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TRICKLING FILTER/SOLIDS CONTACT PROCESS: FULL-SCALE STUDIES

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16. ABSTRACT

Use of the trickling filter/solids contact process has increased significantly since its successful demonstration at the Corvallis, Oregon Plant in 1979. The purpose of this study was to document the design features and performance of existing trickling filter/solids contact facilities and to gain more knowledge about the design and operation of the process. The studies included a total of 29 weeks of field investigations at four plants and an analysis of operating records at these and other plants. Special studies addressed several issues. The primary objectives included (1) defining the trickling filter/solids contact process; (2) assessing the effect of cosettling in the primary sedimentation tanks on primary treatment performance; (3) assessing the effect of trickling filter loading, contact tank operating parameters, secondary clarifier overflow rate, and coagulant addition on trickling filter/solids contact performance; and (4) assessing flocculation and soluble BOD removal in the aerated solids contact tank.

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FOREWORD

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the nation's land, air, and water systems. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. The Clean Water Act, the Safe Drinking Water Act, and the Toxic Substances Control Act are three of the major congressional laws that provide the framework for restoring and maintaining the integrity of our nation's water, for preserving and enhancing the water we drink, and for protecting the environment from toxic substances. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Water Engineering Research Laboratory is that component of EPA's Research and Development program concerned with preventing, treating, and managing municipal wastewaer discharges; establishing practices to control and remove contaminants from drinking water and to prevent its deterioration during storage and distribution; and assessing the nature and controlability of releases of toxic substances to the air, water, and land from manufacturing processes and subsequent product uses. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

The purpose of this report is to provide the engineering community and related industry a new source of information to be used in the planning, design, and operation of present and future treatment plants that employ the trickling filter/solids contact process. It is the intent of the manual to supplement the existing body of knowledge in this area.

Francis T. Mayo
Water Engineering Research Laboratory

ABSTRACT

Use of the trickling filter/solids contact process has increased significantly since its successful demonstration at the Corvallis, Oregon, plant in 1979. The purpose of the full-scale studies was to document the design features and performance of existing trickling filter/solids contact facilities and to gain more knowledge about the design and operation of the process.

The studies included a total of 29 weeks of field investigations at four plants and an analysis of operating records at these and other plants. Special studies addressed several issues. The primary objectives included (1) defining the trickling filter/solids contact process; (2) assessing the effect of cosettling in the primary sedimentation tanks on primary treatment performance; (3) assessing the effect of trickling filter loading, contact tank operating parameters, secondary clarifier overflow rate, and coagulant addition on trickling filter/solids contact performance; and (4) assessing flocculation and soluble BOD removal in the aerated solids contact tank.

A summary of the project results and conclusions follows. Cosettling will reduce thickening costs but may affect primary treatment performance and increase sludge disposal costs. In the narrow range of average trickling filter organic loadings studied, loading exerted some influence on performance, but primary effluent suspended solids and filter effluent suspended solids were also important.

Trickling filter/solids contact performance was relatively insensitive to changes in mixed liquor SS concentration and secondary overflow rate. The effect of solids retention time on performance was also studied. The majority of the flocculation in the aerated solids contact tank occurred during the first 12 minutes of contact time at Medford. The contact tank removed an average of 75 percent of the filter effluent soluble carbonaceous BOD.

This report was submitted in partial fulfillment of Contract No. 63-03-1818 by Brown and Caldwell under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from January 1984 to September 1985, and work was completed as of September 30, 1985.

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ABBREVIATIONS

activated biofilter	ABF
average dry-weather flow	ADWF
biochemical oxygen demand	BOD
5-day biochemical oxygen demand in mg/l	BOD_5
degrees centrigrade	C
carbonaceous biochemical oxygen demand	CBOD
cubic feet	cu ft
cubic feet per minute	cfm
cubic feet per minute per 1,000 cu ft	cfm/1,000
dissolved oxygen	DO
U.S. Environmental Protection Agency	EPA
degrees Fahrenheit	F
facultative sludge basin	FSB
food to microorganism ratio	F/M
feet	ft
velocity gradient	:
gallons per day per square foot	gpd/sq ft
gallons per minute per square foot	gpm/sq ft
hours	hr
pounds	lb
pounds per cubic foot	lb/cu ft
pound seconds per cubic foot	lb-sec/cu ft
meters	m
cubic meters per square meter per second	m^3/m^2-sec
square meters per cubic meter	m^2/m^3
microns	m
million gallons per day	mgd
milligrams per liter	mg/l
minutes	min
milliliters per gram	ml/g
mixed liquor suspended solids	MLSS
nitrogenous oxygen demand	NOD
peak wet-weather flow	PWWF
pounds per day	ppd
pounds per day per 1,000 cu ft	ppd/1,000 cu ft
seconds	sec
sludge volume index	SVI
solids retention time	SRT
soluble biochemical oxygen demand	SBOD
soluble carbonaceous biochemical oxygen demand	SCBOD
square feet	sq ft
suspended solids	SS
trickling filter	TF
trickling filter/activated sludge	TF/AS
trickling filter/solids contact	TF/SC
total suspended solids	TSS
Water Engineering Research Laboratory	WERL

CONVERSION FACTORS

English unit	Multiplier	SI unit
in.	2.540×10^{-2}	m
lb (mass)	0.4536	kg
lb/1,000 cu ft	16.02	g/m^3
lb/ft	1.488	kg/m
mil gal	3785	m^3
mgd	4.383×10^{-2}	m^3/s
pcf	16.02	kg/m^3
psf	4.883	kg/m^2
sq ft	9.290×10^{-2}	m^2
sq in	6.452×10^{-4}	m^2
yard	.9144	m

Note: (English unit) x (multiplier) = SI unit

(SI unit) ÷ (multiplier) = English unit

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FIELD INVESTIGATIONS

Performance of the field investigations required the participation of many individuals and municipalities. Field investigations were conducted at treatment plants in Chilton, Wisconsin; Medford, Oregon; Oconto Falls,

Wisconsin; and Tolleson, Arizona. These investigations could not have been completed without the commitment of staff and laboratory space from the treatment plants. Robert E. Lee & Associates, Inc., as subcontractor, conducted field investigations at Chilton, Wisconsin, and Oconto Falls, Wisconsin. Jack Muir, with the assistance of plant staff, conducted field investigations at Tolleson, Arizona. David Jenkins and Associates performed microscopic examinations and filament typing of biological samples. Brown and Caldwell, consulting engineers, served as the principal subcontractor and performed the Medford field investigations with the assistance of plant staff.

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CHAPTER 1

INTRODUCTION

Background

The evolution of the trickling filter/solids contact process (TF/SC) has been rapid in recent years, but it began with the development of the trickling filter (TF) process. The TF process has been used for more than a century, and in the 1960s, it was the most commonly used process for treating municipal wastewater.[1] The popularity of the TF process was due primarily to its general simplicity, reliability, and energy-saving features. After the adoption of uniform national treatment standards by the U.S. Environmental Protection Agency (EPA) in 1973, however, the TF process became less popular. Effluent concentrations of biochemical oxygen demand (BOD) and suspended solids (SS) from trickling filter plants did not consistently meet the 30 milligrams per liter (mg/l) limit established for secondary treatment.

Many existing TF plants were faced with a need to improve performance to meet new discharge requirements for secondary or advanced treatment. The wastewater treatment plant at Corvallis, Oregon, was a single-stage TF plant that had to be upgraded to meet new summer discharge requirements of 10 mg/l for the monthly averages of 5-day BOD (BOD_5) and SS (10/10). To improve performance, the plant was converted to a coupled trickling filter/activated sludge (TF/AS) plant with flocculator center wells in the secondary clarifiers. Results of research at the University of California at Berkeley[2] led the design engineers, Brown and Caldwell, to believe that the plant could meet the 10/10 summer discharge requirements without tertiary filtration if the secondary clarifier flocculation features were included.

In 1978 and 1979, the Corvallis coupled TF/AS plant was operated with and without the activated sludge aeration tanks. When the activated sludge aeration tanks were out of service, secondary sludge had to be delivered to an aerated return sludge channel along the side of the activated sludge aeration tanks. The return sludge was aerated for about 10 minutes and then combined with trickling filter effluent to form the mixed liquor entering the secondary clarifiers. To the surprise of the plant

staff and design engineers, the treatment plant still produced an effluent that met the summer discharge requirements of 10/10 although the return sludge aeration and aerated contact times were relatively short.[3] Earlier efforts in Seattle pilot studies[4] had been unsuccessful in improving flocculation of TF effluent solids by mixing with settled secondary solids. For 7 days, secondary settled solids were recycled to the beginning of the transfer line between the TF and secondary clarifier. No aeration was provided and the mixture of trickling filter effluent and settled solids was introduced into the side of the secondary clarifier. Effluent SS increased an average of 10 to 13 mg/l above values obtained when solids recycle was not practiced. In retrospect, this failure probably occurred because aeration was not used when sludge recycling was practiced and the contact time was limited.

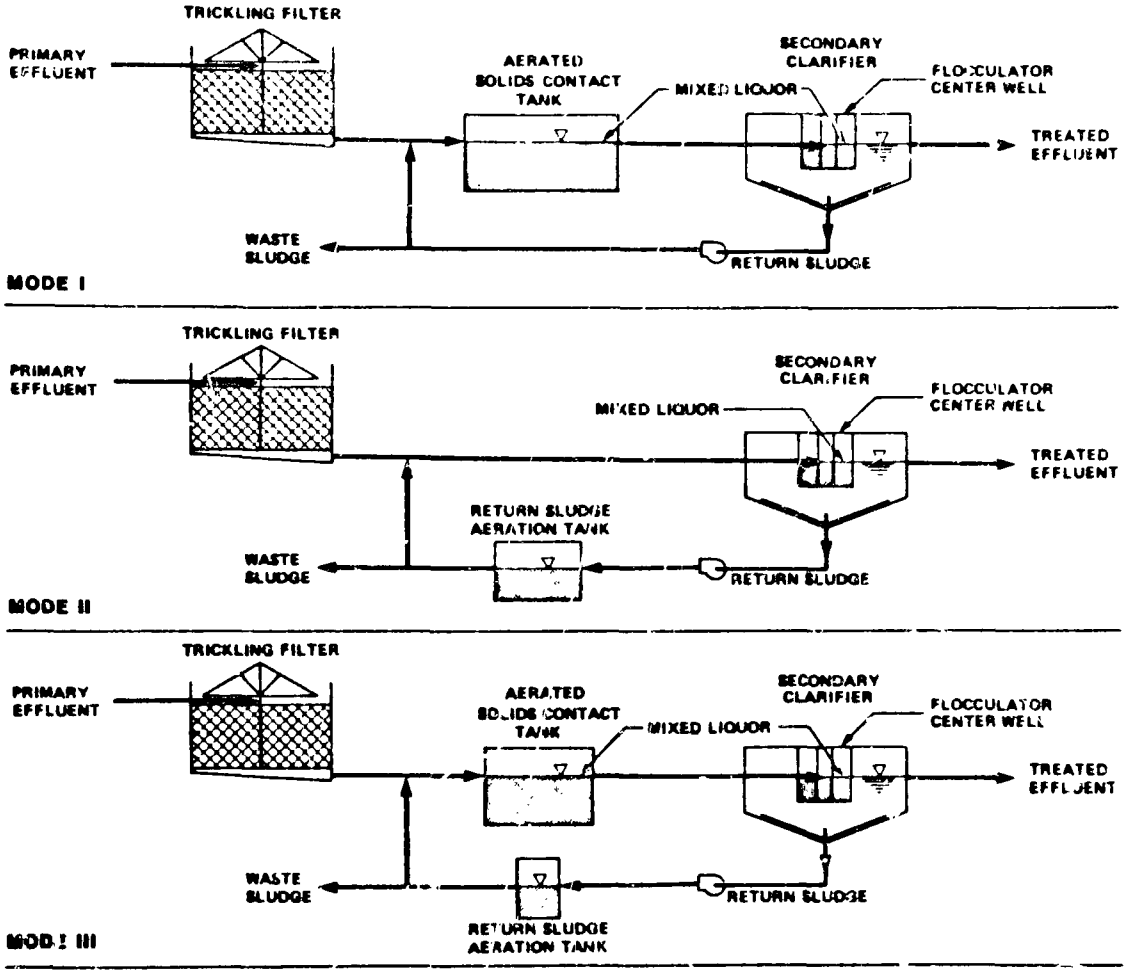
The new process developed at Corvallis was known as the TF/SC process. Research on this process was undertaken in 1980. The intent of the plant-scale research was to develop possible design criteria for the TF/SC process based on operating results at Corvallis. Since the initial work at Corvallis, nine other TF/SC plants have been put into operation, and approximately 30 more are in the planning or design stages. A more detailed description of the TF/SC process, including its process variations (modes), is given below along with a comparison of TF/SC with other process. The objectives and scope of work for this project are then presented.

Description of the TF/SC Process

The TF/SC process is a biological and physical process that includes (1) a TF, (2) an aerobic solids contact period, (3) a flocculation period, and (4) secondary clarification. Two operating features are also important: solids must be maintained in an aerobic, flocculant state; and solids are recycled from the secondary clarifier to combine with trickling filter effluent as a mixed liquor.

The primary function of the first element in the TF/SC process, the TF, is to reduce the soluble BOD_5 in the wastewater. The aerobic solids contact period is then used to provide contact between finely divided solids in the TF effluent and recycled biological solids and to provide additional soluble BOD_5 removal, if necessary. The contact opportunity provides for initial flocculation of dispersed solids into floc. The length of the aerobic solids contact period is governed by the requirements for particulate and soluble BOD_5 removal.

The three modes on Figure 1 illustrate the effects of particulate and soluble BOD_5 removal requirements on the configuration of the TF/SC process. If a significant fraction of



TRICKLING FILTER/SOLIDS CONTACT PROCESS (TF/SC) VARIATIONS

FIGURE 1. VARIATIONS OF THE TF/SC PROCESS

the TF effluent soluble BOD_5 must be removed in addition to particulate matter, an aerated solids contact tank is used. If particulate removal is the primary thrust, only a return sludge aeration tank is required. A combination of the two aerated tanks is required if a modest amount of soluble BOD_5 removal is needed in conjunction with particulate removal. The logic behind choosing between different modes is discussed in more detail in Reference 5. In all three modes, the biological solids must be maintained in an aerobic state to maintain their flocculating properties by using an aerated solids contact tank, a return sludge aeration tank, or a combination of the two.

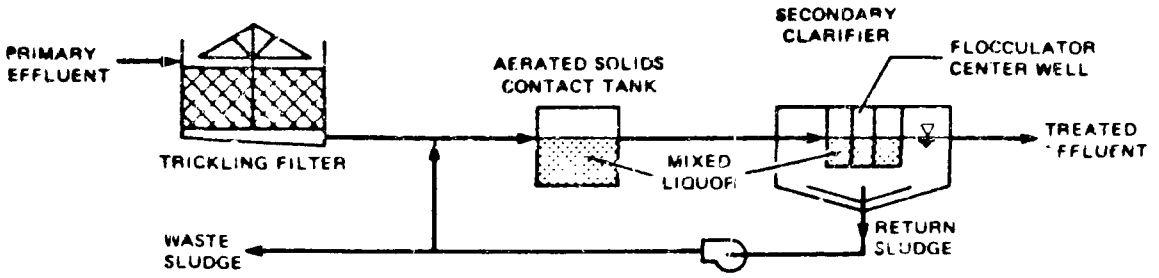
The third element in the TF/SC process is the flocculation period. Flocculation, which is initiated in the contact tank, continues in the clarifier, preferably in a mildly stirred environment of a center well. The flocculation step promotes clear effluent and growth of large, settleable floc that are removed in secondary clarification--the last step.

COMPARISON OF TF/SC WITH OTHER PROCESSES

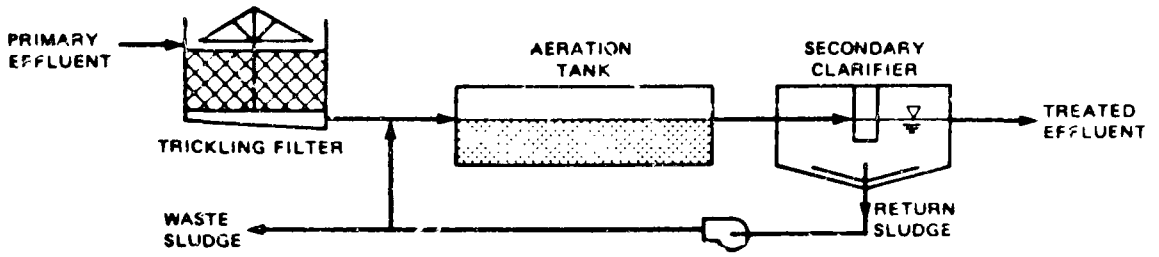
The TF/SC process is related to several conventional treatment systems, but significant differences exist among the systems. On Figure 2, the related systems are shown. The systems differ both in terms of the functions of each unit and the loadings on each unit. As a point of comparison, the primary organic removal unit in the TF/SC process is the TF; BOD_5 loadings are maintained at relatively low levels. The aerated solids contact tank has a low residence time and is used as a polishing unit only to reduce BOD_5 and SS. The clarifier is usually designed with flocculation features to produce the highest effluent quality possible and eliminate tertiary filtration, where it would be required otherwise.

The TF/AS process is often employed where nitrification is desired. In this process, the functions of organic removal are more evenly split between the aeration tank and TF. Here, the TF is often called a "roughing filter" since it is only doing a part of the organics removal job. In addition to a major organics removal function, the aeration tank typically accomplishes nitrification. As opposed to the TF/SC process, specific attention is not typically given to flocculation of finely divided solids in the aeration basin. A conventional secondary clarifier is usually employed.

