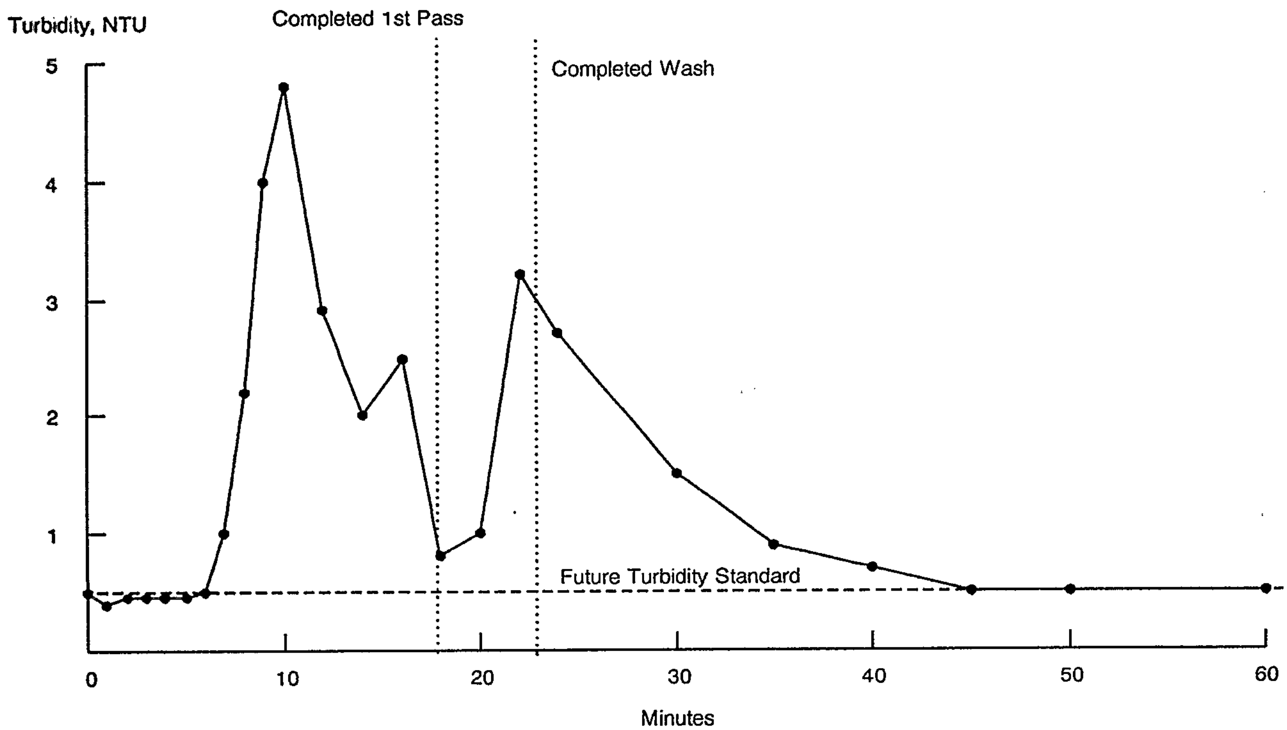
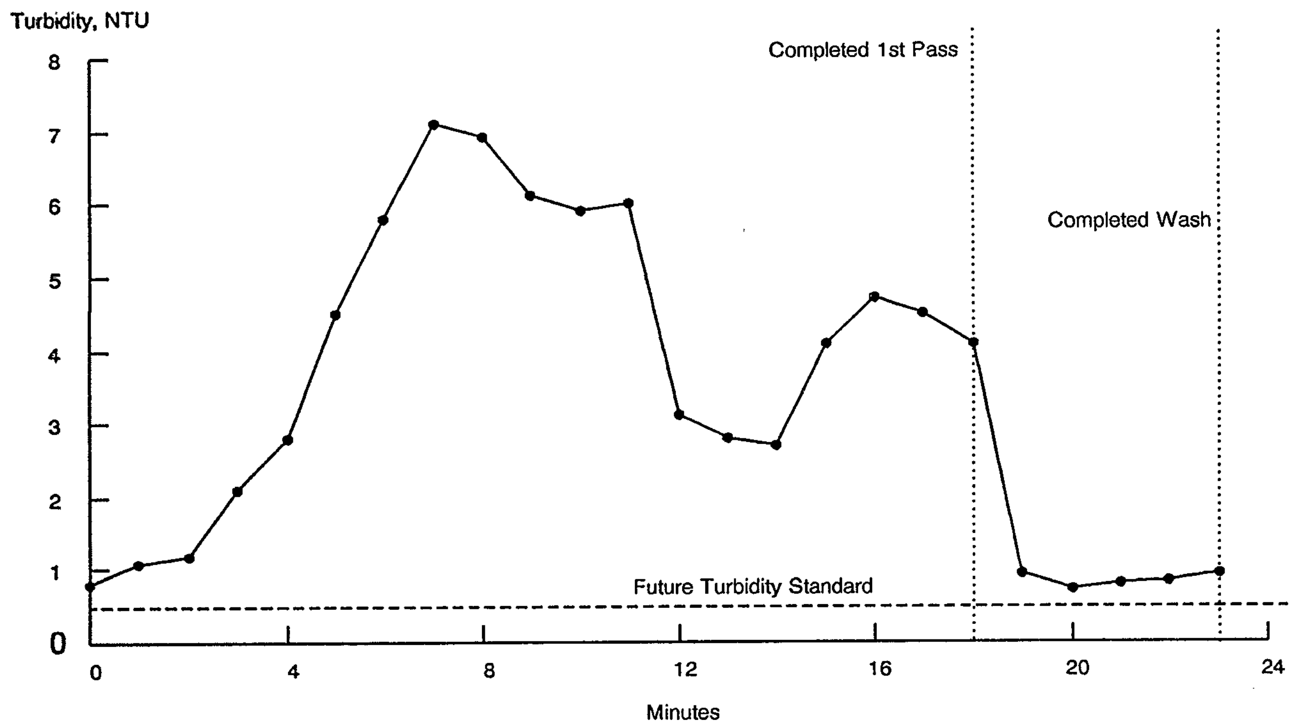


Figure 4-44. Turbidity profile during and after backwash at cell effluent - Plant 9.



limit for over 60 minutes. The study results indicate that a significant amount of the material removed by the filter was allowed to pass through the filter into the treated water reservoir. The significant increase in turbidity is especially indicative of poor performance, since the raw water turbidity was only about 0.6 NTU during the special study.

The special study results, State microscopic evaluations, and plant daily records indicate that the plant is not effectively removing particles found in the raw water. Should a significant number of parasitic organisms such as *Giardia* cysts or *Cryptosporidium* oocysts occur in the raw water (for example, as a result of cattle feeding on the grass above the infiltration system), they would likely enter the plant and pass through the filter. Since some cysts are resistant to disinfection by chlorine, they could pose a significant health hazard to the community.

Performance-Limiting Factors
The factors identified as having a major effect on performance on a long-term repetitive basis were prioritized and are summarized below:

1. Water Treatment Understanding - Operations: The plant superintendent/utilities director is a very motivated operator; however, he has not received any formal training in water treatment practices. This is compounded by the complexity of operating a direct filtration plant treating cold, low alkalinity, low turbidity water. Lack of water treatment understanding was identified as the top ranking factor because it has led to poor operating decisions, such as little or no change in chemical feed rates, filter backwashing based on headloss rather than filtered water quality, and bypass of untreated raw water to the treated water storage reservoir. Operation of the plant will require a process control program and an understanding of coagulation chemistry including chemical feed calculations.

2. Process Control Testing - Operations: There was no process control program in place at the plant. Operation of a surface water plant requires that testing be conducted and results recorded in a systematic manner so that data is available to make process control decisions. Control of the direct filtration plant will require daily monitoring of influent turbidity, continuous monitoring of filter effluent turbidity, and jar testing to select appropriate coagulant aids and to determine optimum chemical doses.

3. Process Automation - Design: The plant is not equipped with a continuous reading and recording turbidimeter, which is necessary to adequately monitor plant performance since the staffing levels do not allow turbidity tests to be conducted more than once each day. A continuous reading turbidimeter would allow filter performance to be monitored following a backwash so that chemical feed could be optimized to reduce the increase in turbidity (turbidity spike) that occurs after a backwash.

4. Disinfection - Design: A detention time of 2 hr is needed to ensure effective disinfection of the treated water prior to the first user. The new regulations that will be promulgated as a result of the SWTR and/or current state criteria may necessitate capital improvements before the water system has adequate disinfection capability. An example of a capital improvement would be the installation of baffle walls in the clearwell to keep the water in the basin longer for disinfection rather than taking a direct route through the basin from the influent to the effluent pipe. This factor was asterisked because the final rule will not be effective until June 29, 1993, following development of State criteria in 1990.

5. Filtration - Design: The filter is presently being operated at too high a rate to expect adequate performance on a continuous basis. In addition, warping of the filter section dividers and the potential inability of the travelling backwash mechanism to properly wash the filter could impact filter performance. This factor was asterisked because it may be possible for the plant to operate at a flow rate consistent with its capability, if water use is reduced to normal levels. Under this condition, the filter dividers and backwash may prove not to significantly impact performance.

Factors identified as having either a minimal effect on a routine basis, or a major effect on a periodic basis are summarized below in order of priority.

1. Process Controllability - Design: The effluent flow meter does not adequately measure the plant flow rate because it is located downstream of the finished water storage reservoir. The flow rate out of the reservoir is not indicative of the plant flow rate. Since accurate flow measurement is the basis for chemical feed calculations and filter hydraulic loading rates, actual plant flow needs to be accurately measured.

2. Laboratory Space and Equipment - Design: The plant is not equipped with a jar test apparatus. Because of the raw water quality characteristics (low turbidity, alkalinity, and temperature), special studies with various coagulant and flocculant aids will likely be required to optimize plant performance. A jar test apparatus will be necessary to conduct the special studies as well as to optimize plant chemical feeds.

3. Alarm System - Design: There were no alarm systems in the plant to warn the operator of

problems, such as chemical feeder shutdown or raw water quality changes. Since the plant is only checked once each day for about 1 hr, it is essential that alarms be provided to warn the operator of a change in conditions. If alarms are not provided, the plant should be staffed any time it is in operation.

4. Watershed Management - Design: Allowing cattle to graze on top of the infiltration system provides an unnecessary public health risk. Cattle are known carriers of *Cryptosporidium*, a parasitic cyst that is extremely resistant to chlorine disinfection and small enough to easily pass through a poorly operated filter. A direct filtration plant provides a limited number of barriers to pathogenic organisms and limited response time for the operator to react to a change in raw water quality.

No factors in the administration or maintenance areas were identified as impacting performance.

Projected Impact of a CCP

Plant 9 produces water that poses a significant health risk to consumers. Conducting a CCP could result in an improvement in finished water quality, especially during and after filter backwashing. However, because peak water demands exceed the rated capacity of the filter and disinfection system, the plant would have to be operated at a lower flow rate. In addition, design aspects of the filter such as backwashing effectiveness and uneven filter dividers, could limit filter performance to the extent that the plant could not meet regulatory requirements on a continuous basis. The CCP might discover that limitations in the filtration system require major capital improvements to ensure continuous compliance with applicable regulations.

Plant 10

Facility Description

Plant 10 is a conventional water treatment plant supplied from a nearby river that provides water for domestic use. The peak operating flow for the plant was established at 22 L/s (0.5 mgd) based on a review of flow records for the previous year. The plant is normally operated for approximately 8 hr/day; however, on several days the plant is operated for longer than 8 hr to meet demands of peak water use. On these days, the treatment processes are still operated only at the 22-L/s (0.5-mgd) flow rate. Plant 10 consists of the following unit processes, shown schematically in Figure 4-45:

- Intake structure located on the bank of the river, consisting of a manhole intake structure and a wet well from which raw-water pumps deliver the water to the plant. A bar screen is provided between the manhole intake structure and the wet well
- Three manually operated vertical turbine raw water pumps; two 22 L/s (350 gpm) and one 16 L/s (250 gpm)
- Raw water flow measurement consisting of an 20-cm (8-in) orifice meter with a chart recorder. Also, a manual rate-of-flow controller
- Volumetric feeder each for alum, lime, and powdered activated carbon
- Two 9.1-m (30-ft) diameter sedimentation basins, each with a surface area of 66 m^2 (707 sq ft) and a volume of 307,000 L (81,100 gal)
- Two 19,300-L (5,100-gal) recarbonation basins
- Four 2.6-m x 3.0-m (8.7-ft x 10-ft) filters with 61 cm (24 in) of sand media
- 94-L/s (1,500-gpm) backwash pump
- Gas chlorination system
- Two clearwells: one with a capacity of 567,750 L (150,000 gal) and the second with a capacity of 56,775-L (15,000-gal)
- Two 47-L/s (750-gpm) vertical turbine high-service pumps
- Venturi-type flow meter, totalizer, and chart recorder

Water from the river is pooled behind a low head dam across the river downstream of the intake structure. Several pipes extend out into the river from the manhole intake structure allowing water to be taken from different locations. The water then flows to the wet well where it is picked up by the raw water pumps.

Raw water pumps located on top of the wet well move the raw water from the intake structure to the plant. Only one of the 22-L/s (350-gpm) pumps is used. Though the plant was originally designed for 44 L/s (700 gpm), the plant staff feels that 22 L/s (350 gpm) is the maximum flow that can be handled because of limitations with the sedimentation basins. Since the plant is operated at a constant rate of 22 L/s (350 gpm), variations in water demand are met by varying the length of time the plant is operated. Raw water flows entering the plant are measured and recorded. A manual rate-of-flow controller is available though not normally used.

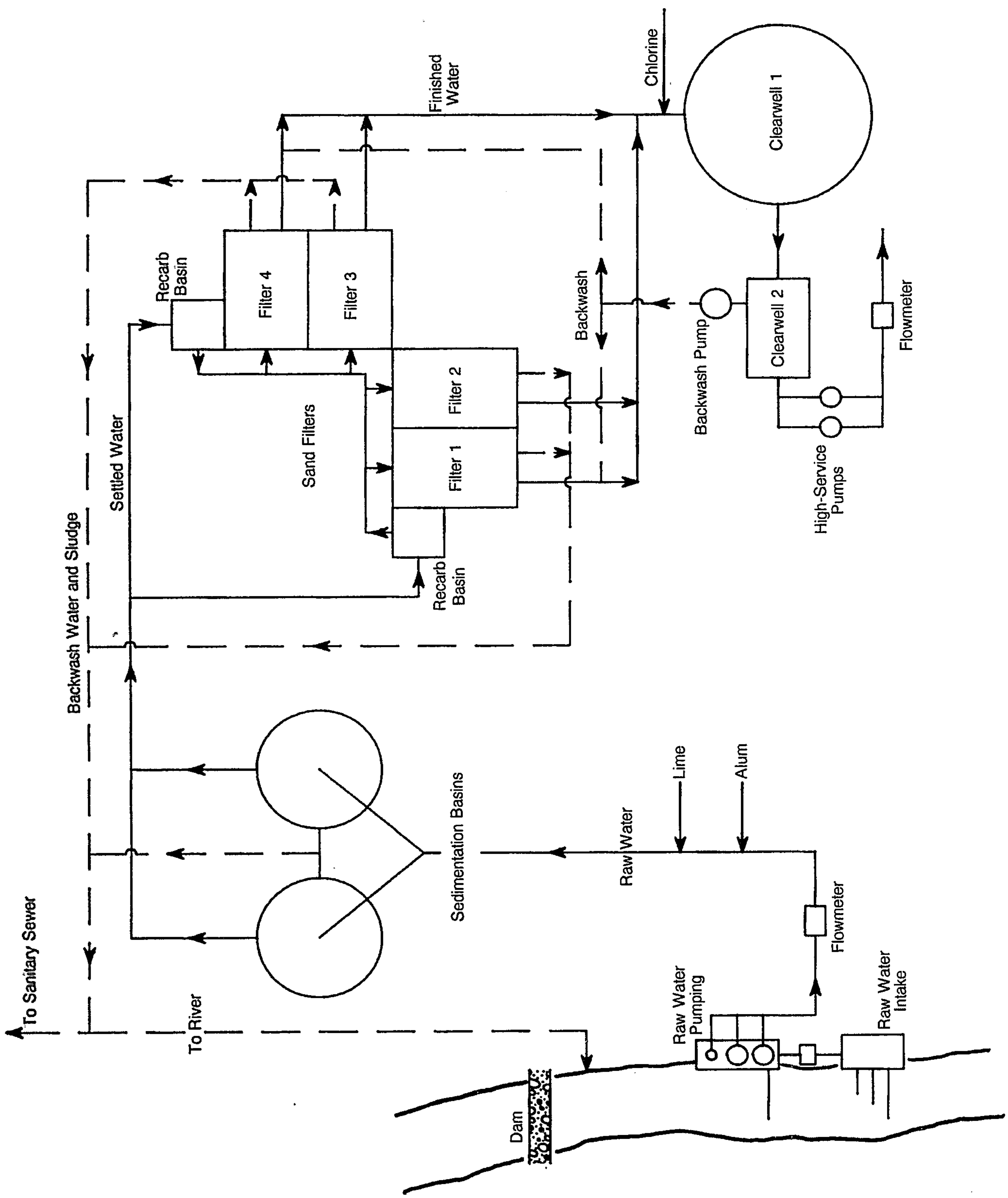
Volumetric feeders discharge dry chemicals into tanks below the feeders, where water is added and mixed to make a slurry. As the raw water flows to the sedimentation basins, alum and lime are added as slurries into the pipe. Chemical feed rates can be adjusted by varying the amount of chemical added to the slurry tanks. These adjustments are made based on observations of floc formation in raw water samples that have been placed on a magnetic stirring apparatus after chemical feed. No mechanical or static flash mixing is provided. Chemical feed rates are not routinely adjusted.