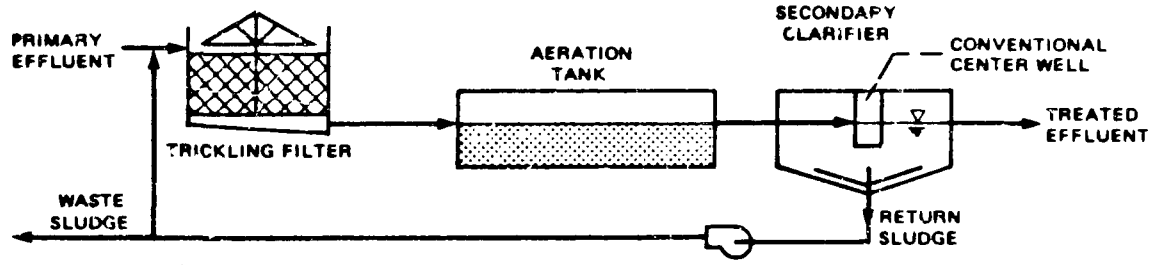
The activated biofilter (ABF) process is more like the TF/AS process than the TF/SC process, because BOD_5 loadings are often higher on the TF and the aeration tank is designed to do more of



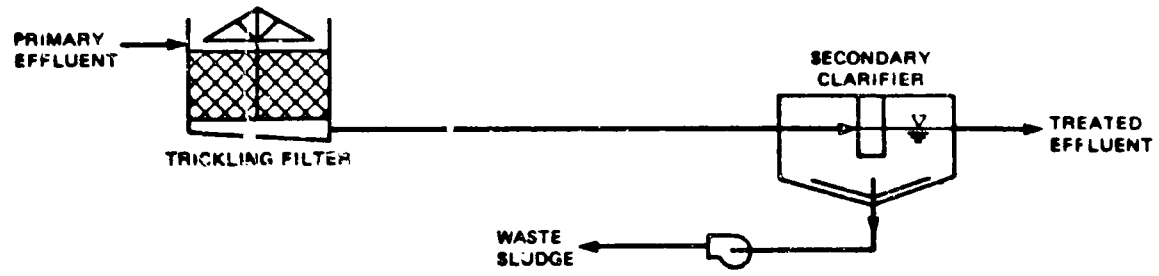
A. TF/SC PROCESS (MODE 1)



B. COUPLED TRICKLING FILTER ACTIVATED SLUDGE PROCESS



C. ABF PROCESS



D. TRICKLING FILTER PROCESS

FIGURE 2. COMPARISON OF TF/SC PROCESS AND CONVENTIONAL PROCESSES

the organics removal job. In some ABF designs, the aeration tank is eliminated and the TF loading is reduced. A design feature of the ABF process is the recycle of sludge over the media. This enhances soluble organics removal.

The conventional TF process is the most similar technology to the TF/SC process. Here, TF organic loadings for both processes are in the same range. Lacking a solids contact tank for flocculation of dispersed solids, the TF process produces an effluent close to the typical EPA limits for secondary treatment (30 mg/l monthly average SS and BOD). In colder, northern climates, conventional trickling filters often do not meet secondary treatment requirements. A conventional clarifier is used.

In summary, the primary features that distinguish TF/SC from other processes are:

1. The primary function of the contact tank and clarifier flocculation features is to increase flocculation and solids capture and reduce particulate BOD.

2. The majority of soluble BOD_5 removal occurs in the TF.

3. Return sludge solids are mixed with TF effluent rather than primary effluent as in the ABF process.

4. The aerated solids contact tank is not designed to nitrify, although nitrification may occur in the TF.

5. The aerated solids contact time is 1 hour or less based on total flow including recycle.

6. The solids retention time (SRT) of the aerated solids contact tank is less than approximately 2 days.

Objectives and Scope of Work

The main objectives of the TF/SC project were to provide a design and performance summary of operating TF/SC facilities and to conduct special studies to increase technical knowledge about TF/SC design and operation. The intent was to provide insight into the design and operation of TF/SC plants and to develop conclusions and recommendations relative to improved design and operation methods. The project was not intended to produce a definitive design manual, since field investigations and operating data were limited relative to many other processes. Special consideration was given to investigating the interdependence of unit processes applied in the TF/SC plants. Results presented in the report are based on operating records from

full-scale TF/SC plants, project field investigations, and other sources. A more detailed description of the design and performance summary and field investigations is presented below:

1. Design and Performance Summary. The purpose of the design and performance summary was to provide a listing of design data for six operating TF/SC plants, a summary of plant data, and a comparison between design and performance for six facilities. The six plants included in the design and performance summary are located in Chilton, Wisconsin; Corvallis, Oregon; Medford, Oregon; Norco, California; Oconto Falls, Wisconsin; and Tolleson, Arizona.

2. Special Studies. The special studies were the main focus of this project. In the initial stages of the project, technical questions regarding TF/SC design and operation were formulated, and special studies based on full-scale field investigations and the analysis of plant records were developed to address technical issues of interest. Special study objectives are given below:

    1. Develop a definition that clearly distinguishes TF/SC from related processes.

    2. Assess the influence of cosettling waste secondary solids with raw sewage solids on primary sedimentation tank performance.

    3. Assess soluble BOD_5 removal kinetics with TF depth.

    4. Assess the effect of TF loading on TF/SC performance.

    5. Assess the effect of media type on aerated solids contact tank performance.

    6. Assess the effect of aerated solids contact tank operating parameters on TF/SC performance.

    7. Assess soluble BOD_5 removal in the aerated solids contact tank.

    8. Assess the effect of aeration rate on TF/SC performance.

    9. Assess the effect of secondary clarifier overflow rate on final effluent quality.

    10. Assess the effect of coagulant addition for phosphorus removal on TF/SC performance.

The special study objectives were accomplished by performing field investigations at Oconto Falls, Wisconsin; Tolleson, Arizona; Medford, Oregon; and Chilton, Wisconsin. Plant records for the first three plants, along with records from Corvallis, Oregon, were also used in the studies.

Outline of the Report

This report presents its conclusions and recommendations first in Chapters 2 and 3. Chapter 4 summarizes the design and operations of six TF/SC plants. This chapter presents the similarities and unique characteristics of six operating TF/SC plants. Chapter 5 describes the individual field investigations performed at four treatment plants as part of the special studies. Methods for addressing special study objectives and the field investigation schedules and sampling programs are also presented. Chapter 6 presents the results of the special studies. Results are presented in the order that the specific unit process appears in a TF/SC plant.

CHAPTER 2

CONCLUSIONS

The evaluation of plants records and special studies performed at operating TF/SC plants showed that the TF/SC process reliably provides high effluent quality. The process has been successful in a variety of climates and situations and has been used to upgrade existing plants; it may also be used as a basis for new plants. The following conclusions can be drawn from the special studies performed at operating TF/SC plants.

1. Cosettling--Primary treatment SS removal averaged between 53 and 62 percent at three TF/SC plants that cosettle and 74 percent at Medford, which does not cosettle. The Medford removals are exceptional. Primary sludge concentrations were typically between 3.7 and 5.3 percent when cosettling was practiced; concentrations of 5 to 7 percent are common when primary solids are thickened in the primary sedimentation tanks and cosettling is not practiced. The use of cosettling may eliminate the need for separate thickeners but increases sludge disposal costs.

2. TF Soluble BOD Removal--The Velz equation successfully modeled soluble carbonaceous BOD_5 removal with depth at Tolleson. Removal rate coefficients for the rock filter media were higher than for plastic media and may be due to differences in hydraulic residence time or differences in oxygen transferred per unit of media surface area.

3. TF Loading--In the range of average TF BOD_5 loadings studied under this project (5.8 to 29 pounds per day per 1,000 cubic feet (ppd/1,000 cu ft), BOD_5 loading does not always exert a strong influence on final effluent SS. Final effluent SS were always correlated with TF effluent SS, which are most sensitive to primary effluent suspended solids concentration. These results emphasize the need for reliable primary treatment and consideration of the effect of primary effluent SS on final effluent quality.

4. Media Type--The microscopic examinations performed on TF effluents suggested that the floc formed in rock media are more compact and less diffuse than those formed in plastic media. Additional data must be collected to confirm differences. The filaments identified in the samples suggest that a wide diversity of environments is present in the TFs.

5. Solids Contact Operating Parameters

   a. Solids Retention Time--Correlations between SRT in the aerated solids contact tank and final effluent SS were not statistically significant at Corvallis and Tolleson, where rock filters precede the contact tank. Final effluent SS at one plant (Medford) with plastic media decreased with increasing SRT and produced a statistically significant but weak correlation.

   b. Mixed Liquor Suspended Solids--Mixed liquor suspended solids (MLSS) concentrations between 900 and 2,300 mg/l at Medford and Tolleson did not affect final effluent SS significantly and only produced an average increase of about 2 mg/l at Corvallis when MLSS concentration was increased from 1,500 to 7,000 mg/l. The insensitivity to mixed liquor level means simplification of operation, since less attention can be given to sludge inventory management.

   c. Sludge Volume Index--Sludge volume index (SVI) values varied from 60 to 130 ml/g at Medford and increasing values were correlated with reduced final effluent SS values. No correlation was observed at Tolleson or Corvallis. Corvallis and Tolleson have large flocculator center wells whereas those at Medford are much smaller. These results suggest that high SVIs are advantageous when only smaller center wells are used.

6. Solids Flocculation--Field test results at Medford suggest that the majority of flocculation in the aerated solids contact channel occurs within the first 12 minutes of aerated solids contact time in a channel that has a hydraulic retention time of 39 minutes. Additional SS removal occurs in the flocculator center well. The results agree with observations at Corvallis, Oregon.

7. Contact Tank Soluble BOD Removal. First-order reaction kinetics adequately describe removal. Although the primary function of the contact tank is to flocculate SS and particulate BOD, a significant fraction of the filter

effluent soluble BOD can be removed. The Medford contact tank removed an average of 75 percent of the soluble carbonaceous BOD in 39 minutes of contact time.

8. Secondary Clarifier Overflow Rate--Secondary clarifiers that include inboard launders, high sidewater depths, suction tube or header sludge removal systems, and flocculator center wells are insensitive to 1,300 gpd/sq ft at Corvallis and up to 700 gpd/sq ft at Tolleson. These are the maximum overflow rates at the respective plants. Because of the insensitivity to overflow rate, these clarifiers may be designed and operated at higher overflow rates than previously believed.

9. Coagulant Addition--Ferric chloride addition in the aerated solids contact tank for phosphorus removal does not adversely effect TF/SC operation.

CHAPTER 3

RECOMMENDATIONS

This project has shown that the TF/SC process will produce a high quality effluent if designed properly. Specific recommendations for further work include extending knowledge on the effect of the TF effluent characteristics on aerated solids contact tank and clarifier performance. Some of the data collected during this project suggest that fundamental differences exist between TF solids formed in rock and plastic media. More extensive information should be collected on TF solids characteristics, such as state of dispersions, filament abundance and type, and floc size and shape. More extensive information on solids characteristics and corresponding solids contact tank and secondary clarifier performance can provide a better description of the effect of TF solids characteristics on TF/SC design and performance.

Additional work on the effect of SRT on TF/SC performance needs to be done. Data from this project suggest that TF/SC plants with rock media filters may be less sensitive to SRT, and that TF/SC plants with plastic media are more sensitive. Differences in sensitivity to SRT may be due to fundamental differences in filter solids characteristics or they may result from the difficulty in estimating the true SRT. More extensive and frequent measurements of solids in the flocculator center wells and sludge blankets should be made to quantify the total mass of solids in the secondary system. If these measurements are made concurrently with MLSS measurements, the effect of including clarifier solids in SRT computations on SRT correlations with TF/SC performance could be evaluated.

The effect of cosettling on primary clarifier performance has not been clearly established. Significant differences between primary solids concentrations at the plants studied has made it difficult to assess the effect of cosettling. Additional measurements need to be made at one or two other TF/SC plants that practice cosettling.

The operating TF/SC plants studied have generally operated with low TF organic loadings. Based on results from this project, increases in loading caused negligible or relatively

small increases in final effluent SS. The TF/SC process should be operated at higher loadings to document its failure point and limits. Likewise, the secondary clarifier performance limits should also be tested. Results from this project suggest the clarifiers may be able to operate at significantly higher overflow rates without adverse effects on performance.

CHAPTER 4

DESIGN AND OPERATIONS SUMMARY

The TF/SC process has been used in many different locations and situations to meet different discharge requirements. The treatment plants are located in warm and cold climates and treat both weak and strong wastewaters. The purpose of this chapter is to present the characteristics and features of six full-scale TF/SC plants studied under this project and to compare and contrast their design and performance. For each TF/SC plant, a brief description, summary of design data, and a comparison of design criteria with actual performance are presented.

DESCRIPTION OF OPERATING TF/SC PLANTS

Six different TF/SC plants investigated in this project are described in this section. Design data for all of the plants are given in Table 1. Process loading factors are presented in a subsequent section of this chapter. The description summarizes the common and distinguishing features of the six operating TF/SC plants studied.

Corvallis, Oregon

The TF/SC process was developed in part through full-scale research performed at the Corvallis, Oregon, wastewater treatment plant as described in Chapter 1. The Corvallis TF/SC plant (Figure 3) has an average dry-weather flow (ADWF) for design of 9.7 million gallons per day (mgd). The peak wet-weather flow (PWWF) for design is high (28.0 mgd), because a portion of the collection system is a combined sewer and storm drain. Two primary sedimentation tanks (one circular and one rectangular) are used for primary treatment. Corvallis practices cosettling of waste secondary solids with raw sewage solids in its primary sedimentation tanks.

The two parallel 8-ft-deep TFs with rock media were part of the original Corvallis TF plant. The Corvallis treatment plant operates in TF/SC Mode III, which includes a return sludge aeration tank and aerated solids contact tank. The actual detention times in the two tanks were based on the physical

TABLE 1. DESIGN DATA FOR TF/SC PLANTS

Element	Wastewater treatment plant					
	Chilton[a]	Corvallis	Medford	Norco	Oconto Falls	Tolleson
Design flow, mgd						
ADWF	0.780	9.7	18/20[b]	0.50	0.375	8.3
AWWF	1.120	-		-	0.500	
PDWF		13.4	-	1.0		12.9
PWWF	3.230	28.0	60	1.5	0.750	17.7
Design loadings, ppd						
BOD, 1,000 lb	1.59	10.9	35/41	1,150	0.67	23.95
SS, 1,000 lb	1.39	11.5	28/31.8	1,250	0.79	21.61
TKN, as N, lb	165					
P, as P, lb	125	-	-	-	20	-
Preliminary treatment						
Influent pumping	No	Yes	No	No	No	No
Comminution	Yes	Yes	Yes[c]	Yes	Yes	No
Mechanical screen	No	No	Yes	No	No	Yes
Grit removal						
Aerated	Yes	Yes	Yes	No	No	No
Other	No	No	No	No	No	Yes
Primary sedimentation						
Rectangular						
Number	1	1	2	0	0	3
Width, ft	16	31	39	-		19
Length, ft	80	136	225	-	-	150
Sidewater depth, ft	9	9.5	9.5	-		9.0
Surface area each, 1,000 sq ft	1.3	4.2	8.8	-		2.8
Circular						
Number	0	1	0	1	1	0
Diameter, ft	-	85	-	35	36	
Sidewater depth, ft	-	9	-	9	6.25	-
Surface area, 1,000 sq ft	-	5.7	-	0.96	1.0	-
Trickling filter						
Number	2	2	1	1	2	1/2[d]
Depth, ft	4	8	14	5	6	20/7
Diameter, ft	100	160	140	55	38	135/135
Media volume, 1,000 cu ft	62.8	321	215	11.9	13.5	286/200
Media type	Rock	Rock	Plastic	Rock	Rock	Plastic/rock
Recirculation[e]	CR	CR	CR	CR+PF	CR+PF	CR/CR
Trickling filter pumps						
Number[f]	2/0	2/0	1/1	1/0	1/1	2/1-2/19
Capacity each, mgd	2.0	11.5	15	0.43	0.72	7.5/8.0
Intermediate clarifiers[h]						
Circular						
Number	0	0	0	0	0	2
Diameter, ft	-	-	-	-	-	80
Sidewater depth, ft	-	-	-	-	-	8/12
Surface area each, 1,000 sq ft	-	-	-	-	-	5.0

(continued)

TABLE 1. DESIGN DATA FOR TF/SC PLANTS (CONTINUED)

Element	Wastewater treatment plant					
	Chilton[a]	Corvallis	Medford	Norco	Oconto Falls	Tolleson
Activated sludge aeration tanks						
Number	2,1	2	2	0	0	0
Length, ft	40/49	156	360	-	-	
Width, ft	20/16	40	40	-	-	-
Sidewater depth, ft	12.5/9.5	15	15	-	-	-
Total volume, 1,000 cu ft	37.5	187.2	432	-	-	
Solids contact system operating mode	I or III	III	I	II	I	I
Return sludge aeration tank						
Number	0	1	0	1	0	0
Length, ft		88	-	11.7	-	-
Width, ft	-	6		5	-	-
Depth, ft		5	-	5.5	-	
Volume, cu ft	-	2,640	-	320	-	-
Aerated solids contact tank						
Number	1	1	1	0	1	1
Length, ft	224	-	795	-	29	95
Width, ft	3	-i	-i	-	3	10
Depth, ft	4	-i	-i	-	4	10
Volume, cu ft	2,688	2,700	42,800	-	348	9,500
Aeration system						
Type[j]	FB-domes	CB	FB-tubes	CB	FB-tubes	CB
Aeration rate, cfm/1,000 cu ft	50	-k	60	-k	85	51
Return sludge system[l]	FP	FP	C	C	FP	FP
Secondary clarification						
Circular						
Number	2	2	4	1	1	2
Diameter, ft	50	115	90	35	40	110
Sidewater depth, ft	16	18	15	9	15	16
Surface area, 1,000 sq ft	3.93	20.5	25.4	0.96	1.26	19.0
Weir location[m]	IB	IB	IB	P	IB	IB
Sludge collector[n]	SH	ST	ST-3 SH-1	SC	ST	SH
Flocculator center well						
Diameter, ft	20	40	20	-	16	40
Skirt depth, ft	10	12	8	-	9	10
Mechanical flocculators	0	4	0	0	2	0
Tertiary filter						
Number	0	0	0	1	0	0
Surface area, sq ft	-	-	-	165	-	-
Media						
Type	-	-	-	Sand	-	-
Depth, inches	-	-	-	10	-	-

(continued)

TABLE 1. DESIGN DATA FOR TS/SC PLANTS (CONTINUED)

Element	Wastewater treatment plant					
	Chilton[a]	Corvallis	Medford	Norco	Oconto Falls	Tolleson
Chlorine contact tank						
Number	2	1	1	1	1	-
Volume, 1,000 cu ft	8.7	99.8	55.0	3.70	2.80	Outfall
Effluent quality requirements[o]						
BOD_5, mg/l	10	10/25[p]	20/30[p]	20	30	30
Suspended solids, mg/l	10	10/25[p]	20/30[p]	20	30	30
Total phosphorus, mg/l as P	1	-	-	-	1	
NH_3, mg/l as N	6/15[p]		-	14	-	-
Coliforms	-	200	-	2.2	200	-
Chemical systems						
Phosphorus removal	Yes	No	No	No	Yes	No
Suspended solids removal	No	Yes	No	Yes	No	No
Solids handling						
Anaerobic digestion	Yes	Yes	Yes	Yes	Yes	Yes
Aerobic digestion	No	No	Yes	No	No	No
Sludge lagoon	No	Yes	Yes	No	No	Yes
Liquid disposal	Yes	Yes	No	No	Yes	Yes
Belt filter press	No	No	No	No	No	Yes
Cosettling[q]	Yes	Yes	No	Yes	Yes	Yes
Drying beds	No	No	Yes	Yes	No	Yes

[a]Chilton normally operates in the TF/AS mode.

[b]Second value for canning season. Plant may operate in TF/AS mode as flows and loads approach design limits.

[c]Standby service.

[d]First-stage trickling filter/second stage trickling filters.

[e]CR - constant recirculation, CR+FF - constant recirculation plus forward flow.

[f]Primary/standby.

[g](First-stage pumps) - (second-stage pumps).

[h]Located between first- and second-stage trickling filters.

[i]Dimensions not constant.

[j]CB - coarse bubble, FB - fine bubble.

[k]Information not available.

[l]FP - flow proportional, C - constant rate.

[m]IB - inboard, P - peripheral.

[n]ST - suction tube, SH - suction header, SC - scraper.

[o]Monthly averages except weekly averages for Chilton. Coliform limitations are based on median instead of average.

[p]Summer/winter.

[q]Cosettling of waste secondary solids with raw sewage solids in primary sedisentation tanks.

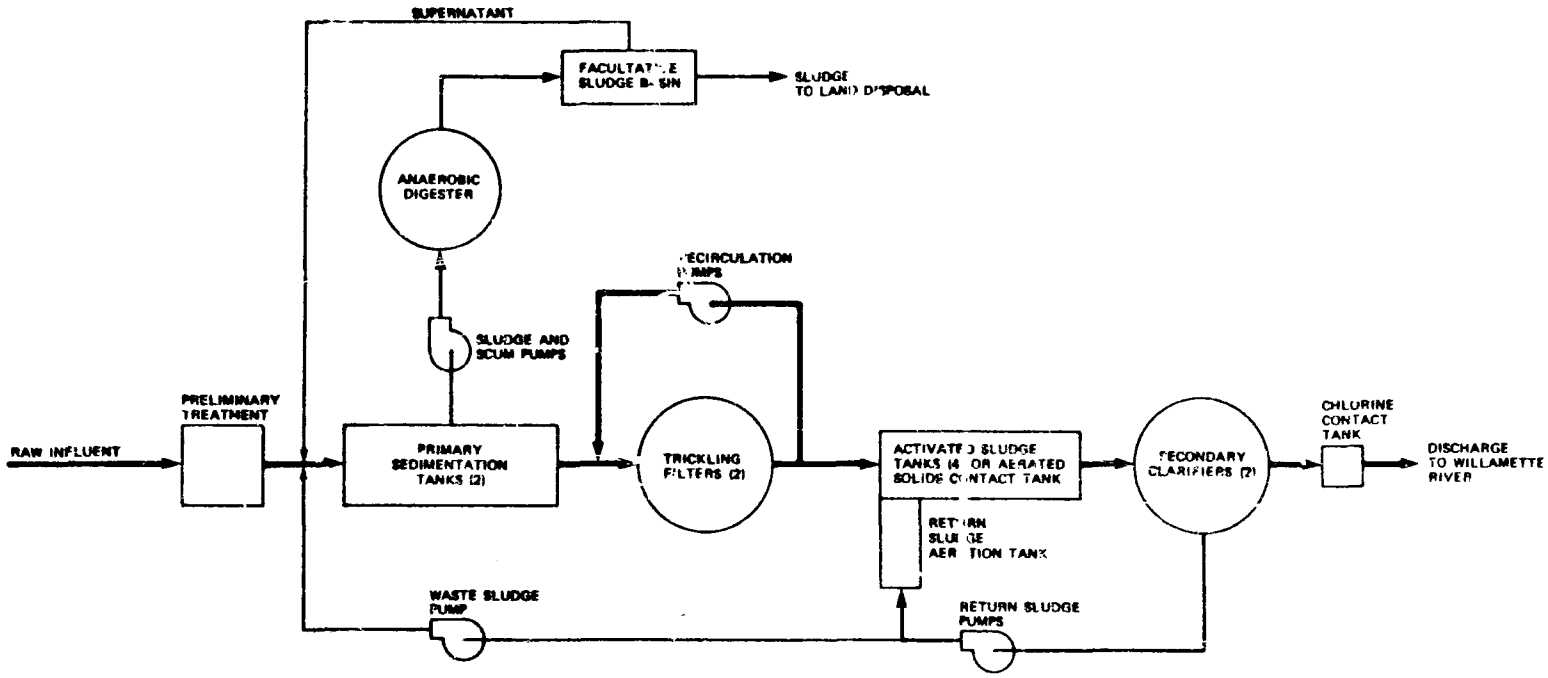


FIGURE 3. CORVALLIS, OREGON, WASTEWATER TREATMENT PLANT FLOW SCHEMATIC

constraints of the activated sludge transfer channels designed for the coupled TF/AS process Secondary clarification is performed in two 18-ft-deep clarifiers that include flocculator center wells, inboard effluent launders, and suction tube sludge removal systems. The plant has an excellent operating record and consistently meets its summer discharge requirement of 10 mg/l for BOD_5 and SS (10/10) and its 25/25 requirement during other times of the year (see Table A-1).

Tolleson, Arizona

The Tolleson treatment plant was originally a two-stage TF plant that was built in part to help treat local industrial flows (primarily meat-packing waste) as well as residential flows. The plant was later expanded to 8.3 mgd and converted to the TF/SC process (Figure 4). Primary treatment and cosettling are performed in three rectangular sedimentation tanks. The two-stage TF system is used in the TF/SC process and includes one 20-ft-deep plastic media filter followed by two intermediate clarifiers and two 7-ft-deep rock media filters. The plant operates in TF/SC Mode I and provides about 9 minutes of aerated solids contact time at 33 percent solids recycle flow and a design flow of 8.3 mgd. The two secondary clarifiers are similar to those used at Corvallis except mechanical flocculators were not included in the design. Although the plant discharge requirement is 30/30, the plant was designed to meet 15/15 at the city's request. The plant experiences wide fluctuations in influent strength because of the industrial load fluctuations. Variations in effluent quality do occur, but monthly averages for BOD_5 and SS are almost always below 15 mg/l (see Table A-5).

Oconto Falls, Wisconsin

The Oconto Falls treatment plant was originally a TF plant with a single-stage TF process. The Oconto Falls TF/SC plant (Figure 5) is small with a design flow of 0.375 mgd. Primary clarification and anaerobic digestion are combined in one unit called a clarigester. Raw sewage and waste TF/SC solids are settled and digested in the clarigester. The two 6-ft-deep, rock media TFs operate in parallel and are covered for winter protection. The aerated solids contact tank for this Mode I TF/SC plant is an upflow/downflow tank adjacent to the secondary clarifier. At design flow, approximately 8 minutes of contact time is provided in the aerated solids contact tank. The single secondary clarifier has the same flocculation features as the Corvallis clarifiers including mechanical flocculators. The effluent discharge requirements for Oconto Falls are 30 mg/l for BOD_5 and SS and 1 mg/l for total phosphorus. Table A-4 documents Oconto Falls plant performance. Effluent concentrations are

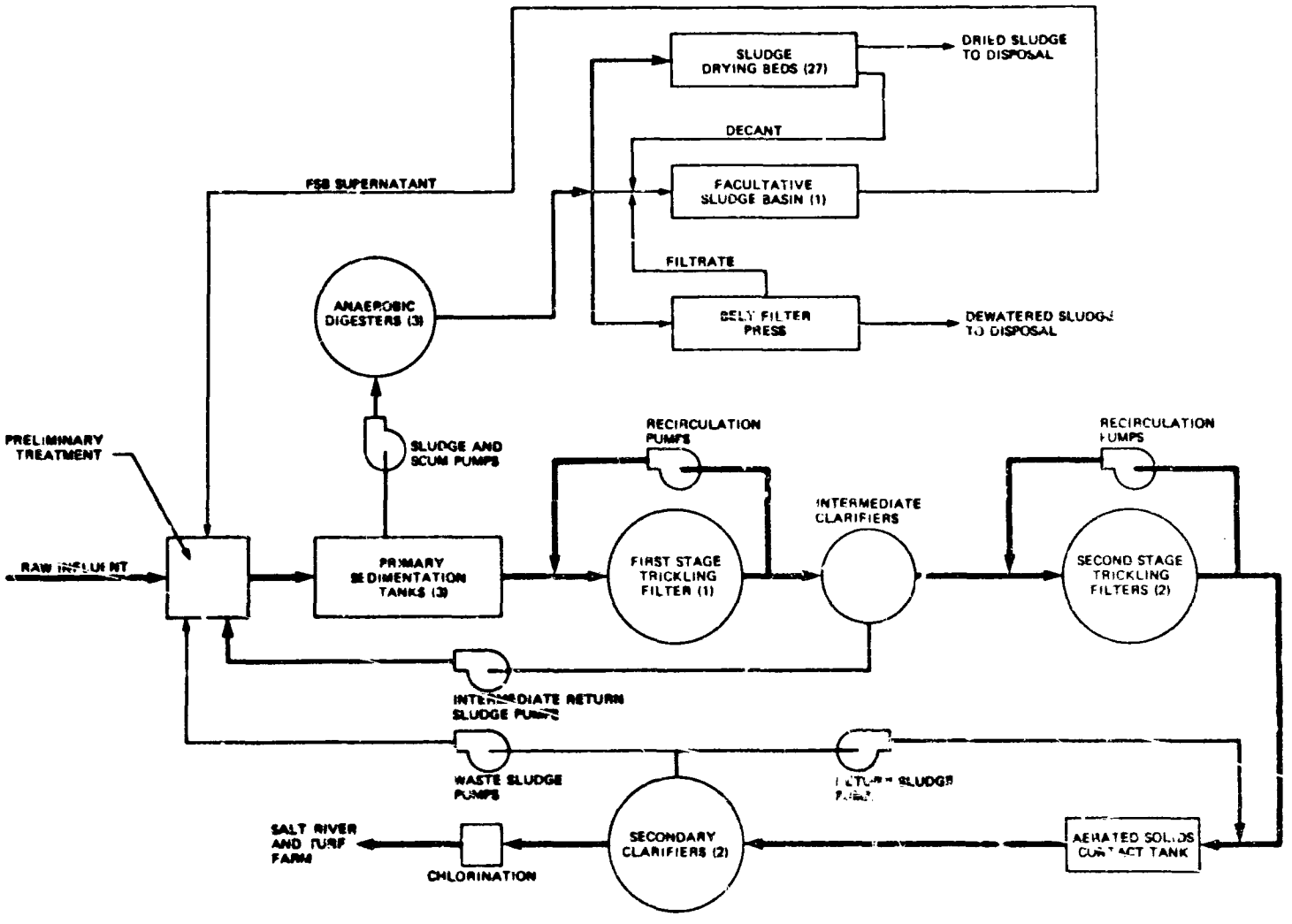


FIGURE 4. TOLLESON, ARIZONA, WASTEWATER TREATMENT PLANT FLOW SCHEMATIC

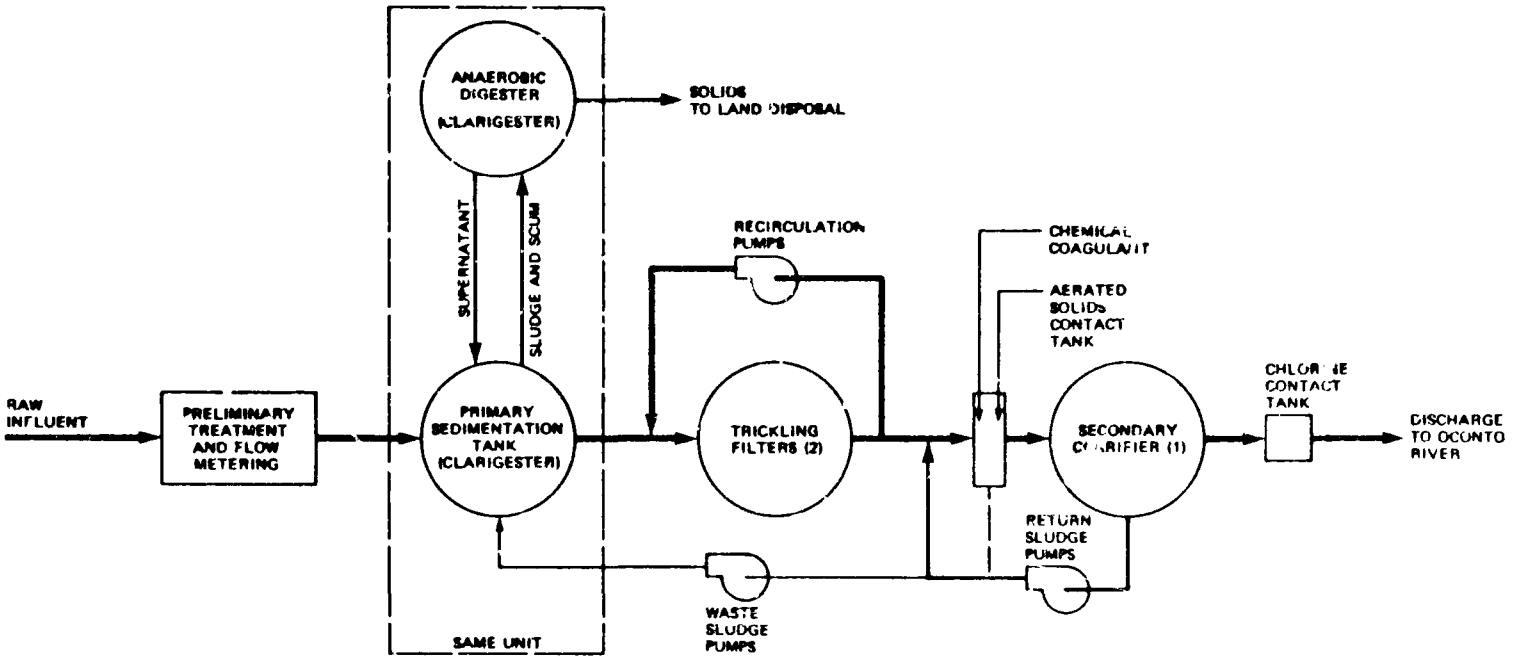


FIGURE 5. OCONTO FALLS, WISCONSIN, WASTEWATER TREATMENT PLANT FLOW SCHEMATIC

slightly higher during winter months. The phosphorus requirement is met by adding ferric chloride to the aerated solids contact tank.

Chilton, Wisconsin

The Chilton treatment plant is a 0.78-mgd TF/AS plant (Figure 6) that has the facilities to operate as a TF/SC plant. Two 4-ft-deep, rock media TFs operate in parallel and typically discharge flow to the aeration tanks. In the TF/AS mode, flow passes through the activated sludge tanks and then to the contact tank (distribution channel). Four aeration tanks are available and either 4, 2, 1, or none of the tanks may be used. In the TF/SC mode, the activated sludge tanks are bypassed and TF effluent is carried directly to the contact tank. The aerated solids contact tank is a 224-ft-long channel located between the last aeration tank and the secondary clarifiers. Prior to this project, the plant had never operated in the TF/SC mode. The secondary clarifiers include inboard effluent launders, high sidewater depths (16 ft), suction header sludge removal systems, and flocculator center wells like the Corvallis, Tolleson, and Oconto Falls clarifiers.

Chilton has one of the most stringent discharge requirements in Wisconsin and must produce effluent with weekly averages of BOD_5 and SS that are less than 10 mg/l. The summer discharge requirement for ammonia is 6 mg/l, which must be met despite high nitrogen loads. In the coupled TF/AS mode, the plant has met its stringent discharge requirements, although high concentrations of heavy metals in the raw waste have caused some permit violations.

Norco, California

The Norco wastewater treatment plant has a design flow of 0.50 mgd and only provides treatment for the California State Rehabilitation Center, a penal institution. The waste strength is higher than anticipated in design and is typically variable. The Norco plant has been classified as a TF/SC Mode II plant (return sludge aeration only), although the process flow schematic (Figure 7) is unique in some respects. The aeration tank used for return sludge also receives a small, but variable amount of primary effluent. The combination is mixed with TF effluent prior to entering the secondary clarifier. Unlike secondary clarifiers at other TF/SC plants studied, the Norco secondary clarifier has peripheral effluent launders, a scraper sludge removal system, no center well, and is relatively shallow (9 ft). Tertiary filtration is used at this plant to polish the effluent. With the help of tertiary filters, the plant has consistently met its 20 mg/l discharge requirement for SS, but has occasionally exceeded its BOD_5 discharge requirement of 20 mg/l (Table A-3).