After chemical addition, raw water flows to the two sedimentation basins. These units were originally designed as a type of upflow solids contact clarifier, eliminating the need for separate flash mix and flocculation processes, but they are no longer operated as designed. Flow enters through a 20-cm (8-in) pipe at the bottom of the unit and strikes a small baffle redirecting the flow in the basin. Basin effluent discharges through peripherally mounted submerged orifice weirs. Each basin originally had a rotating arm located near the bottom powered by pressurized basin effluent. Basin effluent was to be withdrawn and pumped back through nozzles in the arm causing it to rotate and promote flocculation. The rotating arm has been removed from one of the units and is not operational in the second. Sludge is manually removed from the basins twice a year. The plant discharges this sludge to the sanitary sewer or back to the river.

Settled water flows by gravity from the sedimentation basins to the four sand filters and is controlled by float valves in the recarbonation basins. These valves shut off sedimentation basin effluent flow if the level in the filters exceeds the maximum. Operators visually monitor the filter water levels and adjust the flow using rate-of-flow controllers. Flow meters are available for each filter, but are not used for filter flow adjustment.

During the CPE, the standard practice for filter backwashing was to wash two of the filters each day

Figure 4-45. Plant 10 process flow diagram.



using backwash water from Clearwell 2. Headloss or turbidity measurements were not typically used to initiate backwashing. The backwash pump discharges through a rate-of-flow controller, but there are no valves that can easily be operated to slowly start and stop the backwash flow to the filters. The surface of the sand is manually raked during the backwashing. The plant discharges backwash water to the sanitary sewer or to the river. During the CPE, the backwash water was being discharged to the river.

Water from all four filters is discharged to Clearwell 1, immediately following injection of chlorine gas into the pipe. Chlorine doses are controlled to provide a residual of 2.5-3.0 mg/L. Finished water normally flows from Clearwell 1 to Clearwell 2; piping is provided to allow bypassing of Clearwell 1. Clearwell 2 also serves as the suction pipe for the high-service and backwash pumps.

Two high-service pumps supply finished water to the two in-ground storage tanks that feed the village water distribution system. These pumps are operated manually based on water levels in the storage reservoirs.

Major Unit Process Evaluation

The performance potential graph is shown in Figure 4-46. Flocculation is a key major unit treatment process. As originally designed, the sedimentation basins were to provide both flocculation and sedimentation; however, the flocculation aspect of these units has been removed or is inoperable. The CPE team doubts that the units were ever capable of providing acceptable flocculation even if operated as designed. As such, the flocculation process was given a peak instantaneous rated capacity of 0 L/d. This rating implies that the plant cannot be expected to consistently produce the desired water quality of less than 0.5 NTU without adding flocculation process capabilities.

The sedimentation basins were rated at 12 L/s (0.28 mgd) based on a surface overflow rate of 8.1 $m^3/m^2/d$ (200 gpd/sq ft). The surface overflow rate is significantly lower than that for other types of circular sedimentation basins with the same depth as Plant 10. The projected peak instantaneous operating capacity of the sedimentation basins was lowered because of the extremely poor inlet conditions. With the inlet structure located in the bottom of the sedimentation basins, the influent flow disrupts the settled solids and tends to carry them upwards towards the effluent. Properly designed sedimentation basins introduce the influent water near the surface through an inlet structure that directs the flow into the basin, promoting the separation of solids from the clarified liquid over the entire surface area. This allows the separated solids to move by gravity to the bottom of the basin and the clarified effluent to move to the surface where it is removed.

The filters were rated at 22 L/s (0.50 mgd) based on a filter loading rate of 58 $m^3/m^2/d$ (1 gpm/sq ft). This loading rate is lower than typical values because of the air binding observed by the CPE team during filter backwashing. Air binding results in air pockets in the filter media, which prevents water from passing through that portion of the filter, effectively lowering the surface area available for filtration. The filter loading rate, therefore, was lowered in the assessment to compensate for the loss of filter area due to the observed air binding.

The disinfection system was rated at 24 L/s (0.54 mgd). Future drinking water regulations for disinfection will be based on CT values found to be needed for various removals of Giardia cysts and inactivation of viruses. CT is the disinfectant concentration multiplied by the actual time the finished water is in contact with the disinfectant. To establish the CT required, it was assumed that the plant's disinfection system would have to provide 2 logs (99 percent) of cyst removal with 2 logs of removal credited for the other treatment processes. The total of 4 logs of cyst removal required for the plant was based on the CPE team's estimate of the quality of the raw water.

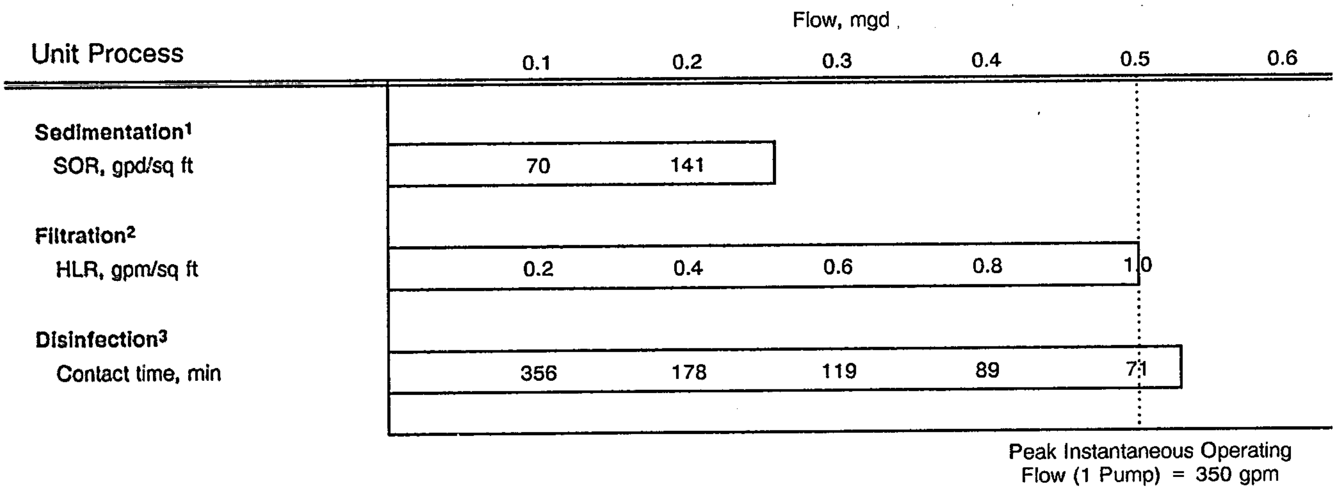
To achieve the 2 logs of cyst removal, the CPE team estimated that the disinfection system would have to provide a CT of 133. This CT value is for chlorine at a 2.0 mg/L dose, pH 7.5, and temperature of 5C. The contact time was based on the chlorine being added ahead of Clearwell 1 and the flow passing through both clearwells. Only 15 percent of the theoretical detention time in the clearwells was used because the clearwells are not baffled and because they are subjected to fill and draw operation. The actual levels of disinfection required for the plant in the future will be determined by the State. The CPE estimates of the required total number of log reductions and the allowances for actual contact times in the clearwells may change when the final state regulations are developed.

The performance potential graph shows that the lack of flocculation severely limits the capabilities of the treatment processes. Without adequate flocculation, the CPE team estimates that there is essentially no flow where the required performance can be obtained. The sedimentation basins also severely limit the capacity of the plant, even if adequate flocculation was provided. These processes prevent the plant from achieving desired performance at the current peak instantaneous operating flow rate of 22 L/s (350 gpm). The filters and disinfection system were projected to be adequate to treat this flow.

Performance Assessment

Turbidity data from the plant records for the raw water, settled water from the sedimentation basins, and finished water over a 1-yr period are plotted in Figures 4-47, 4-48, and 4-49, respectively.

Figure 4-46. Plant 10 performance potential graph.



[1] Rated at 200 gpd/sq ft because of poor inlet conditions, turbulence at the basin bottom, and poor durface area development.
[2] Rated at 1 gpm/sq ft because of observed air binding.
[3] Rated at CT = 133 with 2 mg/L chlorine dose, which requires a 67-min HDT; allowed 15 percent of available volume dfor contact time, temperature = 5°C, pH = 7.5, 4-log required reduction, 2 allowed for plant.

Figure 4-47 shows the fluctuation of raw water turbidity over the year. Well-designed and operated treatment processes are expected to produce a water with consistent turbidity levels even with wide variations in raw water turbidity. As shown in Figure 4-48, the sedimentation basins produced a settled water that also had significant variations in turbidity. The filters reduced the levels of turbidity, as shown in Figure 4-49, but still experience variations as raw water turbidity changes. These results indicate design and/or operational problems. Figure 4-50 shows the finished water turbidity during a 6-month period when the plant was treating a highly variable turbidity raw water. The applicable regulation for turbidity is currently 1.0 NTU. Future regulations will require the plant to meet a 0.5-NTU finished water turbidity 95 percent of the time. Figure 4-50 shows that the plant generally complies with the 1.0-NTU regulation, but is consistently above the 0.5 NTU required by the future regulations. A probability plot of this same data is shown in Figure 4-51, which indicates that under present conditions the plant would only meet the 0.5-NTU standard approximately 50 percent of the time.

During the CPE, a special study was completed to assess the filter performance after backwashing. With adequate facilities and operation of preceding unit processes, a properly operated filter should produce a finished water turbidity of approximately 0.1 NTU and only experience a 0.2-NTU rise in turbidity in the finished water for approximately 10 minutes after restart following backwashing. Filters 3 and 4 were sampled for a 30-minute period after restart following backwashing. The results of this special study are shown in Figures 4-52 and 4-53. Both filters experienced an approximately 0.3-NTU rise in turbidity that did not drop back to the original value even after 30 minutes. These results could indicate a problem with the filters or that the water being applied to the filter has not been properly treated and conditioned in the preceding unit processes.

An evaluation of the filter media was also performed during the CPE. The evaluation team determined that the filters were being adequately backwashed, since no significant mudballs were found. They did find some buildup of chemicals on the surface of the media, but these were not considered to affect performance. Air binding was also observed during the special studies.

Performance-Limiting Factors

The factors identified as having a major effect on performance on a long-term repetitive basis were prioritized and are summarized below:

1. Flash Mix and Flocculation - Design: The plant has no flash mix or flocculation treatment processes, facilities which are required to properly condition the raw water with chemicals prior to the sedimentation and filtration treatment processes. Without these capabilities the plant will have significant problems removing enough turbidity to consistently meet future regulations.

2. Sedimentation Basins - Design: Adequate sedimentation basins are required to remove the coagulated turbidity from the raw water. The sedimentation basins have basic limitations related to the lack of a proper inlet structure. At current

Figure 4-47. Raw water turbidity profile - Plant 10.

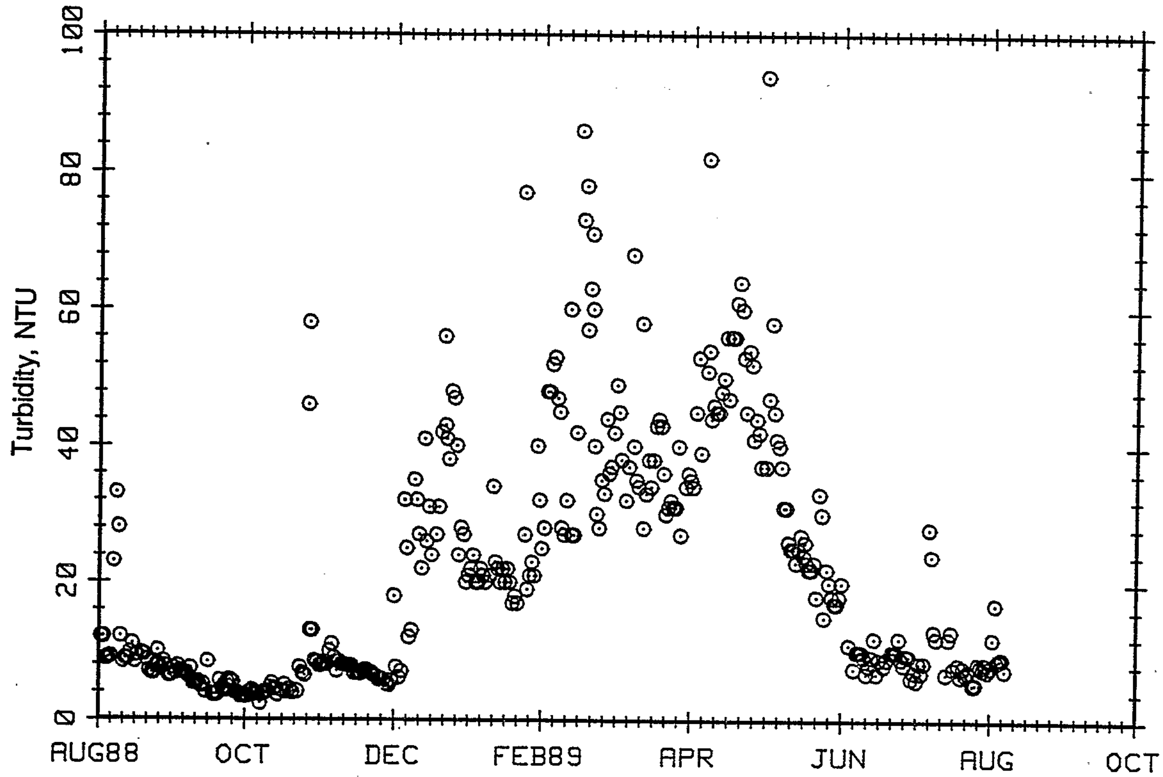


Figure 4-48. Settled water turbidity profile - Plant 10.

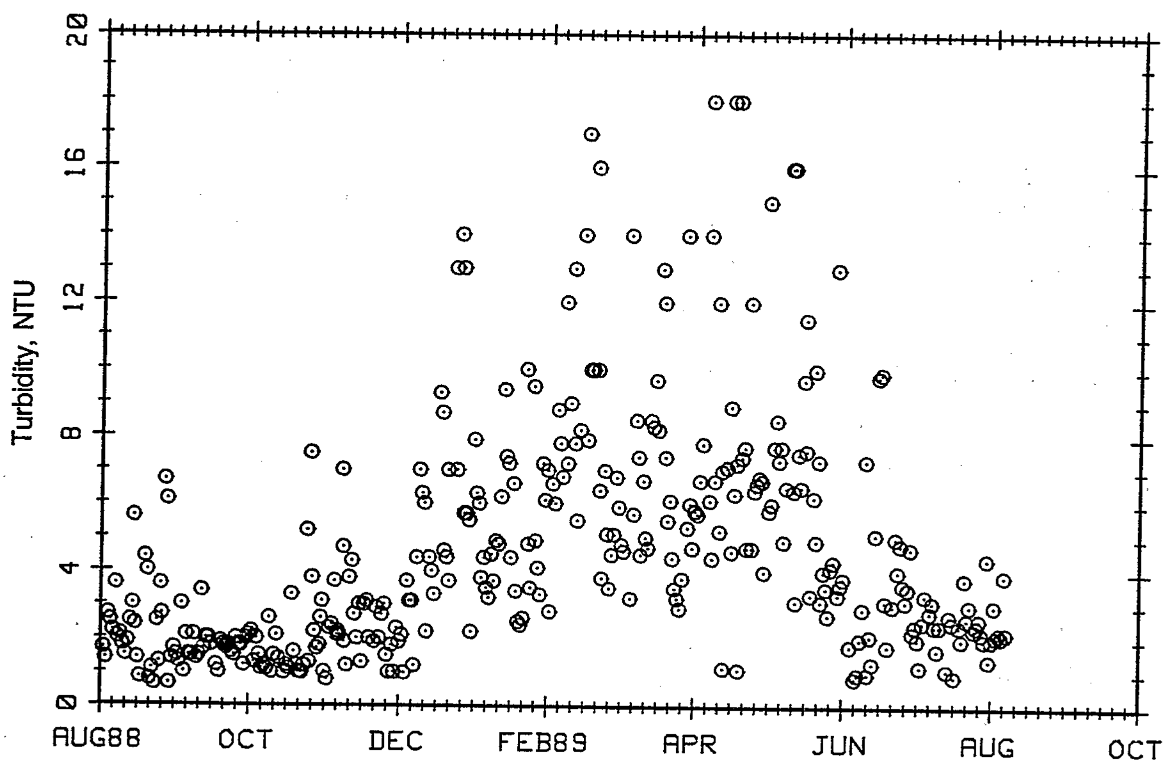


Figure 4-49. Finished water turbidity profile - Plant 10.