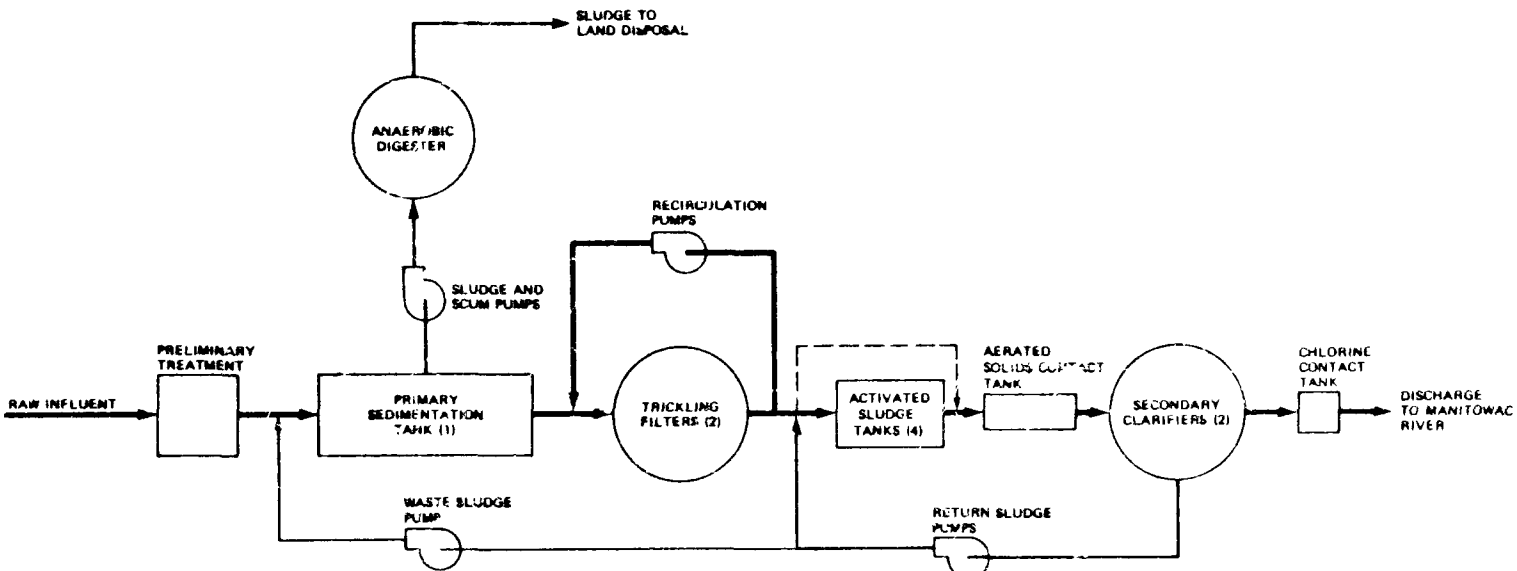


FIGURE 6. CHILTON, WISCONSIN, WASTEWATER TREATMENT PLANT FLOW SCHEMATIC

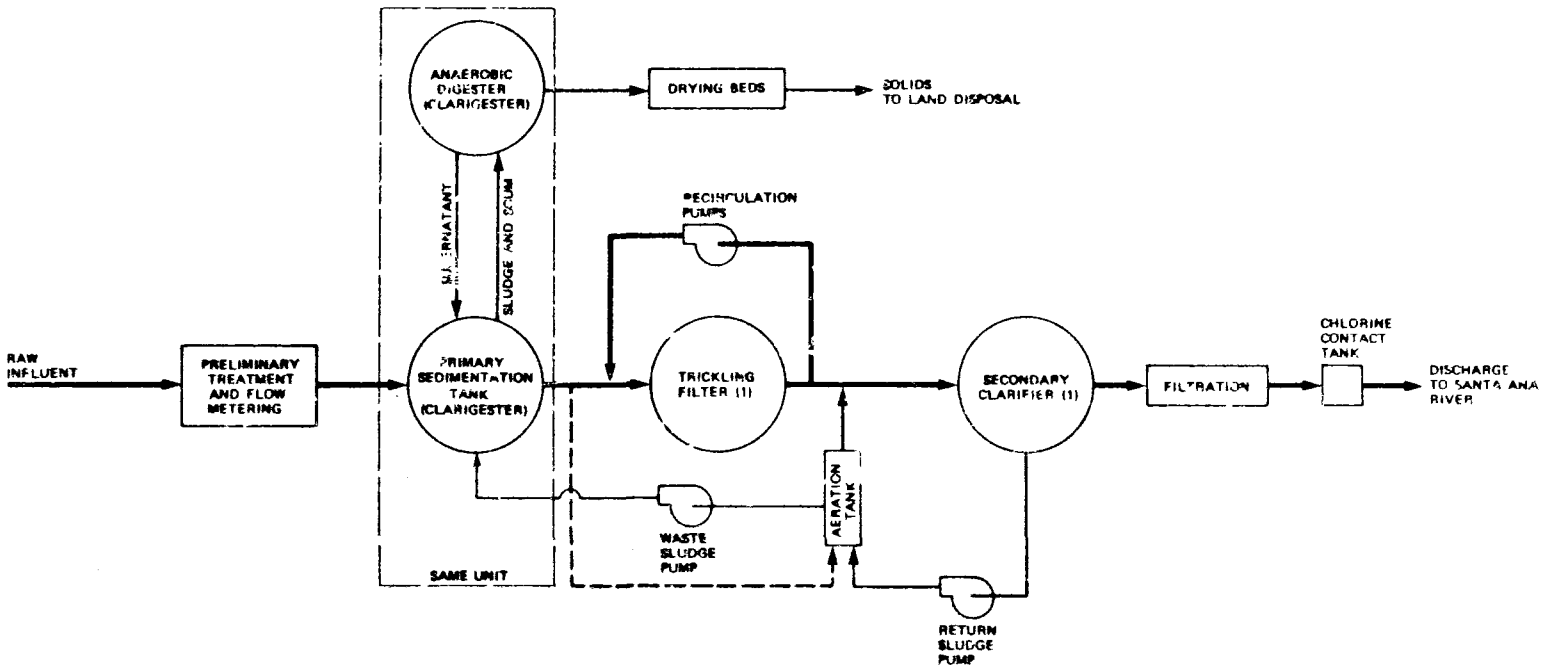


FIGURE 7. NORCO, CALIFORNIA, WASTEWATER TREATMENT PLANT FLOW SCHEMATIC

Medford, Oregon

The Medford plant was originally an activated sludge plant that was recently converted to a coupled TF/AS system (Figure 8). After operating in the TF/AS mode for about 5 months, operators switched the treatment plant to TF/SC by employing channels along the perimeter of the activated sludge tanks as the aerated solids contact tanks. Primary treatment is performed in two parallel rectangular sedimentation tanks; unlike the other plants studied, cosettling is not practiced. One 14-ft-deep plastic media TF follows the primary sedimentation tanks. The Medford TF/SC plant operated as a Mode I plant during this project. The combined length of the aerated solids contact tank is 795 ft, which provides about 39 minutes of aerated solids contact time. The four secondary clarifiers used at the plant have 15-ft sidewater depths, suction tube or header sludge removal systems, inboard launders, and moderately sized center wells. The treatment plant has a 20/20 summer discharge requirement and 30/30 during the rest of the year. TF/SC operation at Medford began during this project, and the plant is consistently meeting its discharge requirements (Table A-2).

COMPARISON OF DESIGN AND PERFORMANCE

Treatment plant design criteria and actual performance are compared below for five operating TF/SC plants investigated in this project. The Chilton treatment plant was not included because it normally operates as a TF/AS plant and operated as a TF/SC plant for only a short time during this project.

Averages for key loading parameters are shown in Table 2 and generally are based on the most recent 12 months of operating data. Since the Medford TF/SC plant began operation during this project, only 4 months of data were available to develop averages.

Appendix A contains monthly averages from plant operating records that were used to develop annual averages shown in Table 2. The monthly averages show seasonal variations in influent characteristics, unit process performance, and effluent quality. The amount of data presented in the appendix tables is dependent on the amount of data the treatment plant normally collects.

A comparison between key design criteria and actual performance data helps to evaluate the performance of a specific wastewater treatment plant. Plant underloading or overloading often explains variations from expected performance. A comparison of design criteria for the different plants provides insight into causes of differences in plant performance.

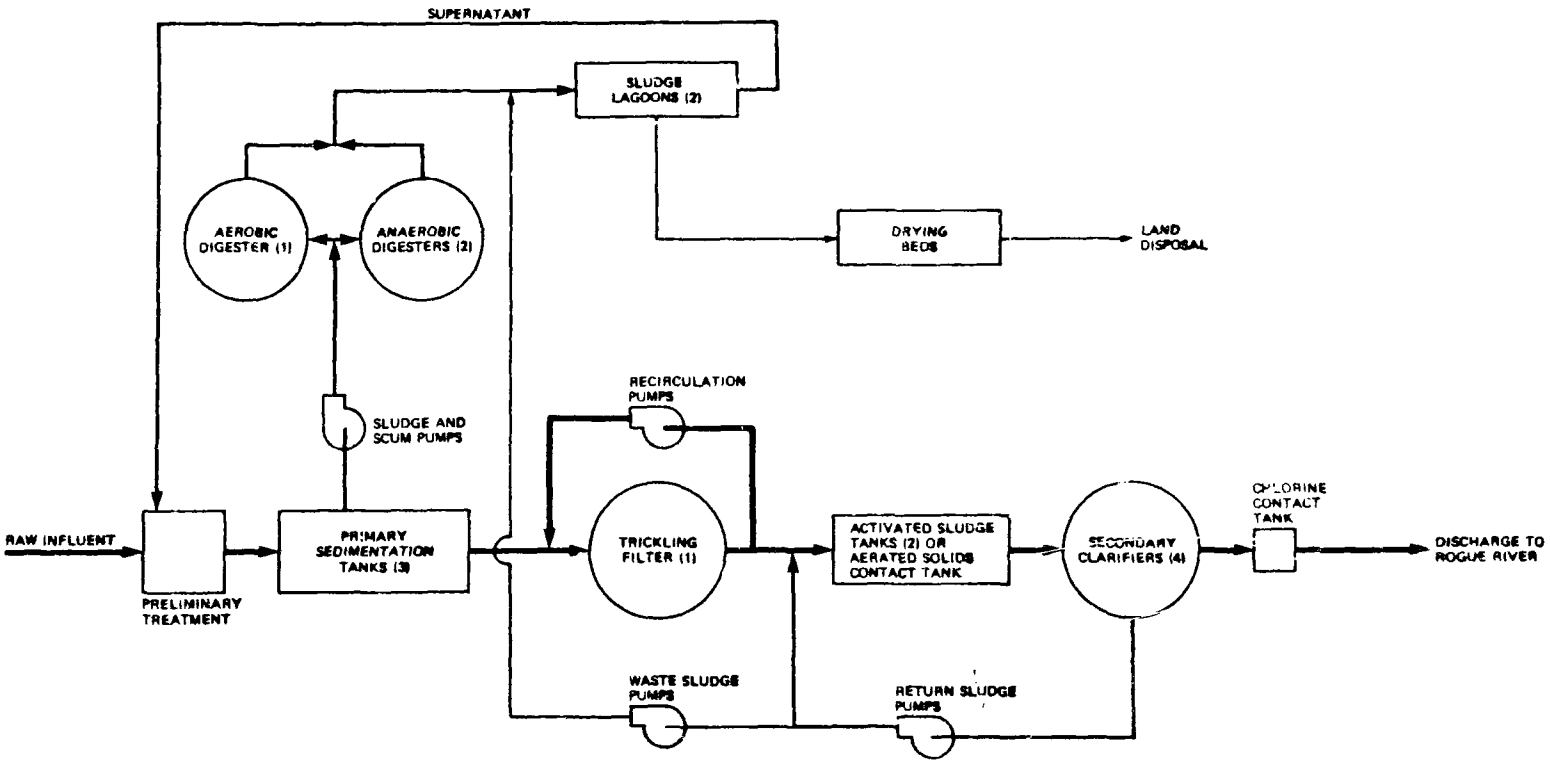


FIGURE 8. MEDFORD, OREGON, WASTEWATER TREATMENT PLANT FLOW SCHEMATIC

TABLE 2. DESIGN AND PERFORMANCE COMPARISON FOR TF/SC PLANTS

Parameter	Wastewater treatment plant									
	Corvallis		Medford		Norco		Niagara Falls		Tolleson	
	Design	Average	Design[a]	Average[b]	Design	Average	Design	Average	Design	Average
Influent										
Flow, mgd	9.7	10.5	18	8.8	0.50	0.491	0.375	0.358	8.3	6.1
BOD_5 load, ppd	10,500	4,370	35,000	11,450	1,150	1,278	670	437	23,950	14,000
BOD_5, mg/l	135	108	233	156	275	313	215	146	346	277
Suspended solids, ppd	11,500	13,320	28,000	10,100	1,250	1,437	790	350	21,610	11,310
Suspended solids, mg/l	142	154	167	133	300	352	250	118	312	224
Primary treatment										
Overflow rate, gpd/sq ft	980	1,050	1,025	500	520	510	370	350	970	715
Detention time, hr	1.7	1.6	1.66	3.4	3.1	3.15	3.0	3.[illegible]	1.66	2.26
BOD_5 removal, percent	30	35	30	47	30	-[c]	30	50[d]	35	38
TSS removal, percent	65	56	65	74	60	-[c]	60	62[d]	-[f]	46
Trickling filter[e]										
BOD_5 loading, ppd/1,000 cu ft	24	19	115	28	68	-[c]	35	16	55/9.1[e]	31/5.8[e]
Hydraulic loading, gpd/sq ft										
Influent	240	258	1,170	572	270	206	165	158	580/290	426/213
Influent and recycle	565	565	1,950	975	290	386	420	413	1,048/560	1,048/560
BOD_5 removal, percent	47	58	50	12.5	-[f]	-[c]	-[f]	40[d]	-[c]/-[c]	-[f]/-[f]
Intermediate clarifiers										
Overflow rate, gpd/sq ft	-[g]	-[g]	-[g]	-[g]	-[g]	-[g]	-[g]	-[g]	825	607
Detention time, hr									2.17	2.95
Return sludge aeration tank										
Detention time,[h] min	-[f]	8	-[g]	-[g]	-[f]	21	-[g]	-[g]	-[g]	-[g]
Return sludge TSS, mg/l	-[f]	11,350			-[f]	12,681				
Aerated solids contact tank										
Detention time,[i] min	-[f]	2	-[f]	39	-[g]	-[g]	[f]	8	9	13
MLSS, mg/l	-[f]	3,127	-[f]	1,660			-[f]	1,620[d]	2,600	1,040
Flocculator center well										
Detention time,[i] min	25	24	-[f]	9	-[g]	-[g]	38	40	25	33
Secondary clarifiers										
Overflow rate,[i] gpd/sq ft	470	500	720	350	520	510	300	285	440	320
Detention time,[i,j] hr	6.9	6.5	3.8	7.8	3.1	3.2	9.0	9.4	6.6	9.0
Tertiary sand filters										
Hydraulic loading, gpm/sq ft	-[g]	-[g]	-[g]	-[g]	2.10	2.06	-[g]	-[g]	-[g]	-[g]
Final effluent										
BOD_5, mg/l	10[k]	5.1/6.8[l]	10[k]	7.8/18.8[l]	20	21.7	30	21	15	7.2
Plant BOD_5 removal, percent	92.6	93.8	95.7	95.0	92.7	93.0	86	85.7	95.7	97.4
Suspended solids, mg/l	10	9.4	10	7.8	20	13.3	30	13	15	8.5
Plant TSS removal, percent	93.0	93.9	94.6	94.4	93.3	96.2	88	89.1	95.2	96.2

[a]Design data for coupled TF/AS system.

[b]See note below.

[c]Necessary data not available to compute this parameter.

[d]Average based on 3 months of data collected during summer 1984.

[e]First-stage/second-stage. Includes intermediate clarifiers.

[f]No design data.

[g]Unit process or operation not used at this plant.

[h]Based on recycle rate of 33 percent of plant flow.

[i]Based on combined plant and recycle flows assuming a recycle rate of 33 percent.

[j]Based on total clarifier surface area or volume including center well.

[k]Based on carbonaceous BOD_5.

[l]Carbonaceous BOD_5/total BOD_5.

Note: Average performance values based on 12 months of data (4/83 to 3/84) except for Medford, which is based on 4 months of data (4/84 to 7/84).

Influent Characteristics

In addition to the significant variation in flows between TF/SC plants that was mentioned earlier, the strengths of the raw wastes also vary. Corvallis, Medford, and Oconto Falls treat relatively dilute wastes with average BOD_5 and SS concentrations generally between 110 and 150 mg/l. Tolleson receives significant contributions from a meat-packing plant, which elevate the raw waste BOD_5 and SS concentrations. Norco serves a local penal institution that discharges high-strength wastes.

Primary Treatment

Primary sedimentation tank overflow rates varied from 350 gpd/sq ft for Oconto Falls to 1,050 gpd/sq ft for Corvallis. Low overflow rates are used at Oconto Falls and Norco to maintain proper operation of the clarigesters. At these two plants, primary sedimentation is performed in the upper portion of the clarigester, while anaerobic digestion is performed in the lower portion. Higher average overflow rates occur at Corvallis because a significant portion of the treatment plant collection system is a combined sewer.

All of the treatment plants except Medford cosettle waste TF/SC solids with raw sewage solids in the primary sedimentation tanks. The SS removal was higher at Medford than at Corvallis, Oconto Falls, or Tolleson. Cosettling may be the cause of lower SS removals at the three plants, although data at Medford is limited. Oconto Falls had the lowest overflow rate, yet its SS removal efficiency was significantly lower than Medford.

Secondary Treatment

TF organic loadings are generally low in the TF/SC process. Average TF BOD_5 loadings ranged from 5.8 ppd/1,000 cu ft for the second-stage Tolleson filter to 28 ppd/1,000 cu ft for the Medford filter. An aerated solids contact tank was employed at most of the TF/SC plants. Average aerated contact times varied from a minimum of 2 minutes at Corvallis to 39 minutes at Medford. Corvallis also uses about 8 minutes of return sludge aeration time. Flocculator center well detention times were typically about 30 minutes; low secondary clarifier overflow rates (285 to 510 gpd/sq ft) were also evident at the TF/SC plants.

Effluent Quality

In general, the TF/SC plants investigated during the project are meeting or exceeding their design standards for effluent quality. Differences in effluent quality were evident with

average final effluent BOD_5 concentrations ranging from 7 to 22 mg/l and from 8 to 13 mg/l for SS concentrations. TF/SC effluent BOD_5 concentrations are subject to interferences from nitrification. BOD_5 discharge limits for Corvallis and Medford are based on CBOD, while limits for other plants are based on total BOD_5.

Corvallis and Tolleson produced about the same average effluent quality, although Corvallis was more consistent. Tolleson had a lower filter organic loading (5.8 lb/1,000 cu ft/day) in the rock filter preceding the contact tank than Corvallis, which had an average organic loading of 19 lb/1,000 cu ft/day. Also, Tolleson aerated solids contact time (13 minutes) was significantly higher than at Corvallis (2 minutes), but return sludge aeration time (8 minutes) at Corvallis may compensate for the difference in aerated solids contact time.

Effluent quality at Corvallis and Oconto Falls differed significantly, although average filter organic loadings were about the same (19 and 16 lb/1,000 cu ft/day, respectively). Although the aerated solids contact time at Oconto Falls was higher (8 instead of 2 minutes), Oconto Falls lacked return sludge aeration. Corvallis has only 8 minutes of return sludge aeration, but this time is significant since return sludge is much more concentrated than mixed liquor. Consequently, the relative mass of solids in the solids contact system at Corvallis is higher.

Performance at Oconto Falls and Tolleson may also be compared. Tolleson typically produces significantly higher effluent quality than Oconto Falls. Differences in performance may be caused by lower loadings and/or longer contact times at Tolleson. Differences may also be caused by differences in weather, since short aerated solids contact times in cold weather regions may require return sludge aeration to increase the system solids mass for consistent performance.

Medford performance is difficult to compare with the other TF/SC plants. The Medford plant has plastic media, the highest organic loading, and longest contact time. Based on 4 months of data, Medford performs as well as Corvallis or Tolleson suggesting increases in contact time may compensate for increases in filter organic loading.

Norco had the highest average effluent BOD_5 and SS concentrations despite tertiary filtration. This relatively poor performance can be explained by the probable high filter organic loading and deficient secondary clarifier. Filter loadings averaged 70 lb/1,000 cu ft/day based on 35 percent BOD_5 removal in the primary sedimentation tank. This loading is about 4 to

12 times higher than rock filter loadings at other TF/SC plants. The secondary clarifier is shallow and has peripheral weirs, scraper sludge removal, and no center well resulting in poor clarification. Consequently, the combination of high filter loadings and poor secondary clarification most probably are the main reasons for poor performance at Norco.

CHAPTER 5

DESCRIPTION OF FIELD INVESTIGATIONS

Field investigations were performed during the spring and summer of 1984 at four full-scale TF/SC plants as part of the project special studies. The field investigations were confined to full-scale studies because results from operating plants are the most representative of full-scale TF/SC operation.

Field investigations were developed for a particular objective if the following conditions were met: (1) it was a high priority objective, (2) existing data were insufficient, (3) it could be studied at a full-scale TF/SC plant despite plant physical limitations, and (4) the full-scale plant was available for study. In many cases, the physical characteristics of the TF/SC plants studied constrained our ability to design field investigations.

Availability of plant operations data was an important consideration, since field investigations were often performed only to augment existing data. At several of the smaller TF/SC plants, critical process control data is not routinely collected because of resource limitations. At these plants, data collected during a field investigation could not be compared to earlier data to determine representativeness. Small plants often have limited laboratory facilities that cannot accommodate additional analytical work, although this limitation can be overcome if a reliable commercial laboratory is located nearby.

In general, the emphasis of the field investigations at the individual full-scale plants varied, although in some cases data were collected for a particular objective at more than one plant. A total of 29 weeks of full-scale data were collected at TF/SC plants in Oconto Falls, Wisconsin; Tolleson, Arizona; Medford, Oregon; and Chilton, Wisconsin. The field investigations for each of the treatment plants are described below.

OCONTO FALLS

The Oconto Falls TF/SC plant was selected as the site of the greatest number of weeks of field investigation because of many factors. The TF/SC plant was easily meeting its discharge

limit of 30 mg/l for BOD_5 and SS. Consequently, full-scale tests could be performed without significant concern for violating plant discharge limits. The plant design was flexible, allowing many of the project objectives to be addressed. Laboratory testing was performed at a local commercial laboratory, since the treatment plant staff and facilities could not accommodate additional work required.

Field investigation results were used to address five objectives including the influence of TF BOD_5 loading and media type, aerated solids contact tank SRT, and coagulant addition on TF/SC performance. Soluble BOD_5 removal in the aerated solids contact tank was also measured.

Field Investigation Schedule

The five objectives addressed Oconto Falls required four phases of treatment plant operation and data collection. Table 3 describes the field investigation schedule including major process changes between phases and the period of testing for each phase. The purpose of the first phase was to characterize the plant's existing operation. In the second phase, coagulant addition was eliminated so its effect on TF/SC operation could be evaluated. In the third phase, the plant was put into the TF mode by wasting all secondary sludge to the primary sedimentation tank instead of returning biomass to the aerated solids contact tank. In the fourth phase, one of the two TFs was removed from service and operation of the aerated solids contact tank was resumed by seeding it with activated sludge from a local treatment plant.

Ten weeks of field investigations were originally planned for Oconto Falls. In general, the field investigations followed the original schedule except for Phase 2. The length of Phase 2 was extended from 3 to 4.5 weeks because of extensive TF sloughing that occurred during the first 9 days and the third week of the phase. Heavy metal concentrations were monitored in the raw influent during the sloughing periods, but no high concentrations were measured.

Laboratory and Field Testing Program

An extensive field and laboratory testing program was conducted at Oconto Falls (Table 4). The program was based primarily on a 3-day-per-week sampling schedule with special studies performed once per week. The results of the testing program are shown in Appendix B. Samples were generally 24-hour composites obtained from automatic samplers with ice or refrigeration units. The hourly discrete samples obtained with the automatic sampler were manually composited the following day

TABLE 3. OCONTO FALLS FIELD INVESTIGATION SCHEDULE

Parameter	Phase			
	1	2	3	4
1. Operating mode	TF/SC	TF/SC	TF	TF/SC
2. Trickling filters in service	2	2	2	1
3. Coagulant addition[a]	Yes	No	No	No
4. Planned length of phase, weeks	2	3	3	2
5. Actual length of phase, weeks	2	4.5	3.5	2
6. Dates				
Start of phase	5/28/84	6/11/84	7/11/84	8/3/84
End of phase	6/11/84	7/11/84	8/3/84	8/16/84

[a]Ferric chloride is normally added for phosphorus removal.

TABLE 4. OCONTO FALLS FIELD AND LABORATORY TESTING PROGRAM

Parameter	Sampling frequency, times per week					
	Raw influent	Primary effluent	Trickling filter effluent	Solids contact tank	Secondary clarifier	Final effluent
Field measurement						
Flow rate	7	-	-	-		-
Filter recycle flow			7	-	-	-
Solids contact recycle flow		-	-	7	-	-
Secondary solids waste flow		-	-	-	7	-
30-minute settleability	-	-	-	3	-	-
Color		-	-	3	-	-
Sludge blanket profile	-	-	-	-	3[a]	-
Coagulant flow	-	-	-	-	7[b]	-
Temperature	3	-	-	-	-	3
pH	3	-	-	-	-	-
Dissolved oxygen	3	3	3	3	3[c]	3
Supernatant SS profile[d]	-	-	1	1[e]	1[f]	-
Clarifier TSS profile	-	-	-	-	1[g]	-
Soluble BOD_5 profile[h]	-	-	1	1	1	-
Soluble carbonaceous BOD_5 profile[h]	-	-	1	1	1	-
Laboratory analyses						
Total BOD_5	3	3	3	-	3	3
Soluble BOD_5[i]	3	3	3	-	3	3
Carbonaceous BOD_5[j]	-	-	3	-	3	3
Soluble carbonaceous BOD_5[i,j]	-	-	3	-	3	3
Suspended solids	3	3	3	3	3	3
Return sludge SS	-	-	-	-	3	-
Volatile solids percentage	3	3	3	3	3	3
SVI	-	-	-	3	-	-
TKN	3	3	3	-	3	-
NH_3-N	3	3	3	-	3	-
Oxidized-N	3	3	3	-	3	-
Total-P	3	3	3	3	3	3
Ortho-P	1	1	1	-	1	1
Microscopic exam	-	-	-[k]	-[k]	-	-

[a]Depth of blanket measured with "Sludge Judge" at four locations: (1) 1 ft inside center well skirt, (2) 1 ft outside center well skirt, (3) below scum baffle, (4) 1 ft from outer wall.

[b]Amount of ferric chloride added for phosphorus removal.

[c]Measured at 1 ft, 5 ft, and 9 ft below the surface in the flocculation center well; at the sludge blanket; and just upstream the effluent launder.

[d]Supernatant SS measured with Kemmerer sampler. Suspended solids of sample also measured before settling.

[e]Measured at two locations: (1) 6 ft below surface in upflow section of solids contact tank, (2) 15 ft below surface in downflow section of solids contact tank.

[f]Measured 3 ft and 12 ft below surface in flocculator center well.

[g]Suspended solids measured with horizontal Kemmerer sampler 4 ft, 8 ft, and 12 ft below the effluent launder.

[h]Grab sample obtained at trickling filter effluent, 8 ft below water surface of upflow section of solids contact tank, 2 ft and 16 ft below water surface of downflow section of solids contact tank, and 4 ft from surface in flocculator center well.

[i]Soluble BOD_5 determined by measuring BOD_5 of filtrate obtained with Whatman 934AH filter.

[j]Carbonaceous BOD_5 obtained by suppressing nitrification in the BOD_5 test with Hach TMCP nitrification inhibitor.

[k]One sample examined.

so that they were flow proportional. Grab samples were taken for mixed liquor and return sludge the day after composite samples were collected.

The field measurements included (1) cataloging routine information collected by the plant; (2) performing field measurements such as temperature, pH, and dissolved oxygen; and (3) performing special studies. Four special studies were performed once per week at Oconto Falls. In the first study, supernatant SS profiles were developed with Kemmerer samples to identify where flocculation was occurring. The Kemmerer sampler is a plastic cylinder with collapsible end-sections that can be tripped with a messenger to seal the sampler after it is lowered to the desired depth. Supernatant SS were measured by taking an undisturbed sample of TF effluent or mixed liquor with a Kemmerer sampler (Figure 9) and allowing it to settle in the sampler for 30 minutes. The SS in the supernatant after 30 minutes of settling were used as an indication of the degree of flocculation that had occurred.

In the second study, the SS concentration was measured for undisturbed samples taken at various depths below the secondary clarifier effluent launder. The undisturbed samples were collected with a horizontal version of the Kemmerer sampler. The SS profile was intended to give some indication of the variation in solids with depth.

In the third and fourth studies, soluble BOD_5 and soluble carbonaceous BOD_5 profiles were developed. Grab samples of mixed liquor were collected with the Kemmerer samplers 8 ft below the water surface of the upflow section, and 2 ft and 16 ft below the surface of the downflow section of the solids contact tank. Grab samples were also collected for the TF effluent and for the flocculator center well mixed liquor 4 ft below the surface. Each sample was settled for 4 minutes, then supernatant was withdrawn and filtered with a 12.5-cm-diameter Whatman 934AH filter. The filtered samples were refrigerated and transported to the laboratory for the BOD_5 analysis.

TOLLESON

One objective of field investigations at Tolleson was to investigate cosettling by varying sludge wasting parameters and primary sedimentation tank overflow rate. A second objective was to collect information on the effect of TF depth on soluble BOD_5 removal. The effect of secondary clarifier overflow rate on final effluent quality was studied by using field investigation data from another study performed at Tolleson.[11]

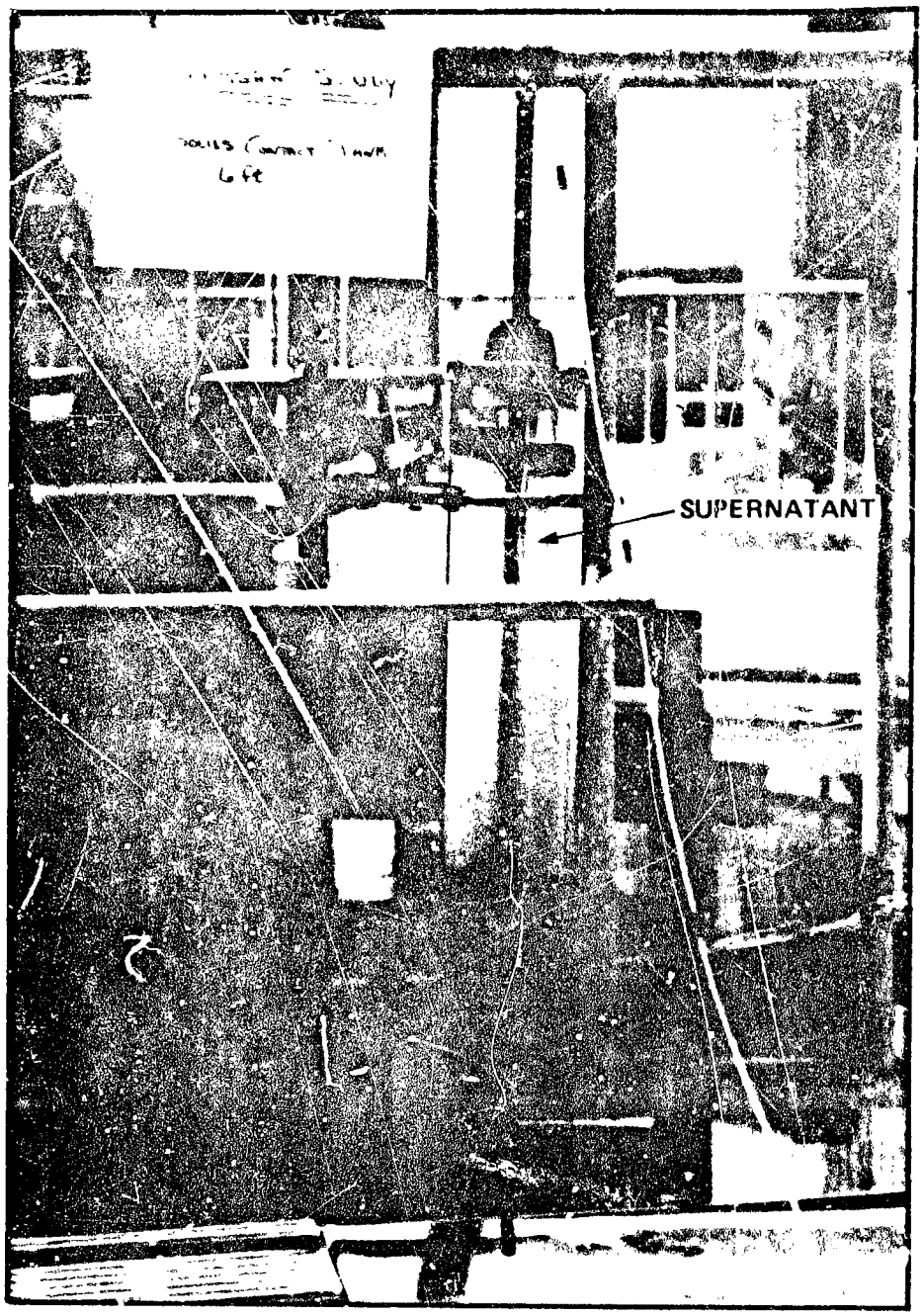


FIGURE 9. KEMMERER SAMPLER FOR SUPERNATANT SUSPENDED SOLIDS MEASUREMENT

Since the Tolleson field investigation effort emphasized primary treatment and the first-stage TF, only factors affecting these unit processes will be described. Primary sedimentation tank influent is composed of a mixture of raw influent, intermediate clarifier return, waste secondary solids, and facultative sludge basin (FSB) supernatant. The volume of FSB supernatant is small--approximately 10 percent of the waste secondary solids flow. The intermediate clarifier return, however, can be a large fraction (up to 50 percent) of the raw influent flow.

Three parallel rectangular primary sedimentation tanks, each with its own sludge and scum pumps, provide primary treatment. The overflow rate at ADWF (8.3 mgd) is 970 gpd/sq ft when all three sedimentation tanks are in service. The pumping frequency for each sludge pump can vary and is typically between 10 and 30 minutes. Once the pump starts, it will continue to run until the primary sludge concentration drops below the minimum required by the density meter. Primary sludge removal is therefore controlled by changing the pumping frequency and the density meter setting.

The first-stage TF has constant-speed recirculation pumps so that the hydraulic load on the TF is constant. The strength of the waste varies since, during peak flow, a smaller percentage of TF effluent is mixed with the primary effluent to form the TF flow. Sample ports consist of perforated tubes that extend horizontally into the TF and are located 1.1 ft, 5.1 ft, 9.5 ft, and 14.5 ft from the top of the media. Samples were also taken at the distributor (0 ft) and at the bottom of the filter (20 ft) to complete the profile.

Field Investigation Schedule

Three phases were required to accomplish the two main objectives at Tolleson (Table 5). In the first phase, sludge removal frequency was decreased and minimum sludge concentration at pump shutoff was increased to obtain more thickening in the primary sedimentation tanks. In the second phase, the overflow rate was increased by taking one of the three sedimentation tanks out of service. A temporary collection system change was made between Phases 1 and 2 that reduced raw sewage flow. Consequently, the primary sedimentation tank overflow rate was increased by only 17 percent instead of 50 percent in Phase 2 as anticipated. The purpose of the second phase was to obtain the maximum sludge concentration under the higher overflow rate, while maintaining a shallow sludge blanket. In the third phase, soluble carbonaceous BOD_5 was measured at different TF depths.

TABLE 5. TOLLESON FIELD INVESTIGATION SCHEDULE

Parameter	Phase		
	1	2	3
1. Cosettling			
a. Increase primary sludge concentration	X	-	-
b. Increase overflow rate	-	X	
2. Soluble BOD_5 with filter depth	-	-	X
3. Planned length of phase, weeks	3	3	1
4. Actual length of phase, weeks	3	3	1
5. Dates			
Start of phase	5/10/84	6/26/84	7/24/84
End of phase	5/29/84	7/17/84	7/31/84

Laboratory and Field Testing Program

Field measurements and laboratory analyses at Tolleson were performed either three or five times per week (Table 6) during the first two phases. The third phase included grab samples of TF flow at different depths for 3 separate days. Data collected during the field investigation are shown in Chapter 6 and Appendix C.

All BOD_5 and SS samples were manually composited flow-proportional samples collected by the treatment plant staff. Return sludge SS and primary sludge total solids analyses were done on grab samples. The primary sludge total solids samples were manual composites from one pump cycle taken in the middle of the day from all sedimentation tanks in operation. In addition to the standard field measurements listed first in Table 6, sludge blanket profiles were developed in Phase 2.

MEDFORD

The Medford TF/SC plant has the longest aerated solids contact time of all the plants studied and its solids contact tank could be modelled effectively with plug-flow kinetics. The long contact time allowed study of soluble BOD_5 removal in the aerated solids contact tank and the effect of aeration rate on TF/SC performance. Microscopic examinations of TF effluent and mixed liquor were also used to study the effect of media type on TF/SC performance.