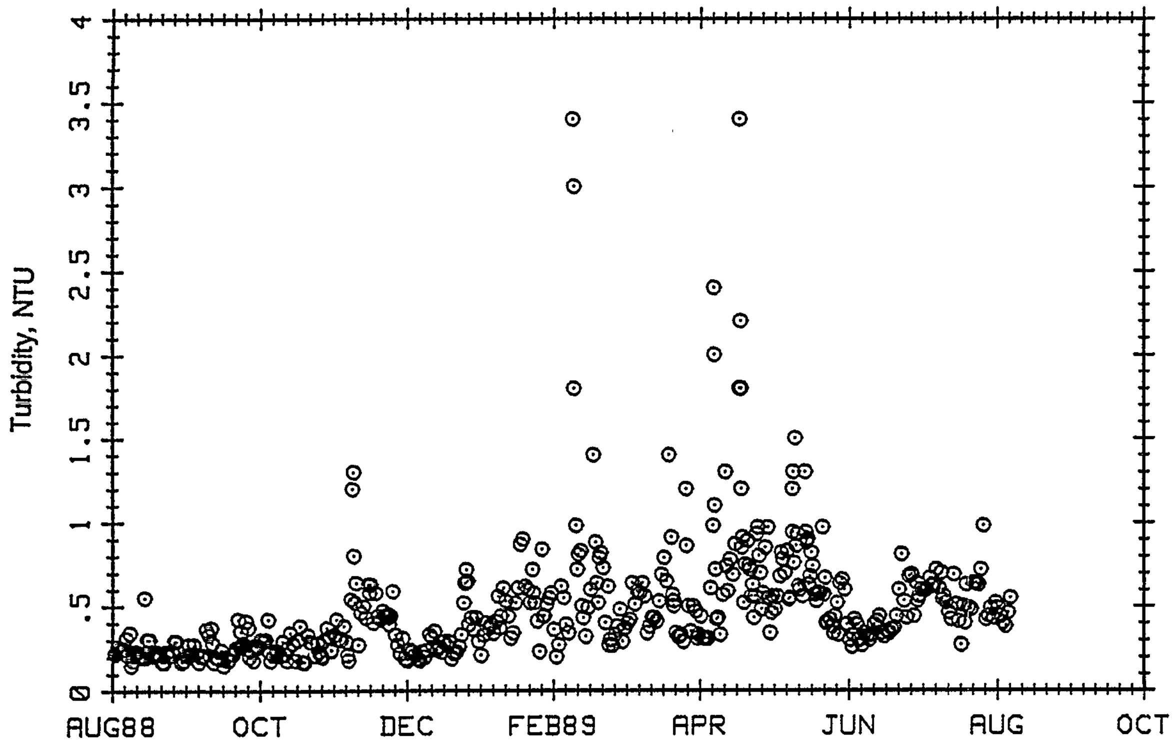


Figure 4-50. Finished water turbidity profile - Plant 10.

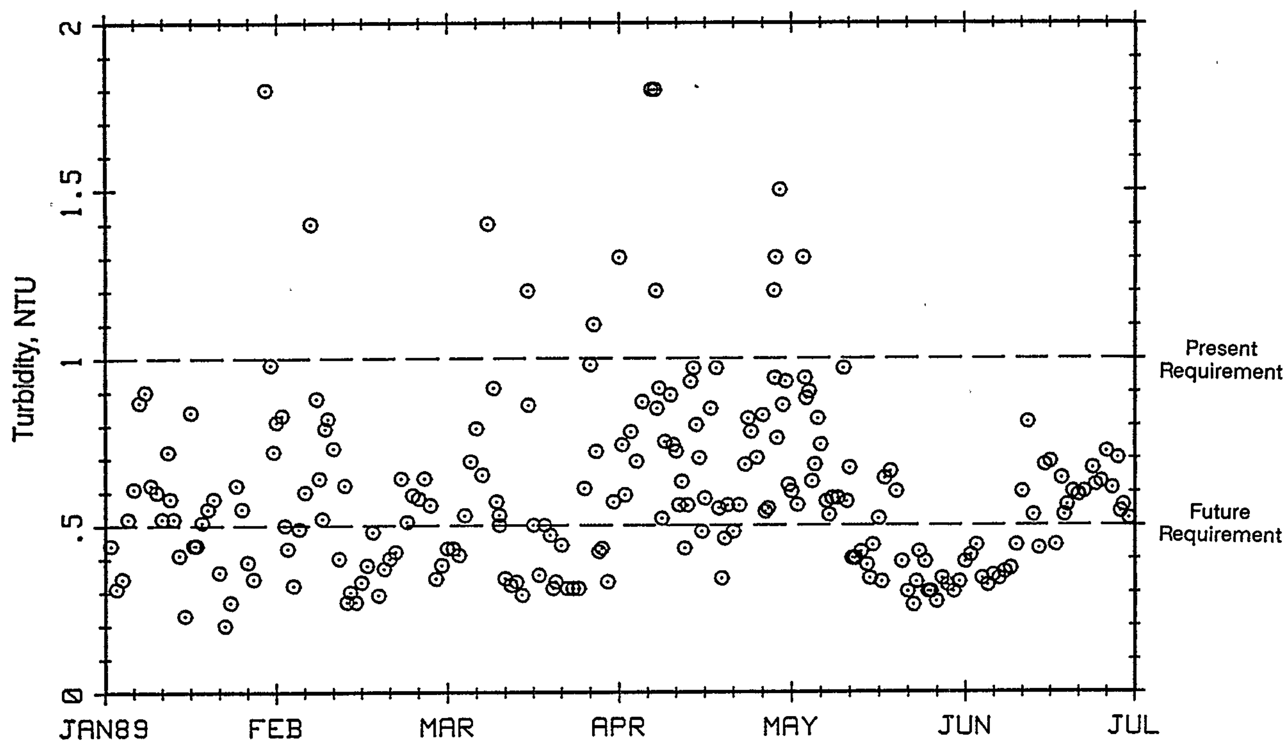


Figure 4-51. Probability plot of finished water turbidity - Plant 10.

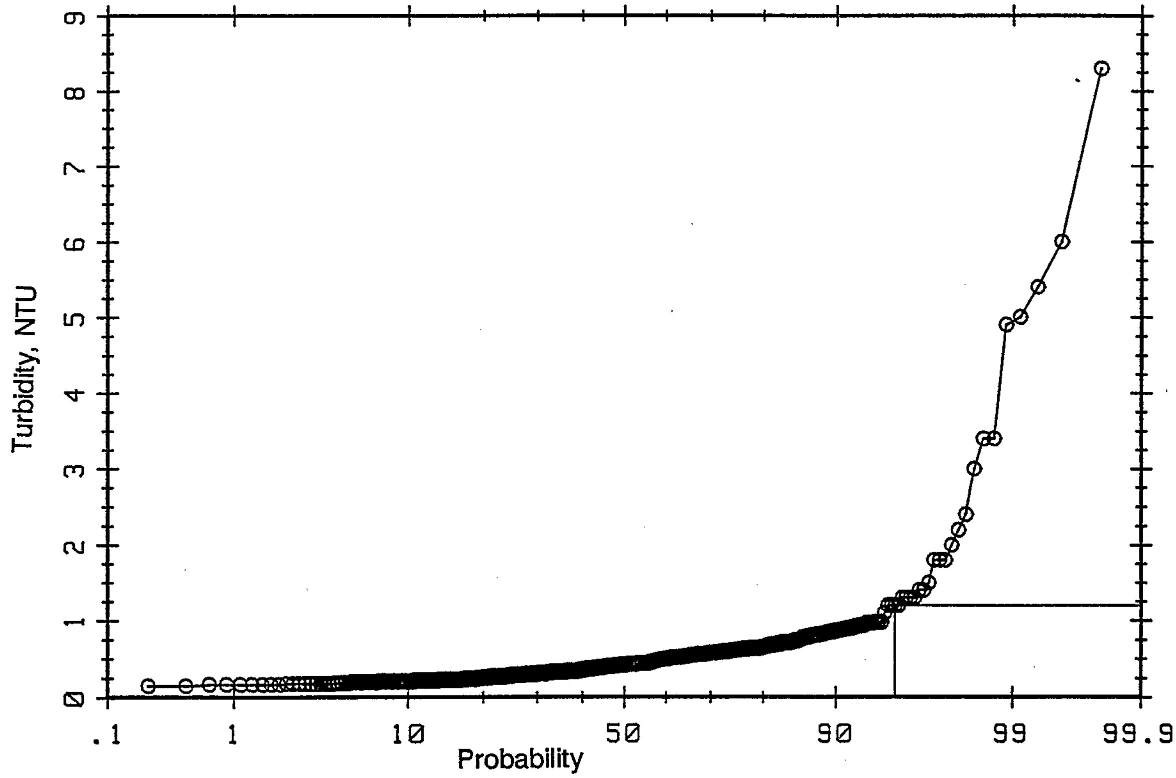


Figure 4-52. Fiulter 3 effluent turbidity profile after backwash - Plant 10.

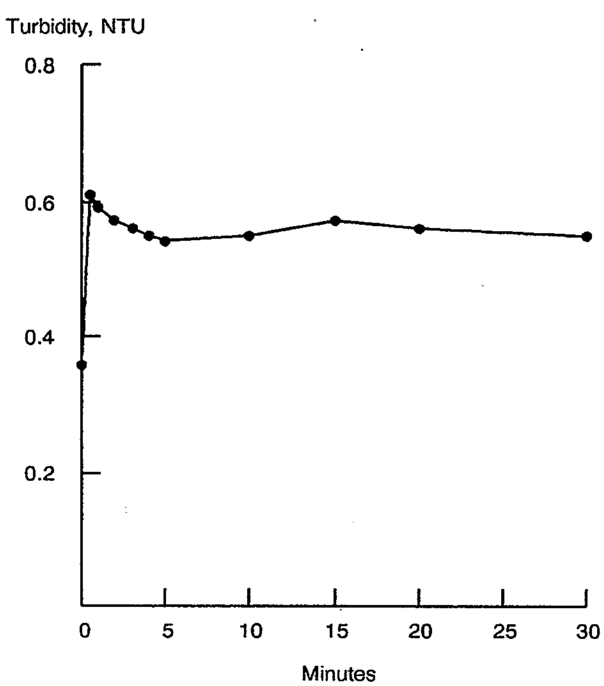
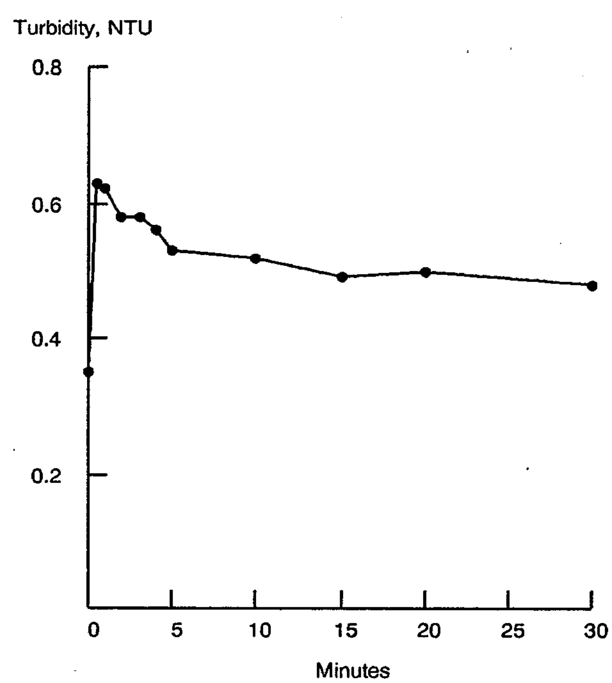


Figure 4-53. Filter 4 effluent turbidity profile after backwash - Plant 10.



loadings (e.g., 22 L/s [350 gpm]), the basin limitations allow high turbidity water to pass to the filters, thus degrading their performance.

3. Number of Plant Staff - Administration: Currently a staff of three persons have responsibility for the operation and maintenance of the water plant, wastewater plant, distribution system, and collection system. CPE interviews with the Board of Public Affairs revealed that a fourth person may be hired after construction of the new wastewater treatment plant is completed. To respond to the variations in raw water turbidity, increased coverage of the water plant to make process changes will be needed. Given this requirement plus other observed responsibilities, even a staff of four may be inadequate.

4. Application of Concepts and Testing to Process Control - Operation: The plant staff appeared to have proper training, understood the basic concepts of process control, and were very motivated. However, the chemical doses were not changed based on changes in raw water characteristics, the alum dose measured during the CPE was excessively high, and the filters were operated without adequate consideration of the turbidity levels in the filter effluent. Additionally, dirty filters were regularly started without any assessment of the impact of this practice on filter effluent turbidity levels. Because of these practices, the CPE team assessed that the plant staff was not consistently applying proper water treatment concepts and process control testing to optimize the plant's performance.

Factors identified as having either a minimal effect on a routine basis or a major effect on a periodic basis are summarized below in order of priority.

1. Filtration - Design: The configuration of the filtration system allows conditions that create air binding in the filters. The air binding is caused by negative pressures being created in the filter media as solids are removed and headloss increases. This causes the dissolved air in the water to come out of solution and be retained in the filter media. Water cannot pass through the portions of the media where the air is retained, which effectively reduces the surface area available for filtration. This condition reduces the plant's capacity and can significantly affect filter performance.

2. Lack of Preventive Maintenance Program - Maintenance: The plant has no formalized preventive maintenance program. Equipment is repaired as it breaks down. A lack of maintenance of a number of key pieces of equipment was considered to have a minimal, but continuous impact on performance. This key equipment included the alum feeder, filter flow measurement devices and control valves, chlorinator controls, clarifier equipment including the weirs, and the raw water pumps. Plant staffing levels appeared to impact the level of preventive maintenance, but even with adequate staff a formalized program would be needed to assure availability of key equipment.

3. Chemical Feed Facilities - Design: The plant needs additional chemical feed facilities to consistently meet required performance. A polymer feed system is projected as a requirement to optimize filter performance, especially during cold weather operation. A backup alum feeder would also be required to assure a consistent source of chemical feed.

4. Alarm Systems - Design: The plant is operated for significant periods of time without any operations staff present to make process adjustments in response to variations in raw water characteristics or correct problems with key processes equipment. During periods of unattended operation process performance could degrade to a point where it poses a potential health risk to the village. A turbidity monitoring system tied to raw and finished water could be used to alert the plant staff to process problems before finished water quality reached undesirable levels.

The age of some of the equipment was identified as a minor factor limiting performance. Though not a performance-limiting factor, the current practice of disposing of sludge and backwash water into the river is in violation of State regulations.

Projected Impact of a CCP

The CPE identified numerous design problems related to the key unit treatment processes, which must be corrected before any process optimization through use of a CCP could be successful. A CCP, therefore, was not recommended.

Plant 11

Facility Description

Plant 11 is a conventional water treatment plant that treats water from a nearby river for domestic use by the village. Based on a review of flow records for the previous year, the peak operating flow for the plant was established at 19 L/s (0.43 mgd). Plant 11 consists of the following unit processes shown schematically in Figure 4-54.

- Intake structure
- 49 million-L (13 mil-gal) reservoir
- Three vertical turbine raw water pumps: two 19 L/s (300 gpm) and one 38 L/s (600 gpm)
- 19-L/s (300-gpm) submersible raw water pump
- Metering pump to feed a ferric chloride solution
- Two volumetric feeders, one for lime and another for alum addition
- Rapid mix basin with a surface area of 0.46 m^2 (5.0 sq ft); and a depth of 0.6 m (2 ft)
- Solids contact clarifier 9.1 m (30 ft) in diameter and 3.8-4.1 m (12.5-13.6 ft) deep; flocculator volume, 29,800 L (7,875 gal); clarifier effective surface area, 61.6 m^2 (663 sq ft), and volume, 205,330 L (54,250 gal)
- Three dual media filters, two 2.4 m x 2.5 m (8 ft x 8 ft), and one 2.1 m x 2.7 m (7 ft x 9 ft) that contain 46-51 cm (18-20 in) of sand and 20-25 cm (8- 10 in) of anthracite media
- Vacuum-controlled solution feed chlorination system fed from 68 kg (150-lb) cylinders
- 151,400-L (40,000-gal) clearwell
- 321,725-L (85,000-gal) clearwell
- Two 24-L/s (375 gpm) vertical turbine high-service pumps
- 15-cm (6-in) orifice plate with a totalizer-indicator-recorder

Water from the river is pooled behind a low dam across the river downstream of the intake structure. River water is normally pumped to the reservoir by the submersible pump. Water from the reservoir flows by gravity to the wet well beneath the intake structure, where it is pumped to the plant by the vertical turbine raw water pumps. These pumps can also pump river water directly to the plant, bypassing the reservoir.

Raw water flows to the rapid mix basin where ferric chloride solution is added via a diaphragm metering pump. A hydrated lime slurry is also fed into the rapid mix basin via a volumetric feeder. A volumetric feeder is in place to feed alum, although it is currently not is use. Flash mixing was not performed during the CPE due to a bearing problem with the mixer. However, the CPE team calculated the G value for the rapid mix basin to be adequate at 1,418 sec^{-1} if the mixer were operating. Chemical feed rates can be adjusted manually by the amount of chemical added to the slurry tanks, or by adjusting the stroke on the metering pump, but they were not routinely changed.

Raw water flows to the center flocculation cone of the solids contact clarifier. After flocculation, water enters the outer clarifier portion of the unit and is removed through peripheral v-notched weir troughs. Sludge is periodically removed automatically from the clarifier, through use of a timed blow-down, and discharged to a sanitary sewer for disposal at the wastewater treatment plant.