Field Investigation Schedule

The Medford field investigation schedule was more flexible than those at the other plants because the field investigations were composed of 1-day experiments. Four weeks were originally planned, but the objectives were accomplished with 3 weeks of intensive 5-day-per-week experimentation. The field investigation schedule is shown in Table 7.

Laboratory and Field Testing Program

The Medford testing program will be described by task rather than the types of laboratory analyses and field measurements taken. The three major tasks performed at Medford were (1) development of soluble carbonaceous BOD_5 profiles for the aerated solids contact tank, (2) supernatant SS profiles, and (3) the evaluation of clarifier performance. The data collected during the field investigations are shown in Appendix D.

TABLE 6. TOLLESON LABORATORY AND FIELD TESTING PROGRAM

Parameter	Sampling frequency, times per week						
	Raw influent	Primary influent	Primary effluent	Waste TF/SC sludge	Intermediate clarifier return	Primary sludge	Trickling filter
Field measurement							
pH	3						
Temperature	5			-			
Flow rate	5[a]			5[a]	5[a]	5[a]	
Return sludge flow				5	5	-	
Sludge blanket depth				-		-[b]	
Laboratory analyses							
Total BOD_5	3[a]	3	3[a]				
Soluble BOD_5[c]	-	3	3				
Soluble carbonaceous BOD_5	-	-	-				-[d]
Suspended solids	3[a]	3	3[a]			-	
Total solids						5[e]	
Return sludge SS				5	5	-	

[a]Treatment plant measures this parameter as part of their sampling program.
[b]Sludge blanket depths were measured along the clarifier in the second phase using a "Sludge Judge."
[c]After filtration through 12.5-cm-diameter Whatman 934AH filter.
[d]Measured on 3 separate days at 6 different depths each day.
[e]Treatment plant measures only once per week.

TABLE 7. MEDFORD FIELD INVESTIGATION SCHEDULE

Parameter	Experimental work[a]		
	Week 1	Week 2	Week 3
1. Soluble carbonaceous BOD_5 profiles			
a. Plant scale	2	2	1
b. Bench scale	-	-	2
c. Initial uptake experiment		-	2
2. Supernatant SS profile	7	14	6
3. Clarifier performance profiles	4	3	3
4. Starting date	6/25/84	7/16/84	8/5/84

[a]Number of experiments performed each week or calendar date.

Soluble Carbonaceous BOD_5 Profiles. Soluble BOD_5 removed in the aerated solids contact tank was studied by performing plant-scale and bench-scale tests. In the plant-scale tests, soluble carbonaceous BOD_5 concentration was measured for mixed liquor samples collected at eight points along the aerated solids contact tank (Figure 10). The same combination of sedimentation and filtration employed at Oconto Falls was used at Medford to rapidly separate biological solids from the liquid waste. At Medford, soluble BOD_5 analyses were initiated within 5 minutes after the completion of the filtration step. Bench-scale tests were performed by using a 5-gallon mixture of TF effluent and return secondary sludge to simulate the aerated solids contact system.

During the first 2 weeks of field investigations, an initial rapid uptake of soluble carbonaceous BOD_5 was noted at the beginning of the aerated solids contact channel. Consequently, during the last week, different ratios of TF effluent and return secondary sludge were prepared and aerated to determine if initial uptake was related to the amount of mixed liquor solids. Samples were aerated for 1 minute and then settled for 4 minutes prior to filtering for the soluble carbonaceous BOD_5 determination.

Supernatant SS Profiles. Supernatant SS profiles were performed to assess the state of flocculation along the aerated solids contact tank under different aeration rates. Kemmerer samplers were used to measure supernatant SS at various locations (Figure 10) as described for Oconto Falls. Varying the aeration rate in the entire solids contact tank at one time was not practical; consequently, the effect of aeration rate was studied by varying the rate in only one section of the aerated solids contact channel at a time, while maintaining conditions relatively constant in other sections.

Clarifier Performance Profiles. The performance of the Medford clarifiers was evaluated by sampling with a "Sludge Judge" and Kemmerer samplers as shown on Figure 11. Sludge blanket depth was measured with the "Sludge Judge"; the Kemmerer sampler was used to measure supernatant SS in the center well at I through J3 and SS at K through N (Figure 11).

CHILTON

The primary objectives of Chilton treatment plant investigation were the determination of soluble BOD_5 removal in the aerated solids contact tank and the effect of SRT in the aerated solids contact tank on TF/SC performance. Unfortunately, during

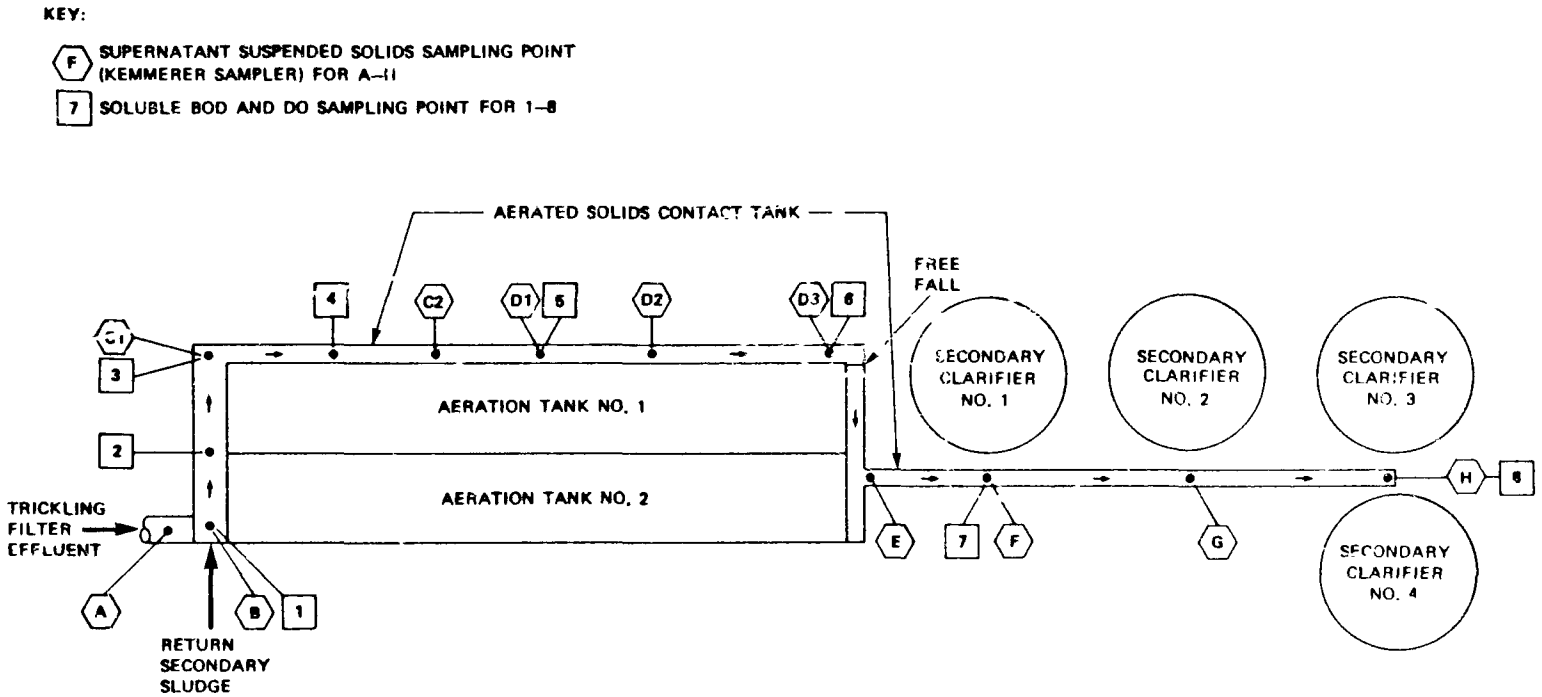


FIGURE 10. KEMMERER AND SOLUBLE BOD SAMPLE LOCATIONS ALONG THE AERATED SOLIDS CONTACT TANK AT MEDFORD, OREGON

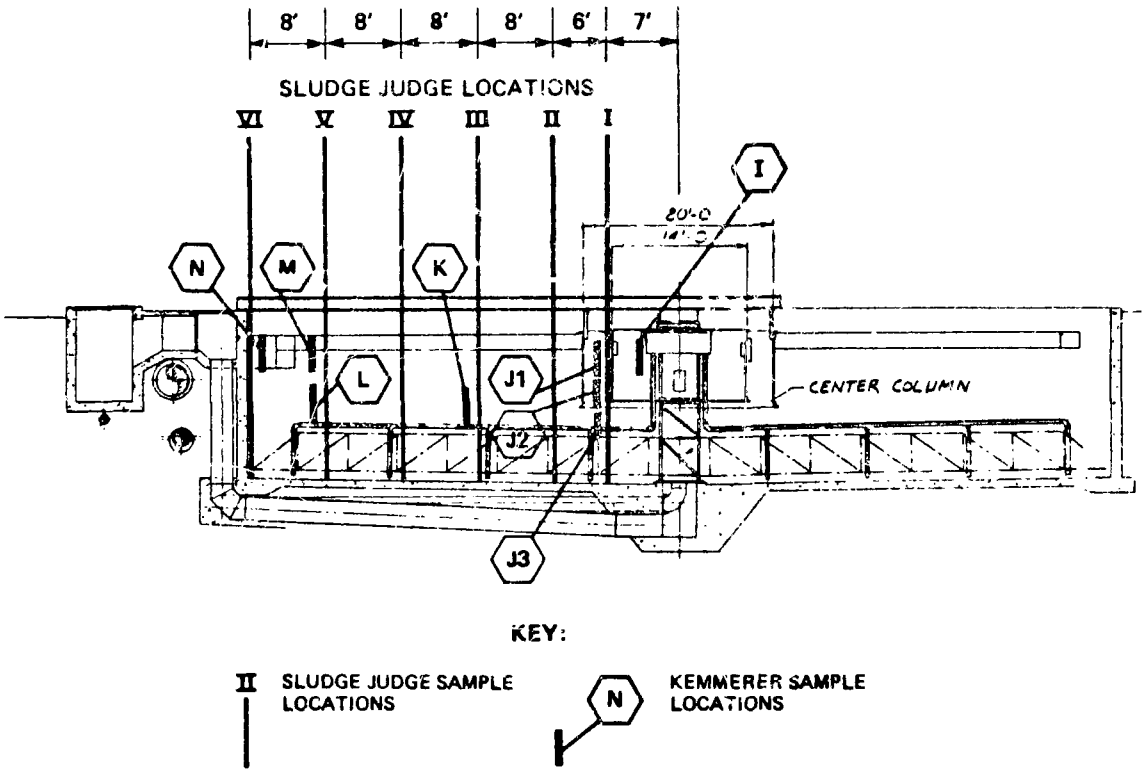


FIGURE 11. KEMMERER AND SLUDGE JUDGE SAMPLE LOCATIONS IN SECONDARY CLARIFIER AT MEDFORD, OREGON

the field testing program, the treatment plant received toxic concentrations of metals in its influent, causing plant upsets and inhibition in the BOD_5 tests. In addition, it was discovered late in the testing that a fraction of the return secondary sludge was leaking into the TF recycle sump. These two factors reduced the usefulness of the Chilton data.

Field Investigation Schedule

The schedule for the Chilton field investigation is shown in Table 8. The major difference between the three phases is the number of aeration tanks in service. Sample collection during the first phase was interrupted by a plant upset caused by high metals concentrations in the raw influent. Because of the interruption and extension of Phase 1, Phases 2 and 3 were shortened.

Laboratory and Field Testing Program

The Chilton testing program is presented in Table 9 and was based on sampling 3 days per week with special studies performed once per week. Samples were collected at the treatment plant and transported to the laboratory for analysis. Sampling and analytical techniques used at Chilton are analogous to those used at Oconto Falls. The data collected during the Chilton field investigation are shown in Appendix E.

QUALITY ASSURANCE PLAN

A quality assurance plan (Appendix F) was developed to provide consistency between laboratories involved in the investigation and promote sound sampling and analytical techniques. The plan describes sampling and analytical procedures, internal quality control checks, and quality control data evaluation.

TABLE 6. CHILTON FIELD INVESTIGATION SCHEDULE

Parameter	Phase 1	Phase 2	Phase 3
1. Operating mode	TF/AS	TF/AS	TF/SC
2. Aeration tanks in service	4	2	0
3. Planned length of phase, weeks	2	2	2
4. Actual length of phase, weeks	3.5[a]	1.5	1.5
5. Dates			
Start of phase	7/1/84	8/1/84	8/12/84
End of phase	7/31/84	8/11/84	8/23/84

[a]All sampling stopped between 7/10/84 and 7/16/84 because of toxic concentrations measured in the primary effluent.

TABLE 9. CHILTON FIELD AND LABORATORY TESTING PROGRAM

Parameter	Sampling frequency, times per week					
	Raw influent	Primary effluent	Trickling filter effluent	Aeration or solids contact tank	Secondary clarifier	Final effluent
Field measurement						
Flow rate	7				-	
Solids contact recycle flow				7	-	
Secondary solids waste flow					7	
30-minute settleability	-	-		3		
Sludge blanket profile			-		3	
Temperature	3				-	3
pH	7	-	-		-	7
Dissolved oxygen	3	3	3	3[a]	3[b]	-
Supernatant SS profile[c]		-	1	1	1	
Clarifier TSS profile		-	-		1	-
Soluble BOD_5 profile	-	-	-	1		
Soluble carbonaceous BOD_5 profile	-		-	1		
Laboratory analyses						
Total BOD_5	3[d]	3	3		3[d]	
Soluble BOD_5	-	3	3	-	3	-
Carbonaceous BOD_5	-	3	3	-	3	
Soluble carbonaceous BOD_5		3	3	-	3	
Suspended solids	3[e]	3	3	3	3	
Return sludge SS	-	-	-	-	3	
Volatile solids percentage	-	3	1	3	3[d]	
SVI	-		.	3	-	-
Microscopic exam			-[f]	-[f]		

[a]Measured at the end of each aerations tank in service and at the beginning and end of the aerated solids contact tank.

[b]Measured 1 ft, 5 ft, and 9 ft below surface in flocculator center well; at the sludge blanket, and in the secondary clarifier effluent.

[c]Supernatant SS measured with Kemmerer sampler. Suspended solids of sample also measured before settling.

[d]Secondary effluent and return secondary sludge.

[e]Measured by plant staff.

[f]Measured one time.

CHAPTER 6

RESULTS AND DISCUSSION

The objectives addressed in the special studies for this project covered a broad range of issues relating to TF/SC design and operation. This chapter presents and discusses results from the special studies, including an analysis of plant operating records and field investigations data. The results are presented in the order that the unit process appears in the treatment plant, although it should be noted that the unit processes are interdependent. A summary discussion is presented at the end of this chapter.

In many cases, close correlations were obtained between variables; in other cases, little or no correlation was obtained between seemingly related variables. Statistics were calculated to determine the significance of correlations between two variables. Generally, linear correlations were assumed unless theory suggested a different relationship was appropriate. For each linear regression, the equation of the line, the correlation coefficient (r), the F-statistic (F), and the statistical significance of the F-statistic (P_F) is presented. If P_F was greater than 0.95, the regression line was assumed to be significantly better than the assumption that no correlation exists.

COSETTLING

A common practice in TF and TF/SC design is to simplify solids thickening by cosettling raw sewage solids and waste TF/SC solids in the primary sedimentation tank. This section presents results from the Tolleson field investigation (Table 10) and information from operating records from Corvallis, Medford, and Oconto Falls. Corvallis, Oconto Falls, and Tolleson practice cosettling; Medford does not. Tolleson has three rectangular sedimentation tanks and treats a warm wastewater from a separate sanitary sewer collection system. Corvallis has one rectangular and one circular sedimentation tank and treats wastewater from a combined sewer system with wide seasonal flow variations. Oconto Falls has one clarigester that combines primary clarification and anaerobic digestion into one unit. Medford has two

TABLE 10. SUMMARY OF TOLLESON FIELD INVESTIGATION ON PRIMARY CLARIFIER PERFORMANCE

Parameter	Parameter average		
	Phase 1	Phase 2	Overall
Raw influent			
Flow, mgd	8.19	6.39	7.25
Suspended solids, mg/l	280	238	260
BOD_5, mg/l	243	197	220
Temperature, degrees C	30	34	32
pH	7.2	6.7	7.0
Primary influent[a]			
Flow,[b] mgd	9.94	7.58	8.70
Suspended solids, mg/l	296[c]	277	287[c]
BOD_5, mg/l	231	181	206
Primary effluent			
Suspended solids, mg/l	139[c]	106	122[c]
BOD_5, mg/l	135	105	120
Performance[d]			
Overflow rate, gpd/sq ft	958	1,120[e]	1,040
Suspended solids loading, ppd/sq ft	2.24	2.23[e]	2.24
Suspended solids removal, percent	50.4	55.5	53.0
BOD_5 removal, percent	44.4	46.7	45.6
Primary sludge concentration, percent	4.0	3.4	3.7

[a]Includes recycle streams.
[b]Assumes recycle flow from facultative sludge basins is negligible.
[c]Excludes data from 5/27/84 because of upset.
[d]Based on raw influent and primary effluent.
[e]Only two of three sedimentation tanks in service.

rectangular primary sedimentation tanks similar in design to Tolleson. The effect of cosettling and operating parameters on primary sludge concentration and SS removal is presented in this section.

Primary Sludge Concentration

The effects of primary sedimentation tank overflow rate and other operational parameters on primary sludge concentration were studied.

In Phase 1 of the Tolleson field investigations, the primary sludge removal frequency was decreased and the sludge concentration at the sludge pump shutoff point was increased to encourage thickening in the primary sedimentation tanks. The maximum sludge concentration increased only slightly to only 4.6 percent. These results suggest that other factors such as raw waste temperature or solids characteristics control the primary sludge thickening properties, since these two factors are the major differences between Corvallis and Tolleson.

The correlation between primary sludge concentration and overflow rate at Corvallis was not statistically significant (Figure 12). The average primary sludge concentrations at two plants that cosettle were substantially different. At Tolleson, the average sludge concentration was 3.7 percent; at Corvallis, the average concentration was 5.3 percent. Data were not available for Oconto Falls since primary solids fall right into the digester. The average sludge concentration at Medford was 4.4 percent. Based on our experience, the concentration seems low for primary sedimentation tanks that do not cosettle.