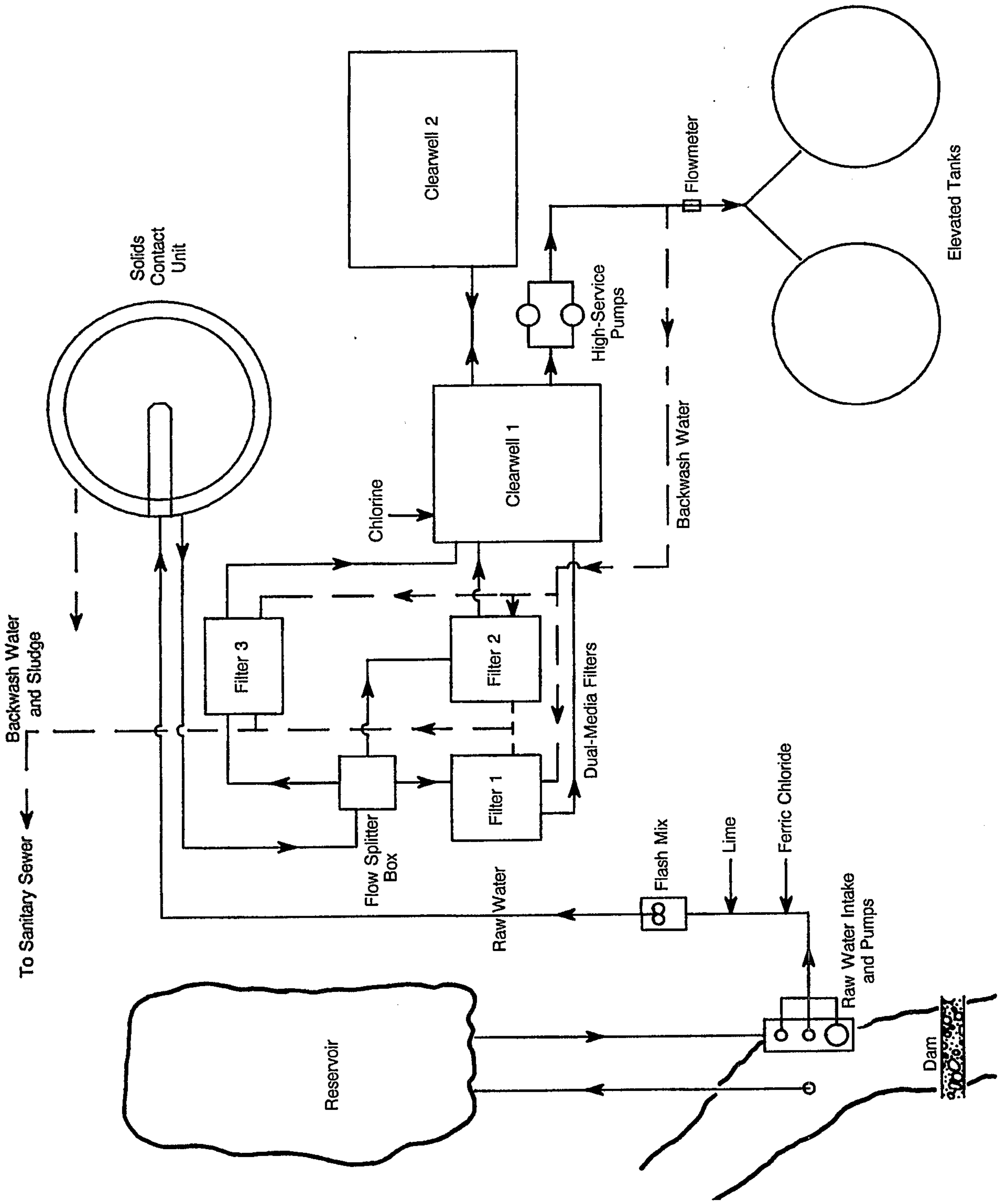
Settled water flows by gravity from the reactor clarifiers to a basin (originally designed as a recarbonation basin), where the flow is split to the three filters. Rate of flow through the filters is controlled by float-activated butterfly valves that open or close to maintain a constant water level above the filter media.

Filter runs are normally 24-27 hr, with the plant operating a total of 8-9 hr/day. One filter is backwashed each day, so that filters operate 3 days before backwashing. No individual filter headloss or turbidity monitoring equipment exists, although the village intends to install headloss gauges. Backwash water is supplied by distribution system pressure from operation of the high-service pumps. The backwash rate was determined during the CPE to be approximately 1,110 $m^3/m^2/d$ (19 gpm/sq ft). The surface of the media is manually raked during backwashing. Backwash water is discharged to the sanitary sewer.

Water from each filter flows through separate pipes into Clearwell 1, where a chlorine solution is injected to maintain residuals between 2.3 and 2.5 mg/L. Finished water normally flows from Clearwell 1 to Clearwell 2. The high-service pumps take suction from Clearwell 1.

Two high-service pumps supply finished water to the two elevated storage tanks that feed the water distribution system. These pumps are operated automatically based on water levels in the elevated storage tanks. The plant comes on and off line usually two to three times during the day based on water levels in the clearwell. Typically, the plant operates 8-9 hr/day at a constant rate of 24 L/s (375 gpm).

Figure 4-54. Plant 11 process flow diagram.



Variations in demand are met by varying the length of time the plant is operated.

Major Unit Process Evaluation

The performance potential graph is shown in Figure 4-55. The instantaneous peak operating flow of 19 L/s (0.43 mgd) assumes that only one of the small raw water pumps will supply the plant.

The flocculation capabilities of the reactor clarifier were rated at 25 L/s (0.57 mgd) based on achieving a hydraulic detention time of 20 minutes. This rating depends on retrofitting the basin with the variable speed drive for the mixers, which was included in the plant's original design.

The sedimentation capabilities of the reactor clarifier were rated at 22 L/s (0.50 mgd) based on a surface overflow rate of 30 $m^3/m^2/d$ (750 gpd/sq ft). The projected capacity of the basins was lowered due to the constraints of the 3.8- m (12.6-ft) basin depth.

The filters were rated at 36 L/s (0.82 mgd) based on a filter loading rate of 176 $m^3/m^2/d$ (3 gpm/sq ft). This loading rate was decreased from more typical values for dual media filters because of the rate control system.

The disinfection system was rated at 15 L/s (0.34 mgd). Future drinking water regulations for disinfection will be based on CT values found to be needed for removal of Giardia cysts and inactivation of viruses. This evaluation used a CT of 127, which is for chlorine at a 2.4 mg/L dose, pH 8.0, and temperature of 5°C. It was assumed that the disinfection system would have to provide 1.5 logs of cyst removal with 2.5 logs of removal credited for the other treatment processes. The 4 logs of total cyst removal required for the plant was based on the CPE team's estimate of the potential for contamination of the raw water. The contact time was based on the chlorine being added ahead of Clearwell 1 and the flow passing through both clearwells. Only 10 percent of the nominal detention time in the clearwells was used because (1) the clearwells are not baffled, (2) the piping arrangement does not assure that all of the flow passes through both clearwells, and (3) the clearwells are subject to fill and draw operation. In the future, the actual levels of disinfection required for the plant will be determined by the State. The estimates of the required total number of log reductions and the allowances for actual contact times in the clearwells may change after the final State regulations are developed.

As shown in the performance potential graph, the major unit processes, with the exception of the disinfection process, have a rated capacity close to or exceeding the instantaneous peak operating flow. The flocculation and sedimentation process, although borderline, were projected adequate to treat the operating flow rate of 19 L/s (0.43 mgd). The filtration system, rated at 36 L/s (0.82 mgd), was rated considerably more than adequate to treat this flow. Lack of baffling in the clearwells and the piping arrangement between the two clearwells limited the projected capacity of the disinfection process.

Performance Assessment

Figure 4-56 shows turbidity data from the plant records. The current applicable regulation for turbidity is 1.0 NTU. The plant normally produces water with turbidities less than 1.0 NTU, but is frequently above the 0.5 NTU level, which will be required by the SWTR, as shown in Figure 4-56. A probability plot of this same data, shown in Figure 4-57, indicates that the plant would only meet the 0.5-NTU requirement approximately 30 percent of the time.

During the CPE, a special study was conducted to assess filter performance after backwashing. With adequate facilities and operation of preceding unit processes, a properly operated filter should experience a 0.2-NTU rise in turbidity in the finished water for approximately 10 minutes after restart following backwashing. Figure 4-58 shows the results of a study that sampled Filter 3 for a 40-minute period after restart following backwashing. The filter experienced an approximate 1.0-NTU rise in turbidity that did not drop back to the original value even after 40 minutes. This delay may be attributed to a problem in the filter, or to improper treatment and conditioning of the water prior to filtering.

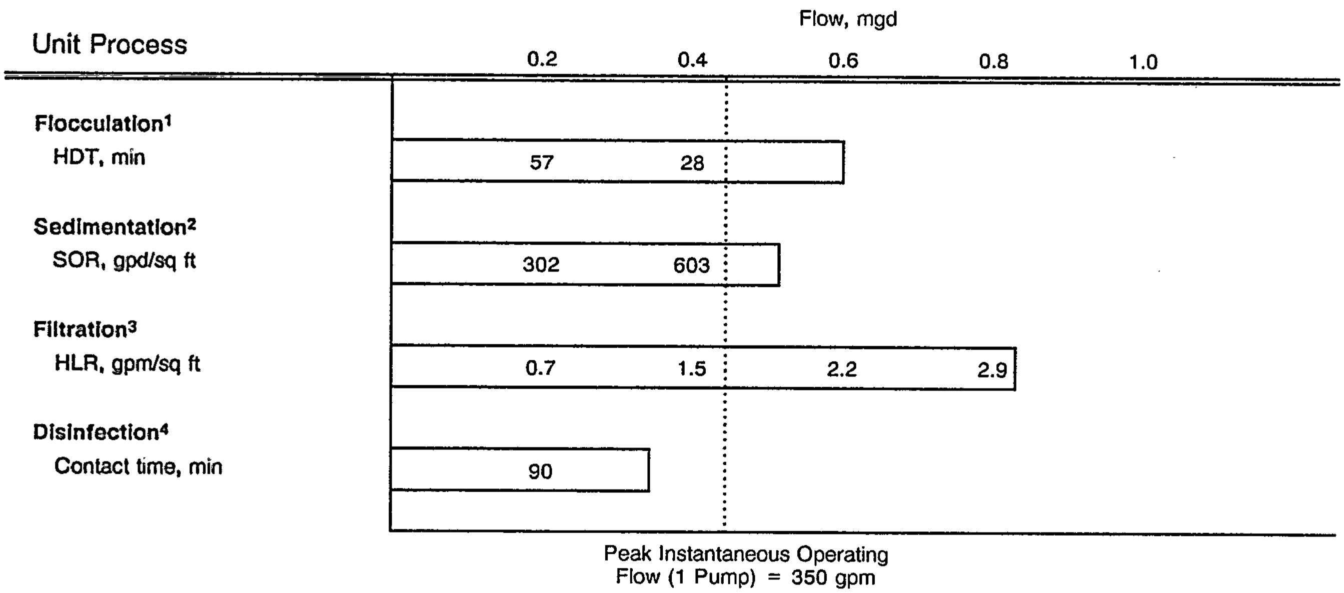
After backwash, Filter 3 was drained and 2.5- to 3.8-cm (1- to 1.5-in) mudballs were observed in the media. As mudballs increase in size, they can settle to the bottom of the media and limit the flow through these portions of the filter. The filter flow is then forced through the remaining media at higher rates, which can impact filter capacity and performance. Proper backwashing procedures, such as adequate length of backwash, gradual increase in backwash flow rates, and sufficient agitation of the media, can minimize the occurrence of mudballs.

Performance-Limiting Factors

The factors identified as having a major effect on performance on a long-term repetitive basis were prioritized and are summarized below:

1. <u>Application of Concepts and Testing Process Control</u> - Operation: Several operational practices performed by the plant staff, including applying ferric chloride and lime at the same point, regularly started dirty filters, and an unawareness of the condition of the filter media, impaired plant performance. Lime raises the raw water pH above the range necessary to achieve optimum coagulation and flocculation using ferric chloride. Starting dirty filters without monitoring the impact on finished water turbidity may represent a

Figure 4-55. Plant 11 performance potential graph.



[1] Rated at 20 -min HDT - assumes variable speed drive would be added.
[2] Rated at 750 gpd/sq ft - 12.5-ft depth discourages higher rating.
[3] Rated at 3 gpm/sq ft. Rate control system considered limiting.
[4] Rated at CT = 127 with 2.4 mg/L chlorine dose, which requires a 53-min HDT; allowed 10 percent of available volume for contact time, temperature = 5°C, pH = 8, 4-log required reduction, 2.5 log in plant, 1.5 log disinfection.

Figure 4-56. Raw water turbidity profile - Plant 11.

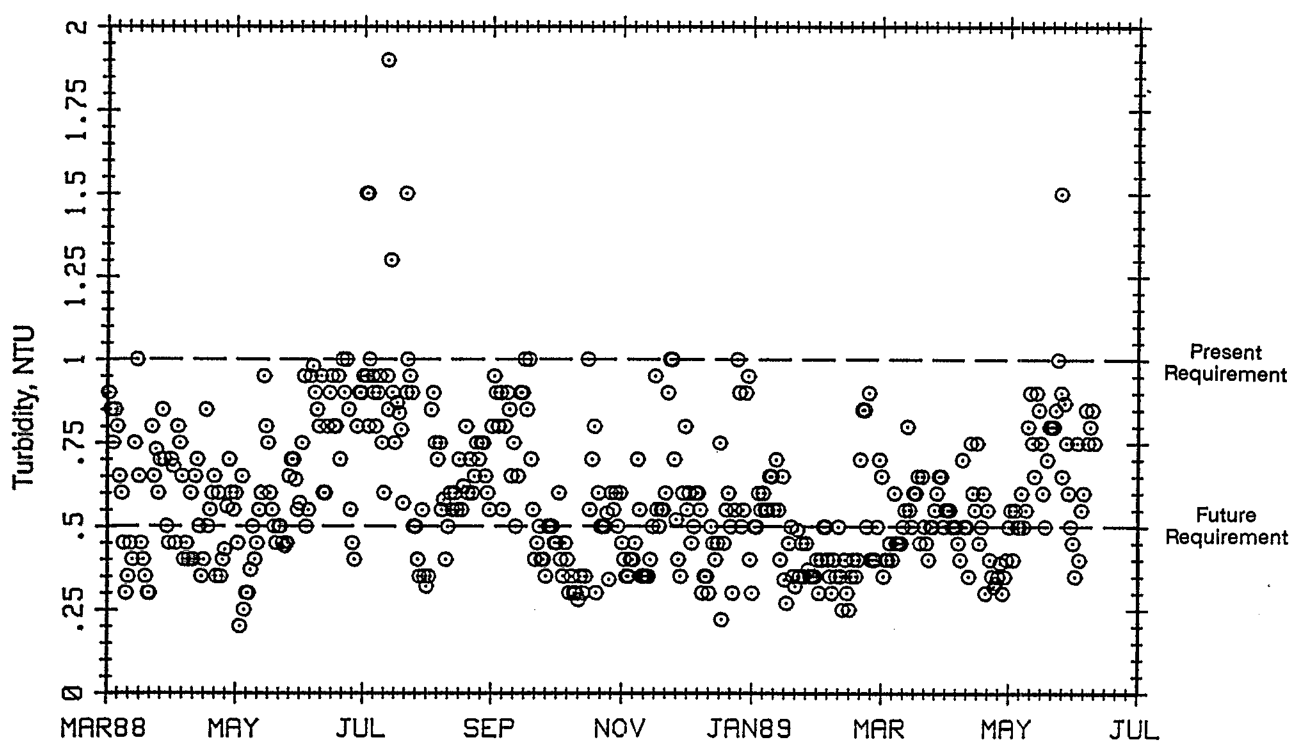


Figure 4-57. Probability plot of finished water turbidity - Plant 10.

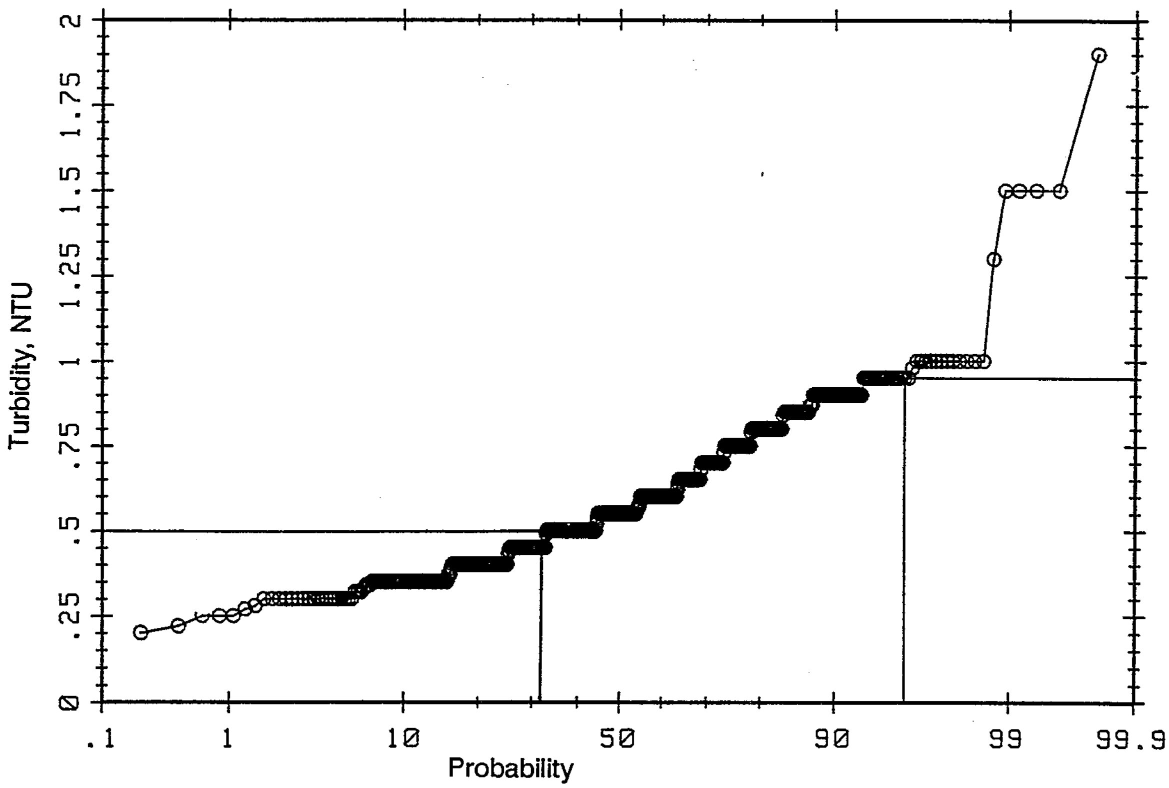
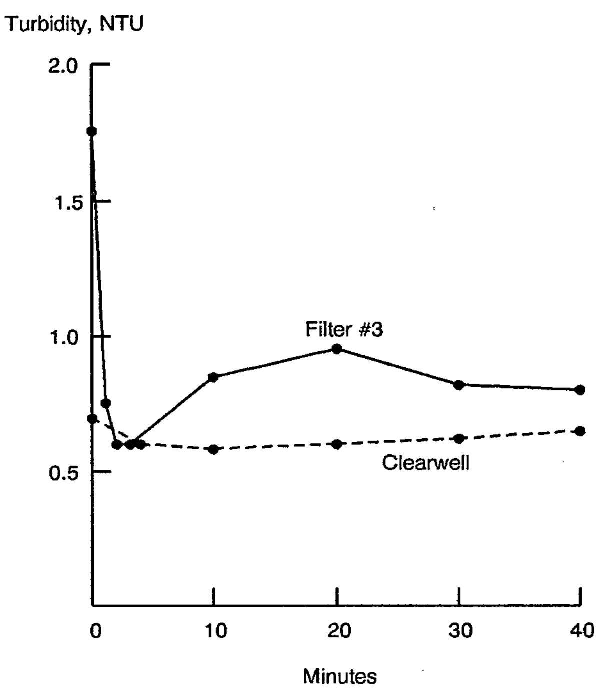


Figure 4-58. Filter 3 effluent turbidity profile after backwash - Plant 10.



potential health risk to the village. If the condition of the media is not known (e.g., mudballs), operational practices causing these problems cannot be changed. The staff's lack of attention to repairing and using the rapid mixer also contributed to this factor's high rating.

2. Process Control Testing - Operation: Process control testing was observed to be minimal. Proper operational decisions require a routine and comprehensive process control testing program. Jar testing is necessary to evaluate changing raw water conditions, and determine optimum coagulant types and feed rates. Also, the solids contact unit requires constant monitoring of solids (e.g., sludge depth, sludge discharge volume, etc.) to optimize turbidity removals. Raw water monitoring is also necessary.

3. Disinfection - Design: The SWTR will require all plants to achieve a particular CT value for the disinfection portion of their plant. Concerns about the formation of trihalomethanes, formed as a by-product of chlorination, will limit the level of chlorine concentrations used by a public water system. In lieu of increasing chlorine dosages, a utility will be compelled to increase the effective contact time. The lack of baffling in the clearwells may limit the effective disinfectant contact time (T) that the utility will need to comply with the SWTR.

The State's interpretation of this rule may lead to different results than indicated by this evaluation.Factors identified as having either a minimal effect on a routine basis or a major effect on a periodic basis are summarized below in order of priority.

1. Supervision - Administration: There is no clear definition or delegation of responsibilities between the superintendent and other members of the staff. To maintain continuity in plant operations, specific tasks should be assigned to each staff member. This would alleviate incidents of poor communication between the plant staff (e.g., staff members arbitrarily resetting chemical feed rates after they have been adjusted by other staff members). Once plant personnel have clear definition of duties, daily planning and priority setting, which is presently minimal, can be optimized to increase plant performance.

2. Process Accessibility for Sampling - Design: The lack of sampling locations to evaluate various plant unit processes limits implementation of an acceptable process control program. At minimum, the plant should have taps to determine influent and effluent turbidity levels for the reservoir (and river, if pumping directly to the plant), solids contact clarifier, each of the three filters, and both clearwells.

3. Alarm Systems - Design: The plant is operated for significant periods of time without any operations staff present to make process adjustments in response to variations in raw water characteristics or correct problems with key processes equipment. As such, finished water quality could degrade and pose a potential health risk to the village. A turbidity monitoring system tied to the clearwell effluent could be used to alert the plant staff to process problems before finished water quality reaches undesirable levels.

4. Number of Plant Staff - Administration: Presently, a staff of four persons have responsibility for the operation and maintenance of the water plant, wastewater plant, distribution system, collection system, and street maintenance. To properly respond to the variations in raw water turbidity, implement a process control program, provide sample taps, etc., increased coverage of the plant will be needed. Given these responsibilities and requirements, a staff of four is inadequate.

5. Plant Staff Morale Pay - Administration: The current pay structure for the staff may discourage more highly qualified people from applying for operator positions. The village does not currently offer a pay scale competitive with other facilities.

6. Chemical Feed Facilities - Design: The plant lacks the capability to feed chemicals to various points in the treatment process. The option to apply chemicals (e.g., lime) will enable optimal use of chemicals and chemical dosages. Additional chemical feed facilities were projected to be required. A polymer feed system could be used to optimize filter performance especially during cold weather operation.

The CPE team identified additional factors that had a minor effect on plant performance. Specifically, the lack of a preventive maintenance program, the lack of variable speed mixing capabilities during flocculation, and the minimal depth of the sedimentation basin. Headloss gauges should also be installed on each of the filters to enable optimization of filter runs based on headloss and/or effluent turbidity levels. The inability to control flow distribution to the filters and control the rate of flow at each filter will also adversely impact filter operation.

Projected Impact of a CCP

Alleviating the identified factors would appreciably improve the performance of Plant 11. As such, implementation of a CCP, if accepted by the village personnel, represented a viable option for the plant.

Plant 12

Facility Description

Plant 12 is a conventional plant that treats water from a nearby river to provide water for domestic use by the city. It consists of two separate sets of treatment process trains that operate in parallel. One of these, designated the "old" plant, consists of the solids contact clarifier and the two circular dual media filters. These were the original treatment processes before the plant was expanded in 1977. The second set, designated the "new" plant, consists of two package plants. Based on a review of plant records, the peak operating flow for the entire plant was 32 L/s (0.72 mgd). Plant 12 consists of two separate sets of unit processes shown schematically in Figure 4-59.

- Raw water intake structure containing two submersible pumps: one 25 L/s (400 gpm) and the other 31 L/s (500 gpm)
- Propeller-type raw water flow meter
- Seven volumetric chemical feeders: two for alum, three for lime, one for fluoride, and one for $KMnO_4$/PAC
- Two 3.4-m (11-ft) diameter flocculation basins, 2.7 m (8.8 ft) deep, each equipped with vertical paddle flocculators and variable speed drives. Each unit is divided into two sections by a mid-depth horizontal perforated baffle
- Two package plants each with sedimentation and filtration. The sedimentation section has a surface area of 4.8 m^2 (51.8 sq ft) and contains a 1.7-m (5.7- ft) high module of 7.5-degree tube settlers. Each filter has 10.2 m^2 (110 sq ft) of surface area and 76 cm (30 in) of mixed media
- 6.4-m (21-ft) diameter, 3.0-m (10-ft) deep upflow solids contact clarifier. Center flocculation cone has a volume of 8,515 L (2,250 gal) with a vertical paddle mixer
- Two 2.7-m (9-ft) diameter dual media filters containing 69 cm (27 in) of media
- Two clearwells: one "old", with 246,782-L (65,200-gal) capacity and the other "new", with 199,470-L (52,700-gal) capacity
- Two backwash pumps: one "new" 63 L/s (1,000 gpm), and the other "old", est. at 31 L/s (500 gpm)
- Vacuum-controlled solution feed chlorination system fed from 68-kg (150-lb) cylinders
- Three high-service pumps: two "old", estimated at 16 L/s (250 gpm) and 38 L/s (600 gpm) and the third "new" 31 L/s (500 gpm)
- Propeller-type finished water flow meter
- 333,080-L (88,000-gal) backwash water and sludge holding basin

Water is taken from the middle of the river through an intake pipe. Either of two submersible pumps is used to supply raw water to the plant. The plant is operated usually 6-8 hr/day and meets higher demands by operating for longer periods.

The raw water is split between the "old" and "new" plant by separate valves at the flow split. Capabilities exist to pre-chlorinate the raw water. The raw water flow meter for the "old" plant had been removed for repair and had never been replaced. For the "new" plant, raw water flows can be measured and controlled. During the CPE, the flow meter was operational, but had not been calibrated and, thus, was not used by the plant staff. The rate-of-flow controller was out of service. Neither the flow meter or controller had been used for a long time.

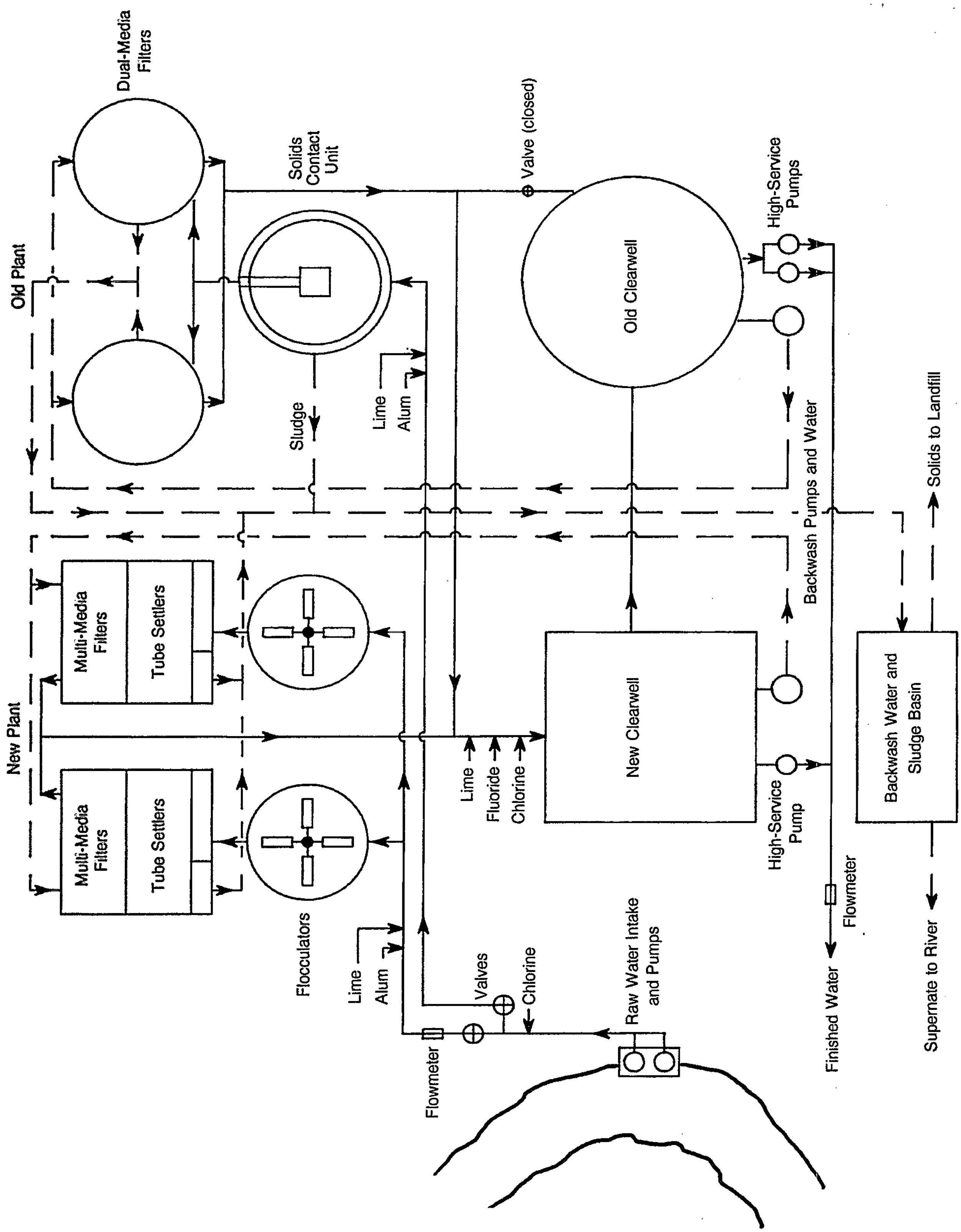
Alum and lime are added to both of the plants using volumetric dry chemical feeders. On the "new" plant, alum and lime slurries were prepared by adding water to the dry chemicals in mixing tanks beneath the feeders. These slurries were conveyed by gravity to the pipe carrying the raw water to the flocculators. No mechanical or static flash mixing was provided. Chemical feed rates for both plants were adjusted with changes in raw water turbidity based on the operator's experience. A jar testing apparatus was available at the plant, but not used. Feed rates were not routinely adjusted.

The two flocculators on the "new" plant had been modified by removing the horizontal, perforated baffles. These baffles, intended to separate each of these units into two stages, would have provided improved flocculation. The mechanical mixers on these basins were also not operational.

From the flocculation basins, flow to the "new" plant enters a tank that has a sedimentation and filtration section. Flow is directed to the bottom of the sedimentation section and then flows up through a module of 7.5 degree-tube settlers. Settled water discharges into a trough that conveys it to the filtration section. After passing through the mixed media filter, the finished water flows to the clearwells.

The filtration units were designed for automatic operation with electrically actuated valves controlling the filter flow rate based on level measurements. Backwashing was also designed to use automatic electrically actuated valves. Continuous turbidimeters for the raw and finished water were provided. During the CPE, however, none of the automatic valves or turbidimeters were operational. Instead, the plants were operated manually, but the plant staff could not

Figure 4-59. Plant 12 process flow diagram.



adequately control the flow through the filters. Settled water was observed cascading onto the surface of the filter media. When a filter is properly operated, the surface of the filter media is flooded, but under the observed conditions, flow was passing through only a portion of the media. Both the filters and the tube settlers were backwashed at the same time using water pumped from the clearwells. Backwash water was discharged to the holding basin.

In the "old" plant, a volumetric feeder adds dry alum directly into the center flocculation zone and lime is prepared as a slurry and piped to the flocculation zone. A mechanical mixer provides mixing in the zone.

The upflow solids contact clarifier on the "old" plant consists of two sections that provide for both flocculation and sedimentation. Flocculation occurs in a mechanically mixed cone-shaped center section, while sedimentation occurs in the outer portion. Raw water enters the flocculation section and then flows downward before proceeding through the bottom of this section into the upflow sedimentation section. The mechanical mixer promotes flocculation and settled water discharges over peripheral weirs. Proper operation of solids contact clarifiers relies on the measurement and control of the solids maintained in the unit. At the plant, solids levels and concentrations were not measured or controlled.

The "old" plant filters were circular steel tanks that showed significant signs of corrosion. Two troughs above the media distributed the settled water to the filters and collected the backwash water. Filter flow rates were controlled by float-actuated valves that were intended to maintain a constant water level above the filter. During the CPE, these valves were not operational. Settled water was observed cascading onto the media surface instead of flooding the filter media. These filters are backwashed with water pumped from the clearwells. Backwash water is then discharged to the holding basin.

Finished water from both plants combines ahead of the "new" clearwell where chlorine, fluoride, and lime are added. Chlorine doses are adjusted to maintain a residual of 2.0 mg/L in the finished water leaving the clearwell. Both pre- and post-chlorination are used. The staff attempts to maintain a 50/50 split between the two addition points, but no provisions are available to measure this split.

All finished water enters the "new" clearwell, but both clearwells are interconnected so that the flow is distributed between them. Separate high- service pumps draw from each clearwell, an arrangement that prevents the two clearwells from operating in series, and thereby optimizing the contact time with the chlorine. During the CPE, one of the "old" high-service pumps had been removed for service. High-service pumps are operated manually to supply the four storage tanks in the distribution system.

Major Unit Process Evaluation

The performance potential graph is shown in Figure 4-60. Three sets of bars are presented for each unit process representing the "old" plant, the "new" plant, and the total for both plants combined. Disinfection was only evaluated for the combined plants because the units are interconnected. The shortest bar represents the treatment process that limits plant capacity to achieve the desired performance of less than 0.5 NTU.

The instantaneous peak operating flow for the plant was established at 16 L/s (0.36 mgd) for each of the two plants, or 32 L/s (0.72 mgd) for the total plant. This flow is based on a review of flow records for the previous year and the practice of only operating one of the raw water pumps. On days the plant operates for longer than 8 hr, the treatment processes are still operated at a maximum flow rate of 32 L/s (0.36 mgd).

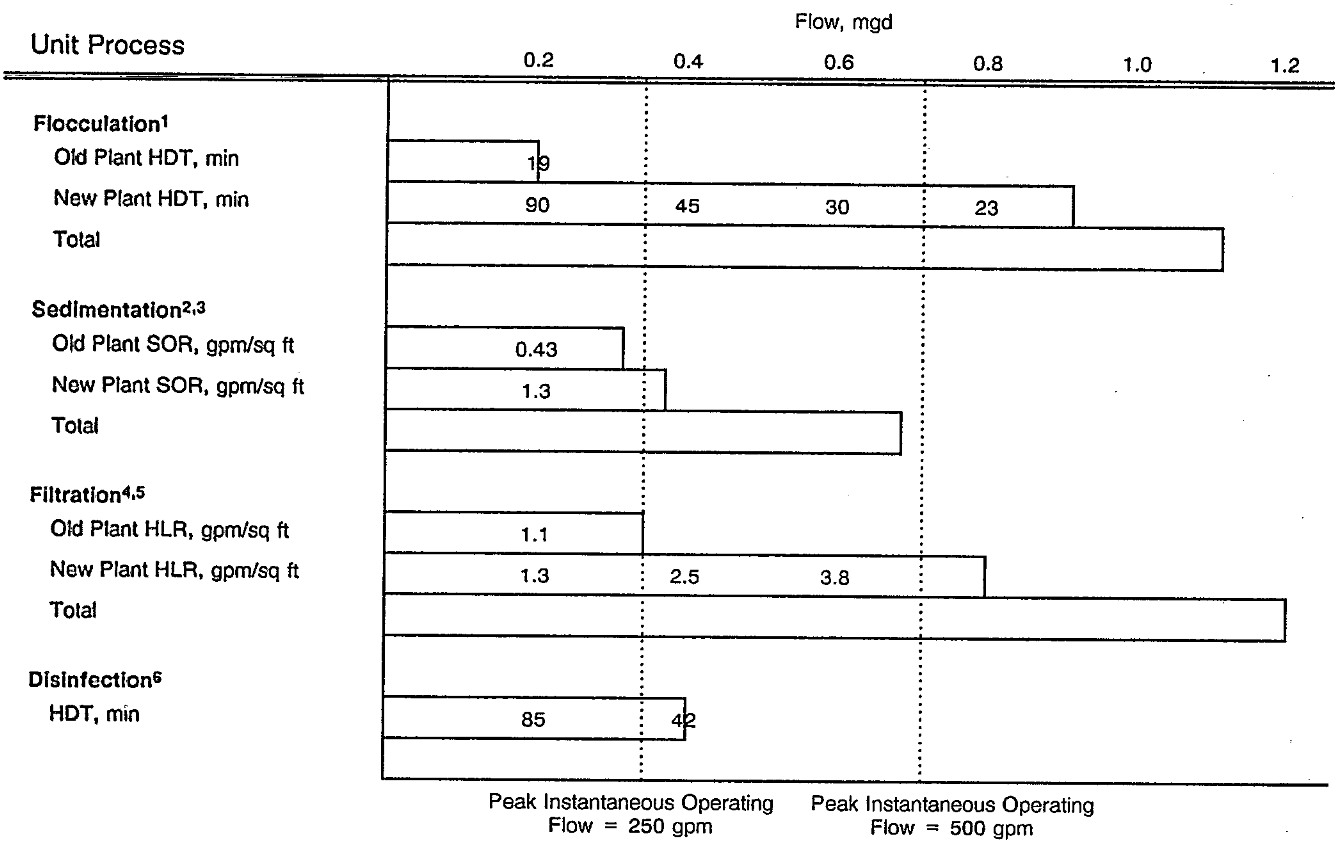
The flocculation basins were rated at 48 L/s (1.1) mgd for the total plant. Most of the flocculation capabilities, however, are provided by the "new" plant. The two flocculators were rated at 39 L/s (0.90 mgd), under the assumption that the horizontal perforated baffles would be replaced and the mechanical mixers made operational. The flocculation portion of the "old" plant's solids contact clarifier was rated at 8.3 L/s (0.19 mgd).