SS Removal

In addition to sludge thickening, the major task that primary sedimentation tanks must accomplish is efficient SS removal. The SS removal in Phase 2 (56 percent) of the field investigation was slightly higher than in Phase 1 (50 percent) (Table 10). In Phase 1, the main objective was to obtain the maximum primary sludge concentration possible without regard for the sludge blanket level. In Phase 2, the objective was to obtain the highest sludge concentration while maintaining a shallow sludge blanket. The field investigation results suggest that although a slightly higher sludge concentration can be obtained in Phase 1, some SS removal efficiency is sacrificed.

At Corvallis, SS removal decreased as overflow rate increased (Figure 13). Average SS removal was 56 percent. One might expect Corvallis SS removal to decrease only for wet-season flows because of the combined sewer system, but Figure 13 indicates a drop in SS removal also occurred during the dry season.

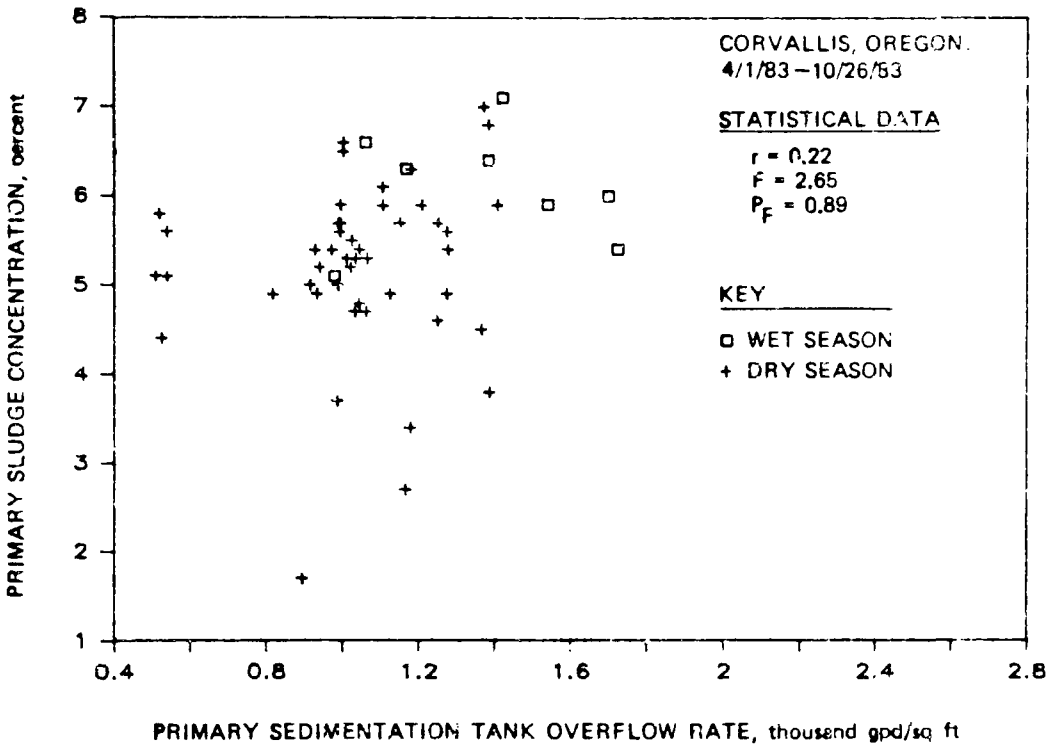


FIGURE 12. EFFECT OF PRIMARY SEDIMENTATION TANK OVERFLOW RATE ON PRIMARY SLUDGE CONCENTRATION AT CORVALLIS, OREGON

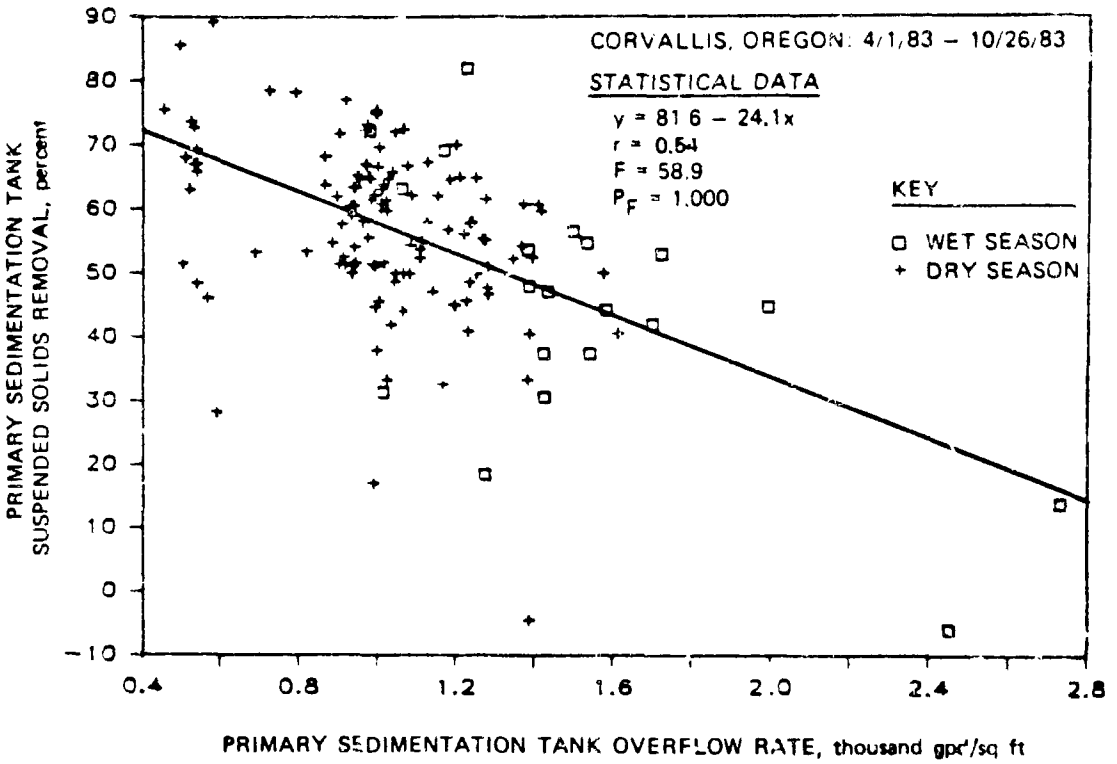


FIGURE 13. EFFECT OF PRIMARY SEDIMENTATION TANK OVERFLOW RATE ON SUSPENDED SOLIDS REMOVAL AT CORVALLIS, OREGON

Average SS removal at Medford was 74 percent, which was higher than Corvallis (56 percent) Tolleson (53 percent), and Oconto Falls (62 percent). Cosettling may reduce SS removal, although the primary SS removal at Medford, which does not cosettle, is unusually high.

TRICKLING FILTER SOLUBLE BOD REMOVAL

The primary function of the TF in the TF/SC process is to remove the majority of the primary effluent soluble BOD_5. Many factors have been correlated with TF effluent soluble BOD_5 by previous investigators including influent soluble BOD_5, media specific surface, TF depth, temperature, and hydraulic loading rate. The modified Velz equation has been used by Gromiec, et al.,[6], Hutchinson,[7] Parker, et al.,[8] and Brown and Caldwell[9,10] to model the effects of these variables on effluent soluble BOD_5. The equation has the form:

$$S_2 = \frac{S_1}{\left\{ [R+1] \exp\left[\frac{k_{20} A_s D \theta^{(T-20)}}{[Q_i (R+1)]^n} \right] \right\} - R} \qquad (1)$$

where

S_2 = soluble BOD_5 concentration in the TF effluent, mg/l

S_1 = soluble BOD_5 concentration in the primary effluent before dilution with recycle, mg/l

R = recycle ratio, defined as the recycle flow rate divided by the primary effluent flow rate, dimensionless

k_{20} = first-order reaction rate coefficient at 20 degrees C, inverse time

A_s = media specific surface, sq ft/cu ft, or m^2/m^3

D = media depth, ft or m

θ = a temperature correction coefficient, dimensionless

T = wastewater temperatures, degrees C

Q_i = TF feed flux, defined as the primary effluent flow divided by the cross-sectional area of the TF, gpm/sq ft or m^3/m^2-sec

n = flow exponent, dimensionless

It is important to note that in this project "soluble" BOD_5 has been operationally defined as the BOD_5 remaining in the filtrate after filtration through a Whatman 934AH filter (1.5 μm retention). In this investigation, TF effluent samples for soluble BOD_5 determinations were treated with a nitrification inhibitor so that nitrification did not interfere with the estimate of carbonaceous BOD_5 removal.

Equation 1 can be restated in a form convenient for data analysis as follows:

$$\ln \frac{S_b}{S_2} = \frac{k_{20}\ \theta^{(T-20)} A_s\ D}{Q^n} \qquad (2)$$

where

S_b = soluble BOD_5 or blended recycle and primary effluent streams, mg/l

Q = total hydraulic feed flux, defined as primary effluent + recycle flow divided by TF cross-sectional area, gpm/sq ft or m^3/m^2-sec

In this section, Equation 2 has been used to analyze soluble BOD_5 removal with filter depth at Tolleson and to develop removal rate coefficients at Medford and Oconto Falls.

Soluble BOD_5 Removal With Filter Depth

Soluble BOD_5 samples were collected from the first-stage TF at Tolleson. The 20 ft-deep, 135-ft-diameter filter has plastic cross-flow media with a specific surface of 30 sq ft/cu ft. Six samples were collected from the filter at various depths on three separate days. All samples were collected between 1:00 and 3:00 p.m., which is the time of peak load at Tolleson.

Results from the Tolleson field tests are shown in Table 11. The results for the first and third sampling days were used to determine k_{20}, since the increase in BOD with depth on the second sample day suggests a sampling error occurred. Equation 2 is a linear equation and is used to analyze the results. When $\ln(S_b/S_2)$ is plotted versus $(\theta^{(T-20)} A_s D)/Q^n$, the slope of the straight line obtained is equal to k_{20}. The line must pass

TABLE 11. SOLUBLE BOD REMOVAL WITH DEPTH IN THE FIRST-STAGE TRICKLING FILTER AT TOLLESON, ARIZONA

Parameter	Test date		
	7/26/84	7/30/84	7/31/84
Waste characteristics			
Total flow,[a] mgd	14	14	14
Temperature,[b] degrees C	34	34	34
Soluble carbonaceous BOD_5 with filter depth, mg/l			
0.0 ft	27.0	6.5	18.5
1.1 ft	24.0	9.0	11.5
5.1 ft	8.0	<1.0	3.5
9.5 ft	<1.0	<1.0	<1.0
14.5 ft	<1.0	<1.0	<1.0
20.0 ft	<1.0	<1.0	<1.0

[a]For blended primary effluent plus recycle flow.
[b]Based on average raw waste temperature between 7/1/84 and 7/16/84.

through the origin. Figure 14 is the plot for the first and third sample dates. In developing the plots, temperature (θ) and flow (n) coefficients of 1.035 and 0.5, respectively, were assumed. Values of k_{20} of 5.4×10^{-5} and 5.3×10^{-5} were obtained for the 2 sampling days.

Since all of the quantifiable soluble BOD_5 was removed in the top 9.5 ft of the filter (Table 11), only the first four sample points were used to determine k_{20}. Figure 14 shows that the modified Velz equation describes soluble BOD_5 removal with depth well for the Tolleson data. The good fit of the lines on Figure 14 indicates that the soluble BOD_5 removal rate coefficient did not vary much with depth.

The removal rate coefficient (k_{20}) measured at Tolleson was higher than values reported by Parker, et al.,[8] for cross flow media. It is interesting to note that if only TF influent and effluent were measured, and the entire filter depth rather than only the top 9.5 ft was assumed to be effective, k_{20} would be reduced to 2.6×10^{-3}. This value corresponds to the k_{20} measured at Tolleson under another study,[11] which used primary effluent and TF effluent soluble BOD_5 data and assumed the total depth was effective.

Removal Rates at Medford and Oconto Falls

Data from the Oconto Falls field investigations and Medford plant operating records were also used to determine removal rate coefficients. Pertinent facilities data and average wastewater characteristics used to calculate average k_{20} values are presented in Table 12. The Medford k_{20} is close to values previously found for vertical plastic media.[8] The Oconto Falls k_{20} values for rock media were substantially higher than the Medford k_{20} value from plastic media. The difference may be due to differences in oxygen transferred per unit of media surface area or hydraulic residence time between plastic and rock filter media. The relatively low removal rate during Phase 2 at Oconto Falls is attributed to the extensive sloughing that occurred.

TRICKLING FILTER LOADING

The purpose of this section is to present data on the effect of TF BOD_5 loading on TF/SC performance. Data are also presented on the effect of primary effluent and TF effluent SS on process performance. Comparisons are based on Oconto Falls field investigation data and operating records from Corvallis, Medford, and Tolleson.

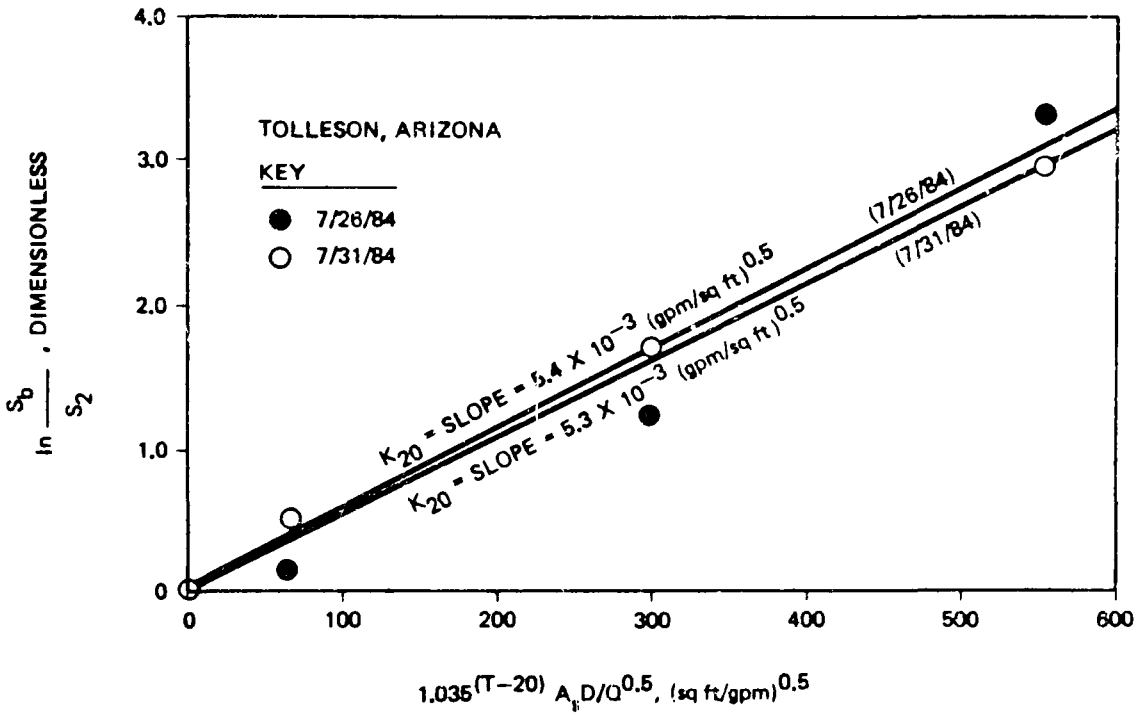


FIGURE 14. DETERMINATION OF REMOVAL RATE COEFFICIENT FOR TOLLESON, ARIZONA

TABLE 12. MEDFORD AND OCONTO FALLS TRICKLING FILTER SOLUBLE BOD REMOVAL DATA

Parameter	Medford data	Oconto Falls field investigation			
		Phase 1	Phase 2	Phase 3	Phase 4
Facilities data					
Number of filters in service	1	2	2	2	1
Filter depth, ft	14	6	6	6	6
Filter diameter, ft	140	38	38	38	38
Media type	Plastic	Rock	Rock	Rock	Rock
Specific surface, sq ft/cu ft	27	13.5	13.5	13.5	13.5
Wastewater characteristics[a]					
Plant flow, mgd	9.0	0.341	0.400	0.418	0.398
Recycle flow, mgd	4.1	0.618	0.622	0.528	0.266
Temperature, degrees C	21.0	12.9	14.9	17.3	17.8
Primary effluent soluble BOD_5, mg/l	57	30	20	25	28
Filter soluble carbonaceous BOD_5, mg/l	13	5	8	7	8
Removal rate					
k_{20}, (gpm/sq ft) coefficient 0.5	2.3×10^{-3}	8.7×10^{-3}	3.8×10^{-3}	4.8×10^{-3}	7.8×10^{-3}

[a]Medford: based on 13 sets of samples collected between 6/26/84 and 8/1/84; Oconto Falls: phase averages from field investigation.

Influence of TF BOD Loading

The effect of TF BOD_5 loading on TF/SC performance is important because designers and operators must know how much load can be applied to the filters before performance is adversely affected. Sarner[12] noted that the settling characteristics of sludge from high-rate TFs are poor and may be related to the activity of sloughed microorganisms. He noted that in a biofilm process high organic load will encourage fast biofilm growth and sloughing of solids that have a low age. Pavoni, et al.,[13] performed batch experiments on suspended growth systems and noted that maximum coagulation of the bacteria occurred during the endogenous phase of growth. Extracellular polymer production increased during the endogenous growth phase and was the probable cause of better coagulation. Based on the results from suspended growth experiments, it seems plausible that increases in BOD_5 loading may have an adverse effect on TF sludge settling characteristics because of increased organism activity and concurrent decrease in polymer production.

In Phase 4 of the Oconto Falls field investigation, one of the two TFs was taken out of service to determine the impact of doubling the filter BOD_5 loading. The Oconto Falls plant was operated with one filter for only 2 weeks. Final effluent SS and total BOD_5 concentrations were substantially higher at the 95 percent confidence level than in the other three phases (Table 13). The effect of BOD_5 loading on secondary effluent quality may have been more significant if the plant had continued to operate with only one filter for a longer period (see Appendix B). The TF mode (Phase 3) performed as well as TF/SC (Phase 2) at Oconto Falls and may be due to the short contact time and filter sloughing that occurred in Phase 2. Differences in performance are discussed in a later section.