For sedimentation, the solids contact clarifier was rated at 14 L/s (0.32 mgd) and the combined package plants at 17 L/s (0.38 mgd) for a total plant capacity of 31 L/s (0.7 mgd). The shallow depth and configuration of the solids contact clarifier were judged to limit its capacity. Higher surface overflow rates were applied to the package plants because of the tube settlers.

Total filtration capacity for the plant was rated at 53 L/s (1.2 mgd). A filter loading rate of 117 $m^3/m^2/d$ (2 gpm/sq ft) was used for the "old" plant, which resulted in a rated capacity of 16 L/s (0.36 mgd). The filters on the "new" plant were rated at 35 L/s (0.79 mgd) based on a loading rate of 293 $m^3/m^2/d$ (5 gpm/sq ft). These ratings assume the rate control valves on both plants will be operational.

The disinfection system was rated at 18 L/s (0.42 mgd). Future drinking water regulations for disinfection will be based on CT values needed for various removals of ***Giardia*** cysts and inactivation of viruses. To establish the CT required, it was assumed the plant's disinfection system would have to provide 1.5 logs of cyst removal with 2.5 logs of removal credited for the other treatment processes. The total of 4 logs of cyst removal required was based on the CPE team's estimate of the quality of the raw water.

Figure 4-60. Plant 12 performance potential graph.



[1] Rated at 20-min HDT - assumes baffles reinstalled and functional micers in new floc basin.
[2] Old plant rated at 0.7 gpm/sq ft - shallow depth and configuration considered limiting.
[3] New plant rated at 2.5 gpm/sq ft - tube settlers allow higher rates.
[4] Old plant rated at 2 gpm/sq ft - integrity of tanks was assumed to be adequate.
[5] New plant rated at 5 gpm/sq ft - assumes rate control valves are operational.
[6] Rated at CT = 100 with 2.5 mg/L chlorine dose, which requires a 40-min HDT; allowed 10 percent of available volume for contact time, temperature = 5°C, pH = 7.5, 4-log required reduction, 2.5 log allowed for plant if operated well.

To achieve the 1.5 logs of cyst removal, the CPE team estimated that the disinfection system would have to provide a CT of 100. This CT value is for chlorine at a 2.5 mg/L dose, pH 7.5, and temperature of 5C. The contact time was based on the chlorine being added ahead of the "new" clearwell and the flow passing through both clearwells. Only 10 percent of the theoretical detention time in the clearwells was used because the clearwells are not baffled and because they are subjected to fill and draw operation. The piping arrangement, which does not assure that a flow passes through both clearwells, also contributed to this rating. The actual levels of disinfection required for the plant in the future will be determined by the State. The estimates in this CPE of the required total number of log reductions and the allowances for actual contact times in the clearwells may change when final regulations are developed.

The performance potential graph shows that, on a total plant basis, the major unit processes have a rated capacity close to or exceeding the peak instantaneous operating flow of 32 L/s (0.72 mgd), with the exception of the disinfection process. Flocculation is adequate up to 48 L/s (1.1 mgd) if the flocculators on the "new" plant are returned to their original condition. The sedimentation processes are projected adequate to treat a flow of 31 L/s (0.70 mgd), which is borderline. The filtration system, rated at 53 L/s (1.2 mgd), was rated considerably more than adequate to treat the peak instantaneous operating flow. Lack of baffling in the clearwells and the piping arrangement between the two clearwells limited the projected capacity of the disinfection process.

On an individual plant basis, the performance potential graph shows that both plants do not have equal capabilities. For the total plant to have a rating of 32 L/s (0.72 mgd), more than half of the flow will have to be treated in the "new" plant. The solids contact clarifier on the "old" plant limits the flow it can adequately treat to 8.3 L/s (0.19 mgd).

Performance Assessment

Figure 4-61 shows the finished water turbidity as reported by the plant staff for a 12-month period. The current State regulation for turbidity is 1.0 NTU. The federal SWTR will require the plant to meet a 0.5-NTU finished water turbidity 95 percent of the time. The plant generally complies with the 1.0-NTU regulation, but is consistently above the 0.5-NTU required by the SWTR. A probability plot of this same data, shown in Figure 4-62, indicates that under present conditions this plant would only meet 0.5 NTU less than 10 percent of the time.

During the CPE, special studies were conducted to assess the performance of both the "old" and "new" filters after backwashing. With adequate facilities and operation of proceeding unit processes, a properly operated filter should produce a finished water turbidity of approximately 0.1 NTU and only experience a 0.2-NTU rise in turbidity in the finished water for approximately 10 minutes after being restarted following backwashing. For this special study, both filters were sampled for a 30-minute period after being restarted following backwashing.

Figure 4-63 shows the results for the "old" filter. Prior to backwashing, this filter was producing 0.22-NTU water. After backwashing, however,the water quality peaked at 38 NTU after 1 minute and did not drop back to the original value even after 30 minutes. A turbidity of 1.0 NTU was not achieved for almost 20 minutes. Figure 4-64 shows the results after backwashing one of the "new" filters. Prior to backwashing, the filter was producing a 12.5-NTU water, significantly above the 1.0-NTU regulation. After backwashing, the water quality improved, but had not achieved adequate performance even after 20 minutes.

These results indicate a significant performance problem that may be attributed to the filters or to the fact that the water being applied to the filter has not been properly treated and conditioned in the preceding unit processes. During the backwash of the "new" filter, large amounts of air were observed bubbling up through the media.

During the two special studies, the team also collected samples of the finished water from the clearwells. These results, shown in Figure 4-65, indicated that significantly high levels of turbidity were passing into the city water systems; well above the levels allowed by the State. Such high levels of turbidity pose a significant health risk to the community.

Performance-Limiting Factors

The factors identified as having a major effect on performance on a long-term repetitive basis were prioritized and are summarized below:

1. Performance Monitoring - Operation: The practice of sampling at optimum times, though allowed by current regulations, has resulted in an inaccurate assessment of the plant's true performance. Accurate monitoring would have alerted the plant staff to the serious performance problems at the plant and likely would have resulted in regulatory pressure to correct them. Improperly operating laboratory instruments used for monitoring also led to an improper interpretation of performance.

2. Plant Administrator's Policies - Administration: Current and historical actions by the mayor and/or city council were inadequate in recognizing the significance of poor water quality and inappropriate in that they did not aggressively address the causes of the situation. The existing new plant, constructed in 1977, had been allowed to deteriorate. Repairs and maintenance to protect system integrity had been largely ignored. Staff with expertise in water treatment were performing numerous other city functions away from the water plant, and staff with virtually no training in water treatment were manning the plant for only portions of the time it was operating. "Muddy" water was accepted as a way of life. Agreements to provide water to other communities were negotiated and perpetuated despite the increased demand that was placed on a marginally functioning system. A significant change in past policies and in emphasis on the water plant will be necessary to reduce the health risk associated with current water plant performance.

3. Maintenance: Years of neglect of all plant equipment have degraded a potentially well-equipped plant to essentially a nonfunctional state. Considerable expenditures will be required to make this equipment operational and to keep it maintained.

4. Water Treatment Understanding - Operation: The plant staff demonstrated a significant lack of understanding of even basic concepts of water treatment, allowing the water to cascade onto the filter media, starting dirty filters, performing no process control testing, and essentially providing no adjustment of chemical feed rates. There was also a lack of urgency to repair and/or replace improperly functioning equipment essential to providing water treatment.

5. Process Control Testing - Operation: A process control testing program to optimize unit process performance did not exist at the plant. Process control testing is essential for water plants served by surface sources because of the frequent and rapid changes in raw water quality. Basic equipment was available to conduct this testing, but was not used.

Figure 4-61. Finished water turbidity profile - Plant 12.

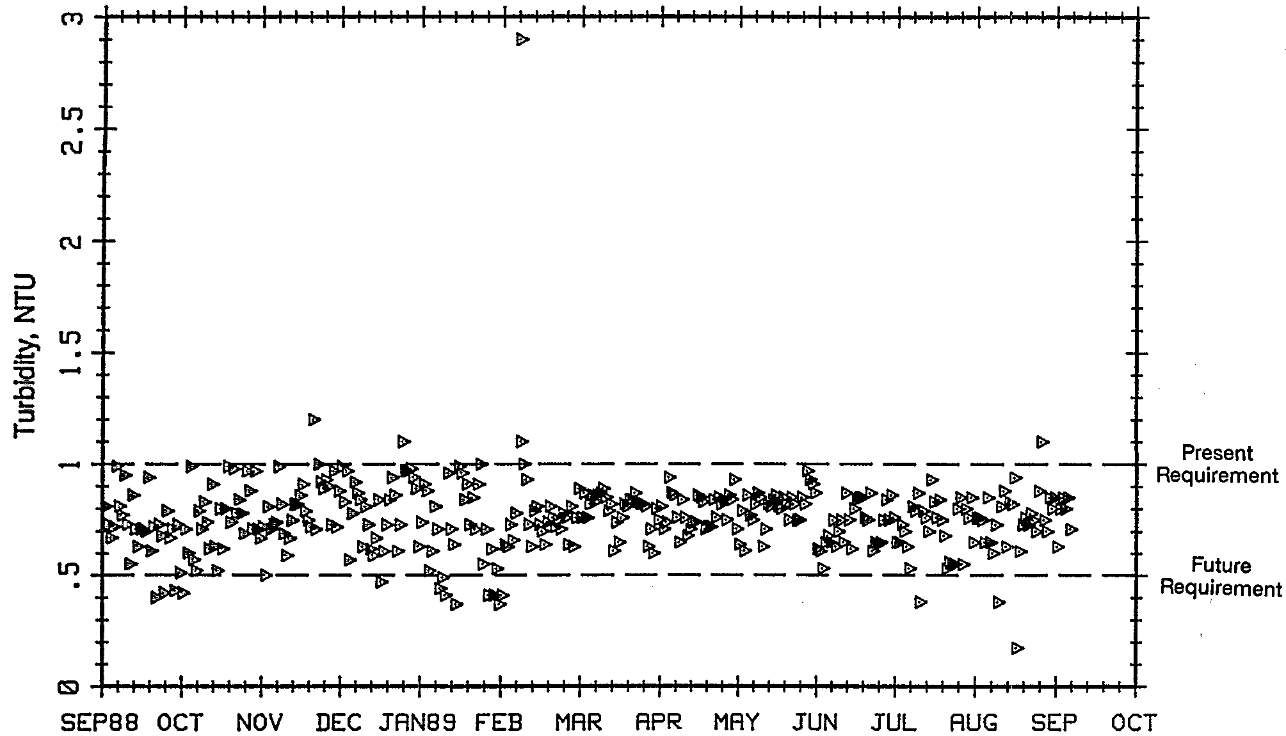


Figure 4-62. Probability plot of finished water turbidity - Plant 10.

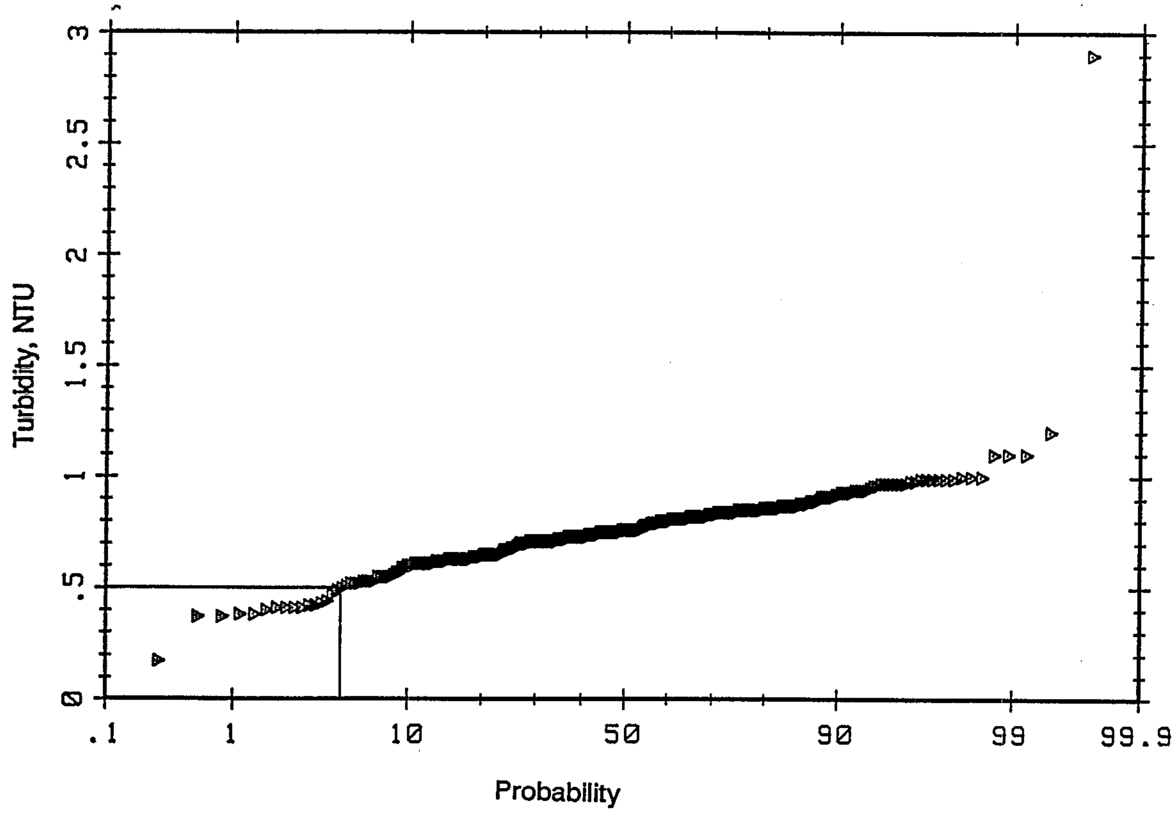


Figure 4-63. Old plant north filter effluent turbidity profile after backwash - Plant 12.

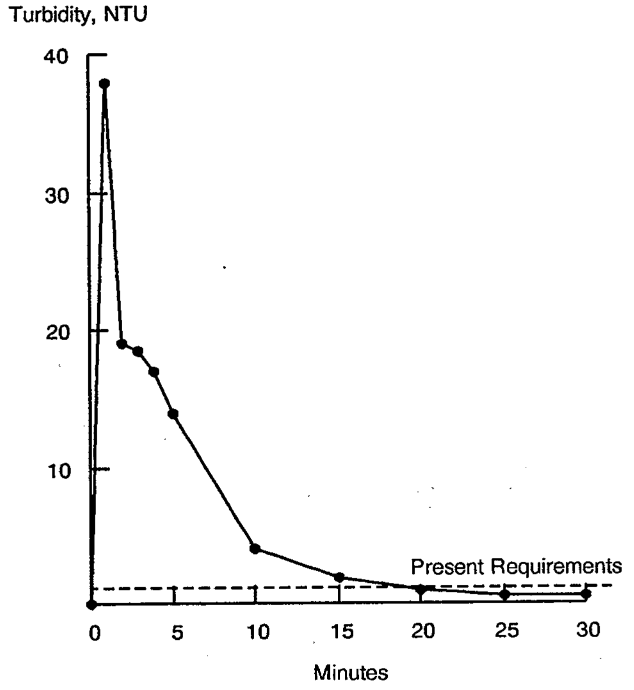


Figure 4-65. Clearwell turbidity profile after filter backwash - Plant 12.

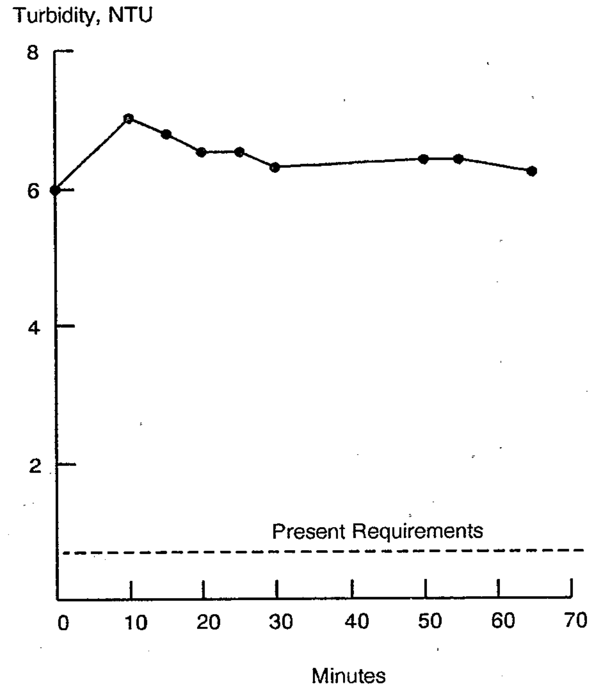
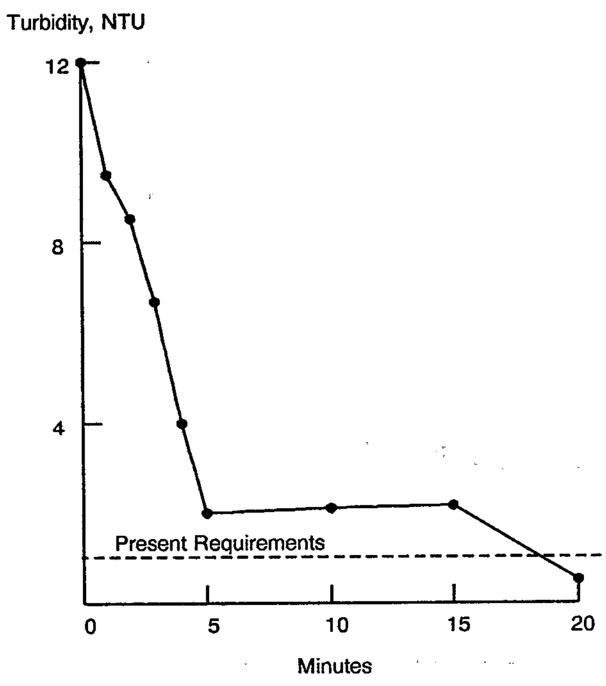


Figure 4-64. New plant north filter effluent turbidity profile after backwash - Plant 12.



6. Filtration - Design*: This factor has an asterisk because of the air observed above the filters during backwash. Air entering the filters during backwash may have disturbed the filter media to the point that it will have to be replaced. The condition of the filter media was not verified during the CPE. The filter tanks on the "old" plant are severely corroded to the point that they could fail entirely.

7. Disinfection - Design*: This factor has an asterisk because it was assessed based on the initial disinfection requirements of the new regulations. These requirements may change when final regulations are developed by the State. On this basis, however, inadequate contact time is provided because of a lack of baffling in the two clearwells and a lack of piping to allow them to operate in series.

Factors identified as having either a minimal effect on a routine basis, or a major effect on a periodic basis are summarized below in order of priority.

1. Staff Number - Administration: Additional staff are required to provide adequate coverage of the plant, to perform the necessary process control, and to complete maintenance functions.

2. Staff Qualification - Administration: All of the plant staff must have high levels of education to make

proper operation and maintenance decisions; all staff should also be certified.

3. Process Flexibility - Design: The capability is needed to feed polymers and filter aids at different locations in the plant to optimize performance. This will be especially critical if the plant is to consistently meet a required finished water quality of 0.5 NTU.

4. Alarm Systems - Design: The plant experiences rapid variations in raw water quality and has a limited number of operations staff present to make necessary adjustments in response to these variations (e.g., adjust chemical or chlorine doses, or correct problems with key process equipment). On these occasions, process performance could degrade to a point where it poses a potential health risk to the city. A turbidity monitoring system tied to raw and finished water and a chlorine residual monitoring system could be used to alert the plant staff to process problems before finished water quality reached undesirable levels.

5. Flow Proportioning to Units - Design: Flow measurement and flow control devices are needed to accurately split flow to ensure that each plant receives the proper flow rate. This is especially critical because the flow to the "old" plant must be limited to achieve desired performance.

6. Flocculation - Design: In the "new" plant, the flocculator's original horizontal perforated baffles will have to be replaced and the mechanical mixers made operational. The flow to the "old" plant must be limited because of the size of the flocculation section of the solids contact clarifier.

7. Sedimentation - Design: The sedimentation capabilities of the plant are marginal because of the shallow depth of the solids contact clarifier and the limited surface area of the sedimentation sections of the package plants.

The amount of bond indebtedness of the city was considered a minor factor, because it could limit the ability to properly fund operation and maintenance or needed repairs to the plant. Practices used for disposal of plant sludges were not considered environmentally sound, but had no impact on plant performance. A lack of simple taps on all of the filters prevented proper monitoring of filter performance.

Projected Impact of CCP

Data collected during the CPE indicated severe performance problems. Correcting the identified factors would appreciably improve the plant's performance and allow it to meet both current and future regulations. As such, implementation of a CCP represented a viable option for the plant.

Plant 13

Facility Description

Plant 13 is a conventional water treatment plant that supplies water to the city for domestic use. Its source is a nearby river. Based on a review of plant records for the year, the peak flow was 66 L/s (1.5 mgd). The plant includes the following unit processes and is shown schematically in Figure 4-66:

- Raw water intake structure and two vertical turbine 60-hp, 65-L/s (1,040-gpm) pumps
- Orifice plate with a totalizer-recorder to measure raw water flows
- Five volumetric chemical feeders: one each for alum, lime, soda ash, potassium permanganate, and powdered activated carbon
- Mechanical 3-hp flash mixer
- Two dual-stage flocculation basins. Each stage is 4.9-m (16-ft) square and 3.7-m (12.2-ft) deep. Each stage contains a vertical paddle flocculator operated from a central 1-hp variable speed drive
- Two sedimentation basins 11 m (36 ft) long and 6.1 m (20 ft) wide, containing 60° tube settlers 11 m x 4.5 m (36 ft x 14.7 ft) and 3.7-m (12.2-ft) deep. Each basin has a weir length of 43.9 m (144 ft)
- Two mixed media filters 3.4 m x 3.8 m (11 ft x 12.3 ft) fitted with rotary surface wash, and containing 84 cm (33 in) of media
- Backwash water and settling basin sludge decant basin
- Four sludge drying beds
- Diaphragm metering pump to feed hydrofluosilicic acid
- Vacuum-controlled solution feed pre-/post-chlorination system fed from 68-kg (150-lb) cylinders
- Two 575,300-L (152,000-gal) clearwells
- 189-L/s (3,000-gpm) vertical turbine backwash pump
- Two vertical turbine high-service pumps with a capacity of 66 L/s (1,050 gpm)
- 6,340-L (1,675-gal) wet well for the backwash and high-service pumps

Water is taken from the river through any of three intake pipes located at different depths. The intake pipes supply water to a wet well. Either of two vertical turbine pumps is used to supply raw water from the wet well to the plant. The plant is usually operated 17-20 hr/day. Higher demands are met by operating the plant for longer periods.

An orifice plate measures raw water flow rates just prior to chemical addition. Flow rates are charted on a totalizer-recorder located on a panel with the reservoir level alarm system.

Chlorine is injected prior to lime and alum addition at concentrations high enough to maintain a 1.5-mg/L residual on top of the filters - 45 kg (100 lb)/d. The rate is changed only when "muddy" waters are observed at the plant influent.

Alum and lime are added using dry volumetric feeders. Alum and lime slurries are prepared by adding dry chemicals to mixing tanks beneath the feeders and conveyed by gravity to a trough carrying raw water to the rapid mixer. Volumetric feeders are also in place to feed potassium permanganate, powdered activated carbon, and soda ash slurries to meet seasonal variations in raw water quality.

Alum feed rates are adjusted based on visual inspection of the floc particles in the flocculation basins. A jar testing apparatus is in place, but is used infrequently (10-15 times/yr). The lime feeder is currently operating at maximum output, and is not adjusted.

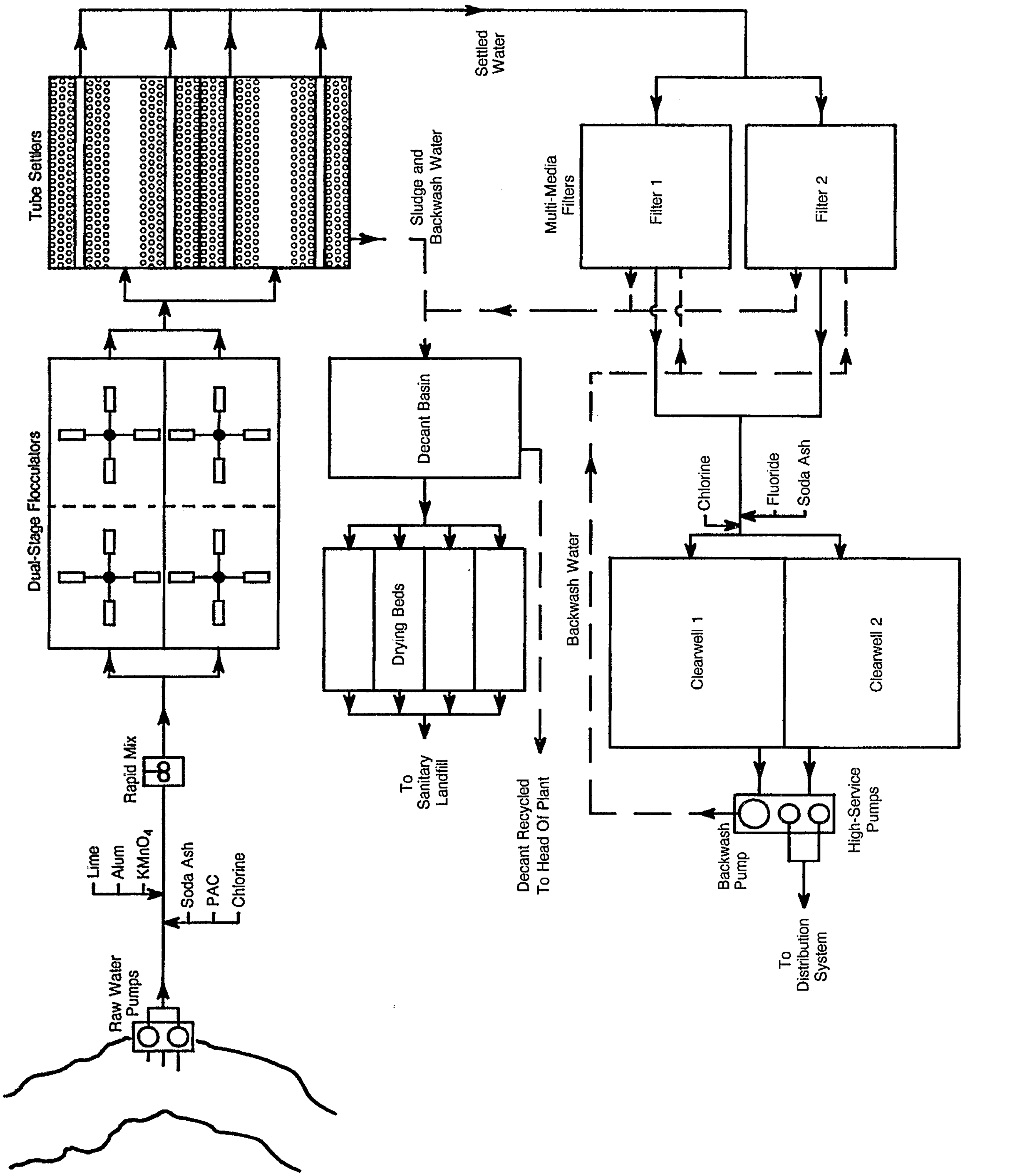
The chemical slurries and raw water enter a 0.9-m square (3-ft square) and 2.4- m (7.8-ft) deep basin containing a mechanical flash mixer. The basin has a hydraulic detention time of 30 seconds. The CPE team calculated the G value for the mixer to be adequate at 894 sec^{-1}.

After exiting the rapid mix basin the water splits hydraulically and flows through a parallel train of identical flocculation, sedimentation, and filter basins, prior to entering the two clearwells.

The coagulation/flocculation process is performed in a dual stage system; each stage is fitted with horizontal paddles. A pair of variable speed motors, one for each stage, drives a central shaft which in turn drives the paddles for each stage of the parallel trains. Each basin has a detention time of 45 minutes and a peak G of 77 sec^{-1}.

Flocculation basin effluent is directed to the bottom of the two pairs of sedimentation basins and flows up through a set of 60-degree tube settlers. Each of the two basins has a detention time of 2.1 hr. The basins have a combined surface overflow rate of 58 $m^3/m^2/d$ (1,420 gpd/sq ft). Sludge is manually removed approximately every 2 months and washed to a decant basin. Originally, decant from the basin was

Figure 4-66. Plant 13 process flow diagram.



recycled to the head of the plant, but the recycle pump is out of service so the decant is discharged to the river. Sludge from the decant basin is washed to the drying beds for ultimate discharge to a sanitary landfill.

Settled water then enters a pair of mixed media filters through metal troughs above 12.6 m^2 (136 sq ft) of media. Filter flow rates are controlled by raw water pumping rates, which in turn actuate pneumatic valves, maintaining an approximate loading rate of 222 $m^3/m^2/d$ (3.8 gpm/sq ft).

Backwash frequency is determined by measuring headloss across the filters or by observing a rise of clearwell turbidity. Filter runs are routinely 40-45 hr. Backwashing routinely consists of 6-7 minutes of surface wash at a rate of 26 $m^3/m^2/d$ (0.45 gpm/sq ft). The media beds are then washed at a rate of 1,055 $m^3/m^2/d$ (18 gpm/sq ft) for an indiscriminate duration.

The influent troughs are then used to discharge backwash water to the decant basin. The filters are capable of filter-to-waste operation, although this is not commonly practiced.

Chlorine (23 kg [50 lb]/d), hydrofluosilicic acid (91 L [24 gal]/d), and, occasionally, soda ash are then added to filtered water prior to entering the two clearwells. Each clearwell has a hydraulic detention time of 4.9 hr. Current piping configurations do not permit operating the clearwells in series.

Finished water then flows into the wet well which supplies water for the two high-service pumps, as well as the backwash pump.

Major Unit Process Evaluation

The performance potential graph is shown in Figure 4-67. The shortest bar represents the treatment process limiting the plant's capacity to achieve the desired performance of less than 0.5 NTU.

The instantaneous peak operating flow was established 66 L/s (1,050 gpm). This is based on a review of flow records for the previous year and the practice of only operating one of the raw water pumps. The plant is normally operated approximately 17-20 hr/day. To meet events of peak water use during the summer, the plant is operated 24 hr/day. On those days the treatment processes are still operated at a maximum flow rate of 66 L/s (1,050 gpm).

The flocculation basins were rated at 149 L/s (3.4 mgd) based on a 20-minute hydraulic detention time and two-stage flocculation with a variable speed input.

Due to the use of tube settlers, the sedimentation basins were rated at 101 L/s (2.3 mgd) based on a surface overflow rate of 88 $m^3/m^2/d$ (1.5 gpm/sq ft).

Filtration capacity for the plant was rated at 85 L/s (1.95 mgd) based on the state maximum allowable loading rate of 293 $m^3/m^2/d$ (5 gpm/sq ft).

The disinfection system was rated at 26 L/s (0.6 mgd). Future drinking water regulations for disinfection will be based on CT values needed for various removals of Giardia cysts and inactivation of viruses. To establish the CT required, it was assumed that the plant's disinfection system would have to provide 1.5 logs of cyst removal with 2.5 logs of removal credited for the other treatment processes. The total of 4 logs (99.99 percent) of cyst removal required for Plant 13 was based on the CPE team's estimate of the quality of the raw water.

To achieve the 1.5 logs of cyst removal the CPE team estimates that the disinfection system would have to provide a CT of 183. This CT value is for chlorine at a 2.5 mg/L dose, pH 8.0, and temperature of 5°C. The contact time was based exclusively on the post-chlorine dose. Only 10 percent of the theoretical detention time in the clearwells was used because the clearwells are not baffled and thus are subject to hydraulic short circuiting. The actual levels of disinfection required for the plant in the future will be determined by the State. The estimates in this CPE of the required number of log reductions of Giardia cysts and viruses and the allowances for actual contact times in the clearwells may change when final disinfection regulations are developed.

Raw and finished water pumping capacity was rated at 66 L/s (1.5 mgd). This rating was based on use of a single raw/finished water pump with one pump out of service.

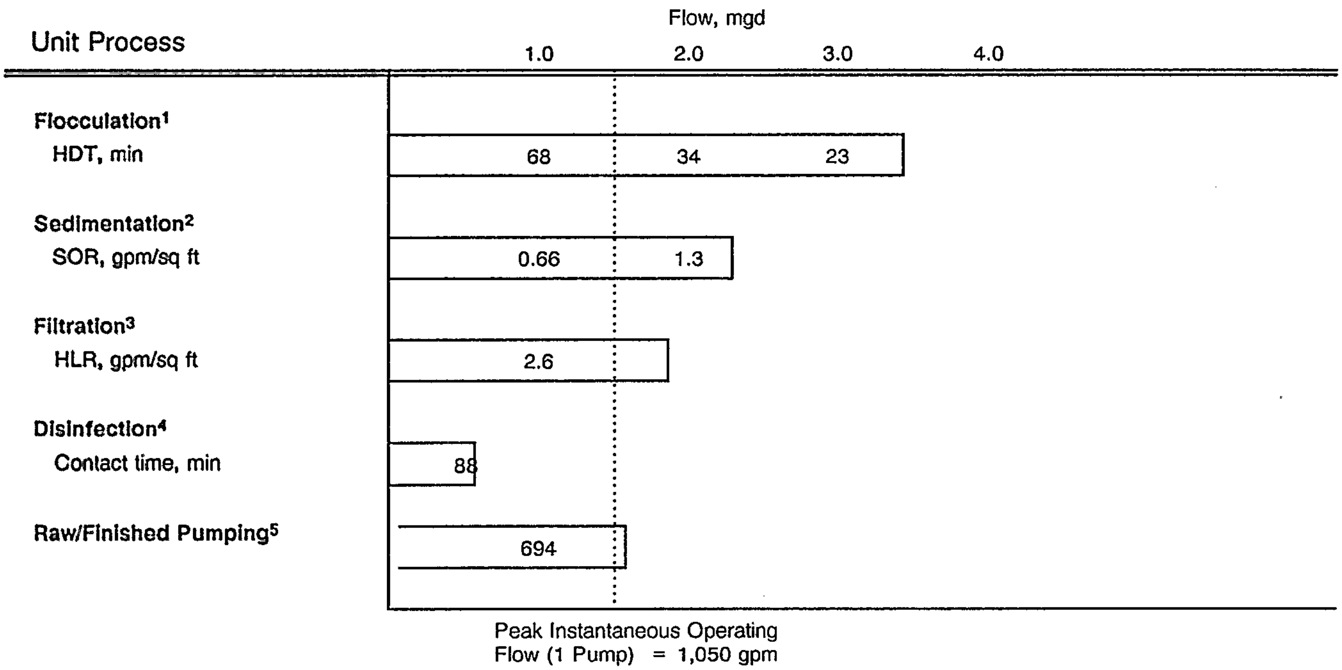
As shown in the performance potential graph, the major unit processes have a rating capacity exceeding the instantaneous peak operating flow, with the exception of the disinfection process. Again, the lack of baffling in the clearwells limited the projected capacity of the disinfection process.

Performance Assessment

Figure 4-68 shows the settled water turbidity measured by the plant staff over the previous 12-month period. Settled water turbidities were generally less than 2.0 NTUs, although there were also several periods of higher turbidity. These appeared to be related to periods of high raw water turbidity, indicating that chemical feed rates were not properly adjusted to compensate for the changes in raw water turbidity.

Figure 4-69 shows the finished water turbidity reported over the previous 12 months. Current regulations for finished water turbidity are 1.0 NTU. Future regulations will require the plant to meet a 0.5-NTU finished water turbidity 95 percent of the time. Except for several days in the first 3 months, the plant met

Figure 4-67. Plant 13 performance potential graph.



[1] Rated at 20 -min HDT - based on 2-stage with variable energy input.
[2] Rated at 1.5 gpm/sq ft - based on tube settlers with annual sludge removal.
[3] Rated at 5 gpm/sq ft - based on State maximum allowable loading.
[4] Rated at CT = 183 with 2.5 mg/L chlorine dose, which requires a 73-min HDT; allowed 10 percent of available volume for contact time, temperature = 5°C, pH = 8, 4-log required reduction, 2.5 log in plant, 1.5 log disinfection.
[5] Assumes firm capacity at 1.5 mgd with one pump out of service.

the 1.0-NTU turbidity requirements and was regularly below the 0.5-NTU required by the SWTR. Figure 4-70 presents a probability plot of this data and shows that the plant produces a finished water turbidity of less than 0.5 NTU approximately 70 percent of the time. Comparing Figures 4-68 and 4-69 reveals that higher finished water turbidity occurred during the same periods that the settled water turbidity was above 2.0 NTUs, providing further evidence that chemical feed rates were not properly adjusted when raw water turbidities changed.

During the CPE, a special study was conducted to assess the performance of the filters after backwashing. With adequate facilities and operation of preceding unit processes, a properly operated filter should produce a finished water turbidity of approximately 0.1 NTU and experience only a 0.2-NTU rise in turbidity in the finished water for approximately 10 minutes after being restarted following backwashing. For this special study, finished water from Filter 1 was sampled for a 40-minute period after being restarted following backwashing.

Figure 4-71 shows the results of this special study. Prior to backwashing, the filter was producing 1.0-NTU water. After backwashing, the turbidity levels increased to 3.6 NTU and did not stabilize at the 0.1-NTU level for 30 minutes. The special study also found a problem with an inadequate amount of backwash water flow at the beginning of the backwash cycle. A period of essentially no flow was followed by a violent eruption of the filter media as the backwash water finally started entering the filter. Further investigation of the problem revealed that the valve that controls the backwash water flow was sticking in a closed position and would finally snap fully open.

These results indicate that a finished water that meets current and future regulations is usually produced. During periods of high raw water turbidity, it appears that the plant staff is not adequately adjusting process control to allow the plant to produce a consistently good quality finished water. Turbidity levels following backwashing also indicate that better process control could be practiced to limit the passage of high turbidity water into the distribution system following filter backwash.

Figure 4-68. Settled water turbidity profile - Plant 13.

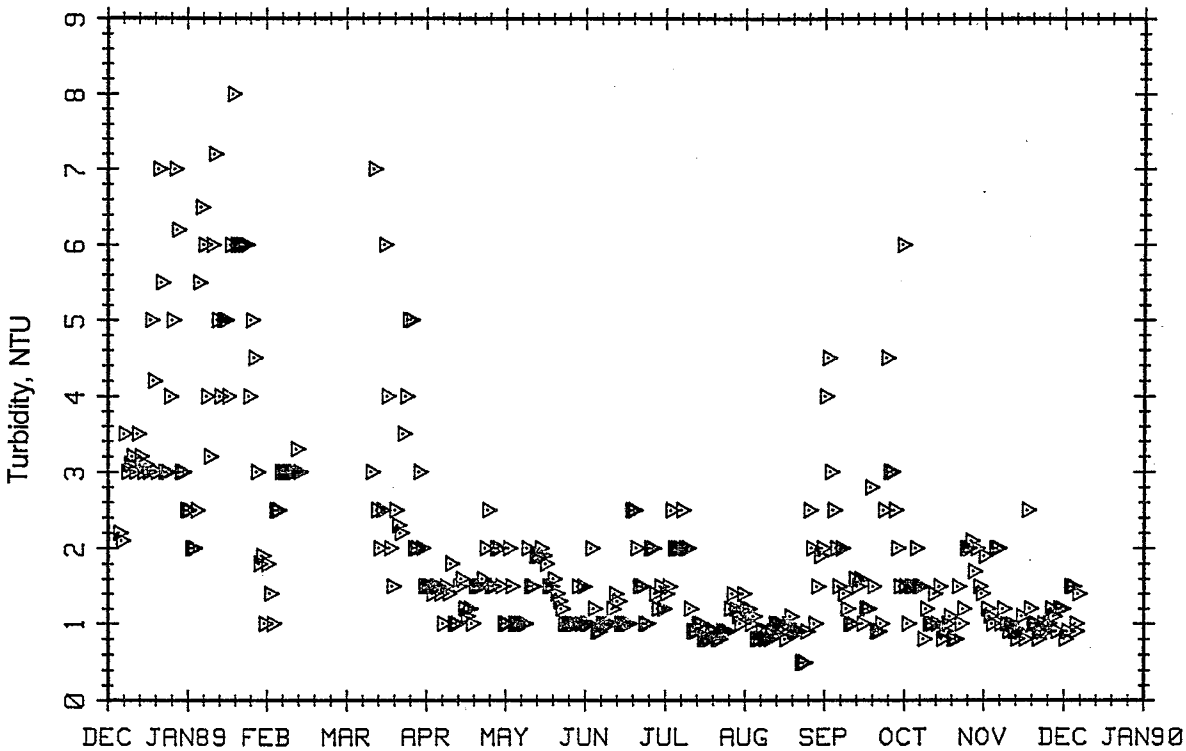


Figure 4-69. Finished water turbidity profile - Plant 13.

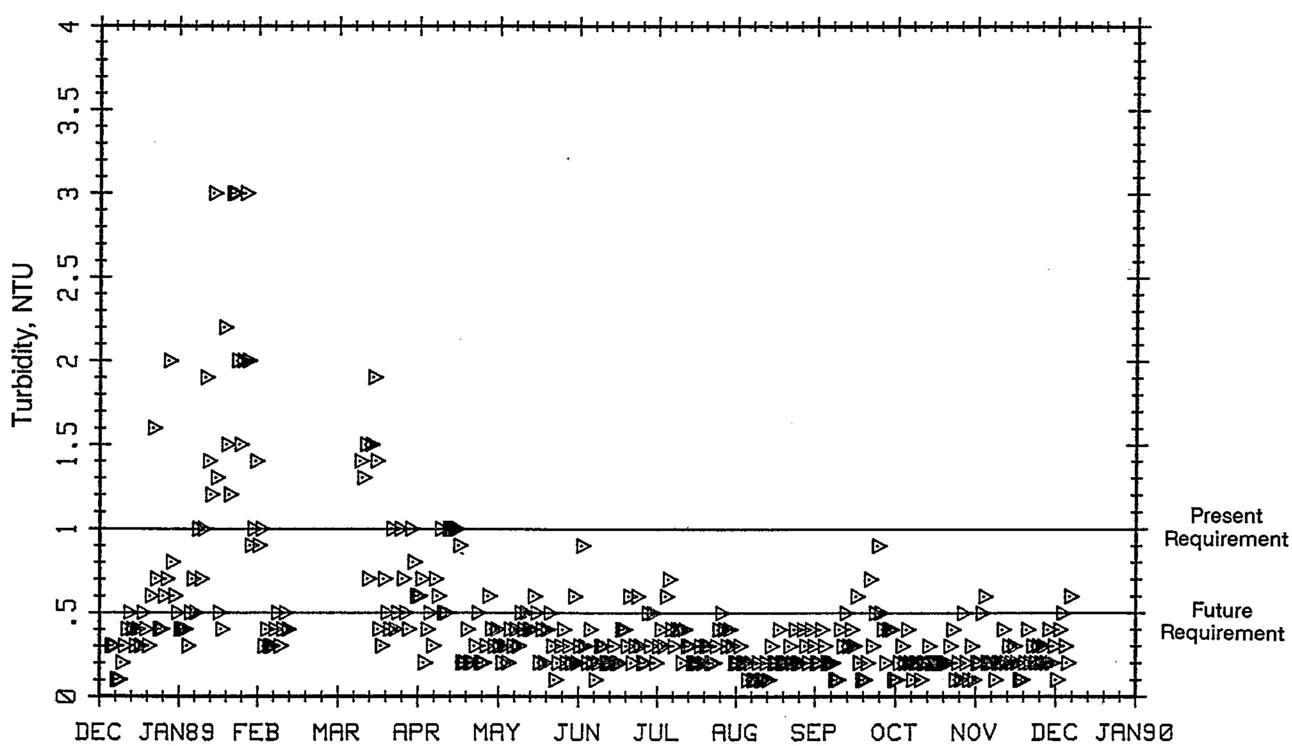


Figure 4-70. Probability plot of finished water turbidity - Plant 13.

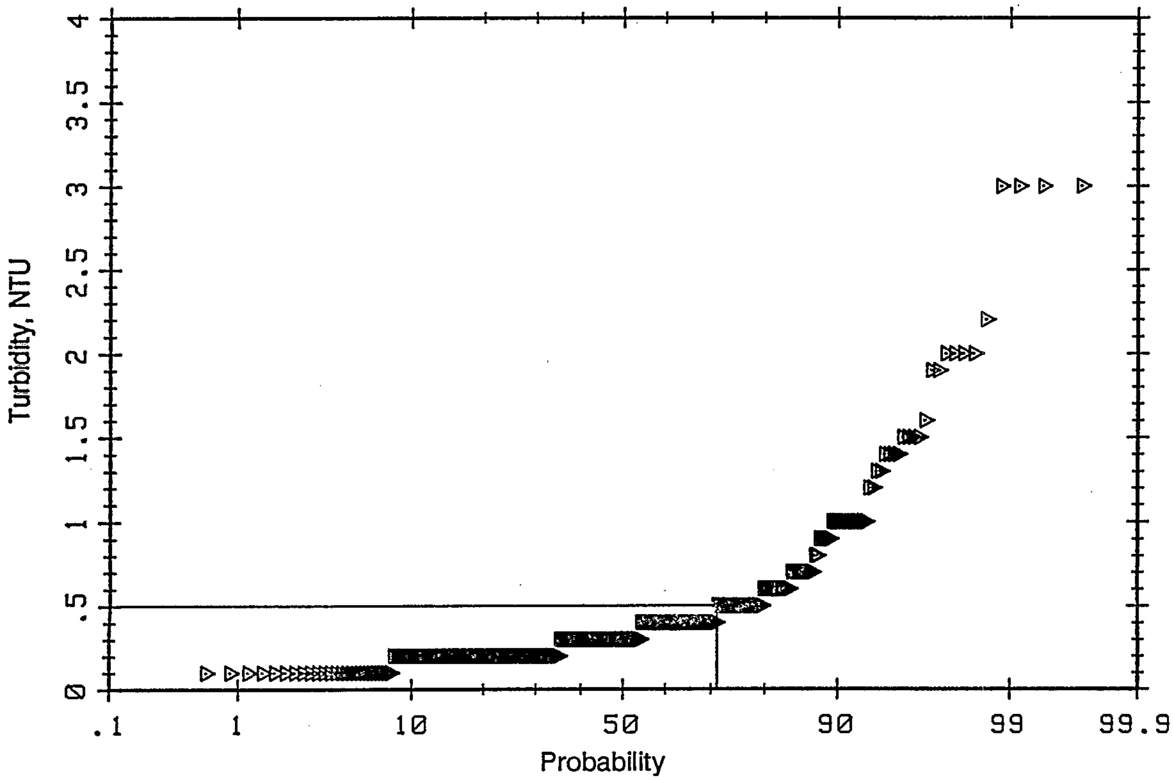
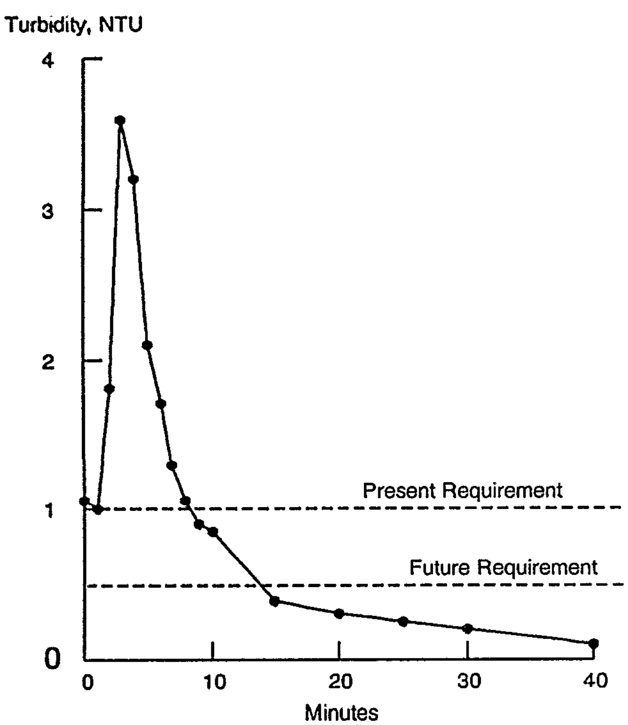


Figure 4-71. Filter effluent turbidity profile after backwash - Plant 13.



Performance-Limiting Factors

The following factor was identified as having a major effect on a long-term repetitive basis:

1. Disinfection - Design*: This factor has an asterisk because it was assessed based on the initial disinfection requirements of new regulations. These requirements may change when final regulations are developed by the State. Using this basis, however, inadequate contact time is provided because of a lack of baffling in the two clearwells and a lack of piping to allow them to operate in series.

Factors identified as having a minimal effect on a routine basis, or a major effect on a periodic basis were prioritized and are summarized below:

1. Supervision - Administration: The plant has 24-hr coverage, which requires a large staff. This large staff works without any formal organizational structure, no lines of authority, no chief operator, and a total lack of leadership. With this absence of supervision, essentially no communication occurs between the staff on the different shifts. There are no regular meetings, no operating log, and no shift overlaps where essential information on the status of the plant can be discussed. Without this essential supervision, the productivity of the plant staff is poor, which encourages poor

performance. For example, the alum feeder that needed repair at the end of the first shift was not repaired during either of the next two shifts. Lack of supervision and communication were made worse by a total lack of standard operating procedures.

2. Application of Concepts and Testing to Process Control - Operation: While the plant staff is certified and has a knowledge of water treatment, they are not able to apply their knowledge to properly control the treatment processes to optimize performance. Filter-to-waste capabilities at the plant are not used to minimize the passage of high turbidity water to the clearwells after filter backwash. The plant was also operated for a month without a turbidimeter. Iron and manganese levels were high in the finished water on several occasions, but no process changes were initiated by the plant staff. Lime is fed at the same point as the alum even though the lime raises the pH out of the optimum range for alum coagulation.

3. Process Control Testing - Operation: A process control testing program to optimize unit process performance did not exist. Process control testing is essential for water plants served by surface sources because of the frequent and rapid changes in raw water quality. Basic equipment was available to conduct this testing, but was not used.

4. Preventive Maintenance - Maintenance: The lack of a maintenance program has resulted in many key pieces of equipment needed for optimal operation not operating or near failure. Filter controls, the influent control valve, the finished water flow meter, and backwash water reclaim pumps are not operating. New alum and lime feeders were not installed to replace the marginal units still in operation. Backwash control valves were malfunctioning and the drives on the flocculators were making excessive noises with no indication of repairs being planned.

5. Water Demand - Administration*: This factor has an asterisk because it is projected that in the spring of 1990 the water demands of the new industry and development in the city will exceed the raw water pumping capacity of the plant. Plant administrators committed the plant to supply this water with little regard to its impact on the capacity or performance of the plant.

Several of the administration's policies are considered to have a minor impact on the performance of the plant. Current rate structures do not allow the plant to be self-sustaining and cover all needed operation and maintenance costs. There is a total lack of long-range planning to allow for growth within the community so as to minimize impact on plant's capacity and performance. Funding for the plant is also kept low, preventing repair of key equipment. Other factors thought to have a minor impact on performance are the low pay of the plant staff as compared to other plants in the State and the lack of process flexibility.

Projected Impact of a CCP

Data collected during the CPE indicated that this plant usually performs satisfactorily, with some problems responding to changes in raw water turbidity. Correcting the identified factors would appreciably improve the consistency of the plant's performance and allow it to meet both current and future regulations. As such, implementation of a CCP represented a viable option for this plant.

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