Correlations between filter BOD_5 loading and final effluent SS were developed for Corvallis, Medford, and Tolleson (Table 14). Typically, the daily filter BOD_5 loadings were between 10 and 40 ppd/1,000 cu ft. A statistically significant but not strong correlation between filter BOD_5 loading and final effluent quality was obtained at Corvallis; the results (Figure 15) agree reasonably well with earlier Corvallis results published by Norris, et al.[14] A significant correlation at Tolleson was also obtained, but the strength of the correlation was weaker than the Corvallis correlation. At Medford, loading did not have a significant effect on final effluent SS. The possible reason for this lack of correlation is discussed in the next section.

Influence of SS

The influence of primary effluent and TF effluent SS on TF/SC performance will be addressed in this section. Sarner[12] noted

TABLE 13. EFFECT OF TRICKLING FILTER LOADING ON OCONTO FALLS PERFORMANCE

Parameter	Parameter value			
	Phase 1	Phase 2	Phase 3	Phase 4
Raw influent				
Flow, mgd	0.342	0.394	0.328	0.396
BOD_5, mg/l	114	139	153	123
Suspended solids, mg/l	136	191	238	152
Primary effluent				
Flow,[a] mgd	0.346	0.400	0.415	0.407
BOD_5, mg/l	74	66	54	57
Suspended solids, mg/l	71	57	55	56
Filter effluent				
BOD_5, mg/l	51	100	38	60
Carbonaceous BOD_5, mg/l	27	61	21	35
Suspended solids, mg/l	69	189	31	86
Secondary effluent				
BOD_5, mg/l	14	23	22	31
Carbonaceous BOD_5, mg/l	9	11	11	15
Suspended solids, mg/l	10	13	11	18
Filters in service	2	2	2	1
Filter BOD_5 loading, ppd/ 1,000 cu ft	15.7	16.2	13.7	28.5
Filter hydraulic loading rate, gpm/sq ft	0.30	0.31	0.29	0.41

[a]Includes raw influent and secondary waste flows.

TABLE 14. CORRELATIONS BETWEEN TRICKLING FILTER LOADING AND TOTAL SUSPENDED SOLIDS

Correlation[a]		Statistical data[b]				
x-variable	y-variable	Regression equation	n	r	F	P_F
Corvallis	Corvallis					
BOD_5 load	Final effluent SS	y = 5.7 + 0.22x	103	0.42	21.1	1.000
BOD_5 load	TF effluent SS	y = 47.8 + 0.71x	103	0.22	5.4	0.978
Primary effluent SS	TF effluent SS	y = 26.4 + 0.50x	249	0.76	331.1	1.000
TF effluent SS	Final effluent SS	y = 5.7 + 0.059x	249	0.28	20.3	1.000
Medford	Medford					
BOD_5 load	Final effluent SS	-[c]	39	0.046	0.079	0.22
BOD_5 load	TF effluent SS	-[c]	36	0.06	0.19	0.34
Primary effluent SS	TF effluent SS	y = -1.1 + 2.1x	39	0.60	20.4	1.000
TF effluent SS	Final effluent SS	y = 4.3 + 0.048x	39	0.54	15.6	1.000
Tolleson[d]	Tolleson[d]					
BOD load	Final effluent SS	y = 4.4 + 0.15x	135	0.29	12.6	0.999
BOD load	TF effluent SS	y = 19.3 + 0.15x	135	0.19	4.7	0.969
Primary effluent SS	TF effluent SS	y = 20.0 + 0.034x	141	0.39	23.3	1.000
TF effluent SS	Final effluent SS	y = 2.7 + 0.25x	141	0.42	29.7	1.000

[a]Units for BOD_5 load are ppd/1,000 cu ft and mg/l for SS.

[b]Regression equation based on linear regression
n number of sample points
r - correlation coefficient
F F-statistic
P_F Based on the F-statistic, the probability that concluding a correlation exists is more correct than concluding no correlation exists.

[c]Not shown because P_F is less than 0.95.

[d]TF BOD_5 loading, TF influent, and TF effluent SS are for the first-stage plastic filter. TF effluent SS is intermediate clarifier effluent SS.

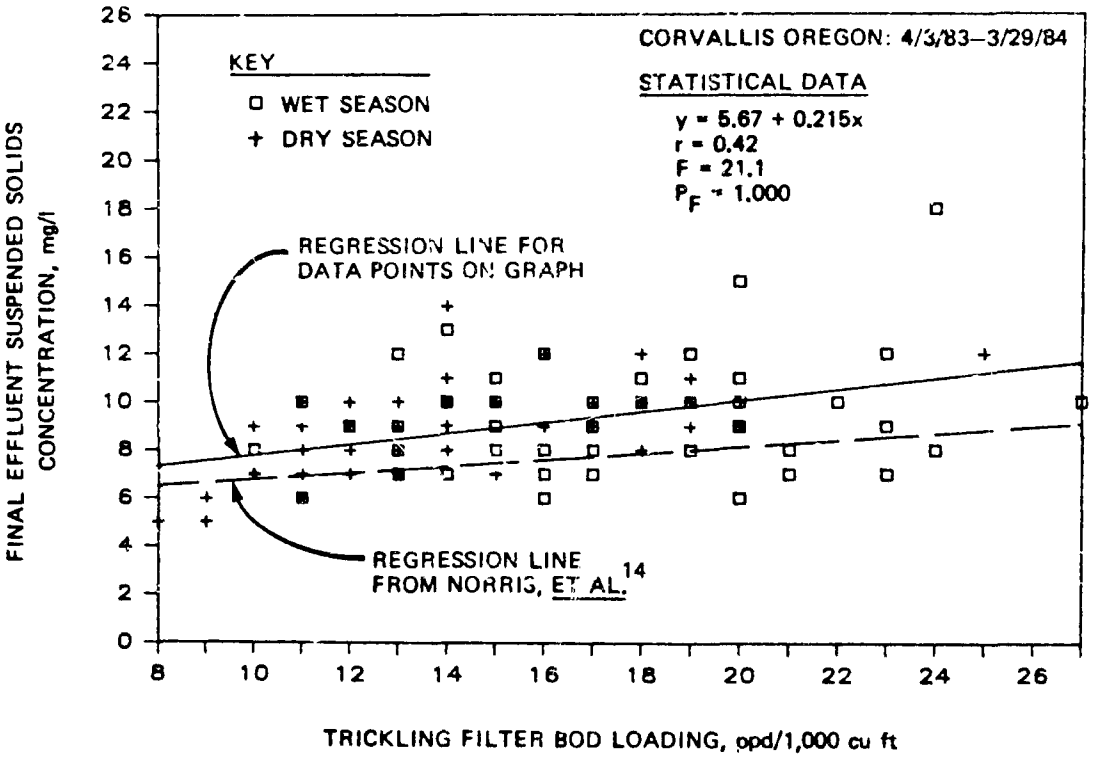


FIGURE 15. EFFECT OF TRICKLING FILTER BOD LOADING ON FINAL EFFLUENT SUSPENDED SOLIDS AT CORVALLIS, OREGON

that the removal mechanisms for dissolved and particulate organics in biofilms are different, and that the removal mechanisms are interdependent. Sarner presented results for TF plants that showed for a given filter BOD_5 loading, final effluent SS increased when SS concentrations entering the TF were increased. These results suggest that primary effluent SS as well as filter BOD_5 loading may affect final effluent quality.

Results presented in Table 14 show that final effluent SS were correlated with TF effluent SS, which are most sensitive to primary effluent SS. The equations for the regression lines describing the relationship between filter effluent and final effluent SS at Corvallis and Medford are surprisingly similar, although the strength of the correlation is weaker at Corvallis. As noted earlier, the correlation between filter BOD_5 loading and final effluent SS was not significant at Medford, nor was the correlation between filter BOD_5 loading and filter effluent SS. These results suggest that in the range of filter BOD_5 loadings studied in this project, filter BOD_5 loading is important only when it affects the concentration of TF effluent SS.

At the low filter BOD_5 loadings studied in the project, the amount of exocellular polymer produced by the TF organisms may be so large that changes in organism activity do not produce adverse affects on settling characteristics. Figures 16 and 17 show the correlation between primary effluent SS and final effluent SS at Medford. TF effluent SS increase as primary effluent SS increase; likewise, final effluent SS increase with TF effluent SS. As Sarner[12] stated in interpreting his data, one does not know whether the solids in the trickling effluent are fine or colloidal particles originating in the primary effluent, or whether the characteristics of these solids are quite different. In either case, there seems to be a relationship between the primary effluent suspended solids and the TF effluent SS, and, consequently, the final effluent SS. These results underscore the need for efficient primary treatment.

MEDIA TYPE

The effect of media type on TF/SC performance was studied by performing microscopic examinations on the TF effluent and mixed liquors at different plants. Data from previous work were used for Tolleson[11] and Corvallis.[14] The intent of the microscopic examinations was to provide information on the fundamental differences between TF biological solids formed in rock media and plastic media. Results are shown in Table 15. In addition to the information on microscopic characteristics, filter BOD_5 loading, SVI, and suspected operating conditions are also presented

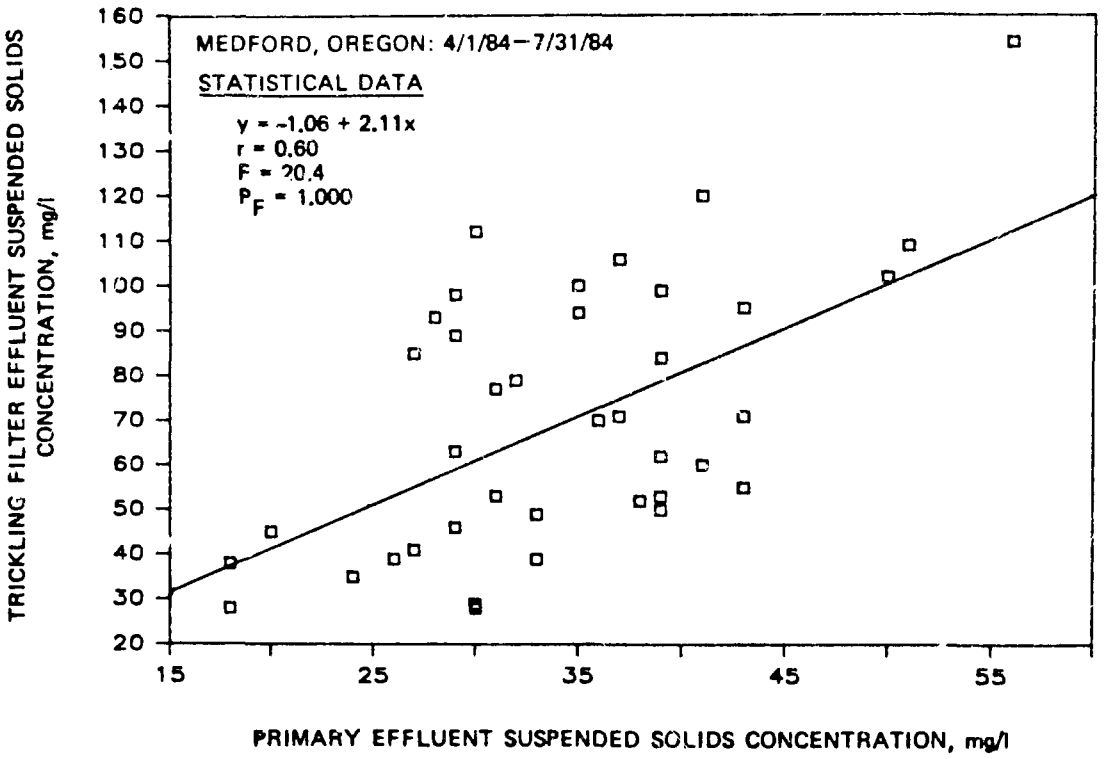


FIGURE 16. CORRELATION BETWEEN PRIMARY EFFLUENT SUSPENDED SOLIDS AND TRICKLING FILTER EFFLUENT SUSPENDED SOLIDS AT MEDFORD, OREGON

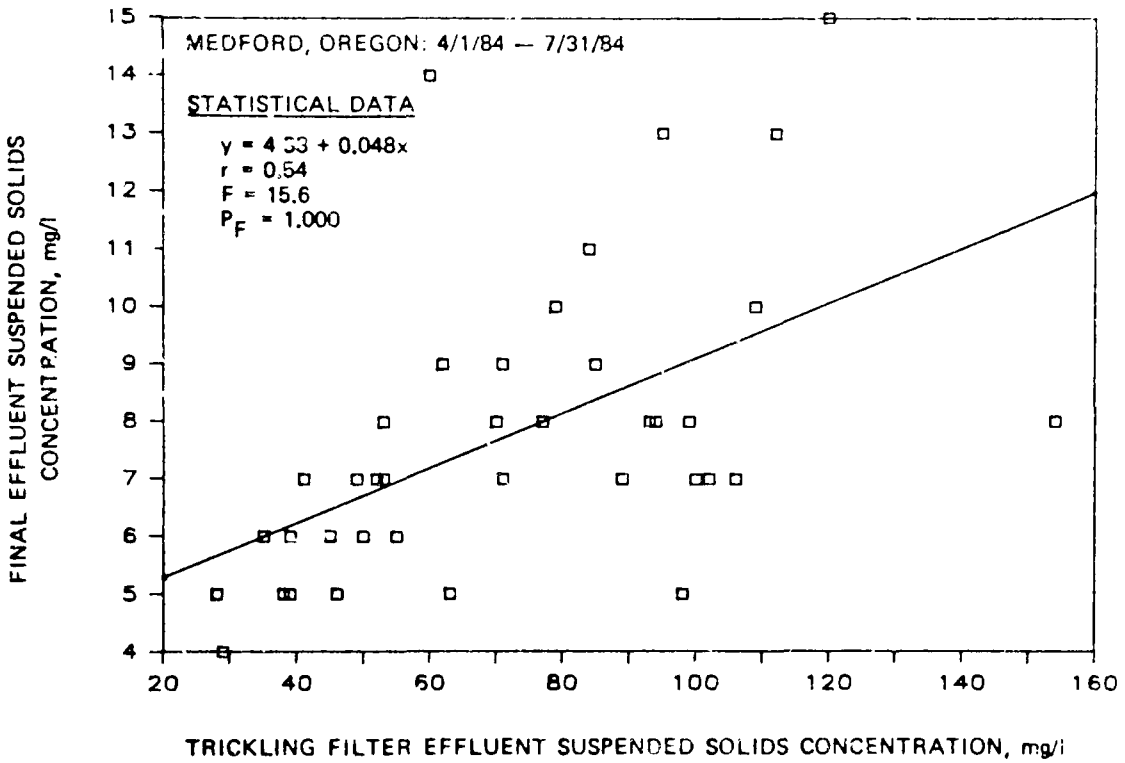


FIGURE 17. CORRELATION BETWEEN FILTER EFFLUENT SUSPENDED SOLIDS AND FINAL EFFLUENT SUSPENDED SOLIDS AT MEDFORD, OREGON

TABLE 15. SUMMARY OF MICROSCOPIC EXAMINATIONS FOR TF/SC PLANTS

DATE	PLANT	SAMPLE LOCATION	TRICKLING FILTER DATA: MEDIA	TRICKLING FILTER DATA: LOAD, ppd/1000 cu ft[a]	SVI, ml/g	FLOC SIZE RANGE, um[b]	FLOC STRUCTURE	DESCRIPTION OF FILAMENTS	FILAMENT ABUNDANCE[c]	SUSPECTED OPERATING CONDITION[d]
7/10/84	CHILTON[e]	MLSS	ROCK	8	21[f]	10 - 250	VERY DENSE, ROUGHLY SPHERICAL FLOC; GOOD SETTLING	NONE	NONE	
8/9/84	MEDFORD	TF EFFLUENT	PLASTIC	28	-	50 - 1500	ROUND, FIRM FLOC; FINGERED ZOOGLEAS	SOME - H. HYDROSSIS FEW - S. NATANS BEGGIATOA - TYPE 1701	FEW	[illegible]
		MLSS			106	50 - 400	FIRM FLOC BUT IRREGULAR & DIFFUSE; FINGERED, AMORPHOUS ZOOGLEAS	COMMON - TYPE 1701 SOME - BEGGIATOA - H. HYDROSSIS FEW - S. NATANS	SOME TO COMMON	[illegible]
8/13/84	OCONTO FALLS	TF EFFLUENT	ROCK	16	-	50 - 250	FIRM, ROUND, COMPACT	FEW - TYPE 021N H. HYDROSSIS BEGGIATOA	FEW	[illegible]
		MLSS			49	50 - 700	FIRM, ROUND, COMPACT	COMMON - BEGGIATOA FEW - SPHAEROTILUS NATANS TYPE 021N H. HYDROSSIS	COMMON	[illegible]
2/28/84	TOLLESON	TF EFFLUENT	PLASTIC ROCK	31/6	-	25 - 60	FIRM, COMPACT; SOME BRIDGING		NONE	
		MLSS			[illegible]	[illegible] - 153	FIRM, COMPACT; SOME BRIDGING	VERY COMMON - TYPE [illegible] FEW - TYPE 1863	COMMON TO VERY COMMON	VERY COMMON [illegible]
3/21/84	TOLLESON	TF EFFLUENT	PLASTIC ROCK	31/6	-	-	FIRM, COMPACT	COMMON - TYPE 021N SOME - TYPE 1863 - H. HYDROSSIS FEW - E. NIDULANS - BLUE GREEN ALGAE - TYPE 1701	SOME	[illegible]
		MLSS			146	25 - 200	FIRM, IRREGULAR, DIFFUSE	VERY COMMON - TYPE 1863 COMMON - TYPE 1835 SOME - H. HYDROSSIS - TYPE 021N FEW - FUNGI - BLUE GREEN ALGAE	VERY COMMON	[illegible]
6/13/80	CORVALLIS	MLSS	ROCK	19	69[m]	- [j]	[j]	ABUNDANT - S. NATANS - H. HYDROSSIS COMMON - TYPE 1701	COMMON TO ABUNDANT	ABUNDANT [illegible] COMMON [illegible]
7/25/80	CORVALLIS	TF EFFLUENT	ROCK	19	-	[j]	[j]	COMMON - H. HYDROSSIS SOME - TYPE 1701 - TYPE 1041 FEW - S. NATANS	SOME TO COMMON	[illegible]
		MLSS			[j]	[j]	[j]	RARE - S. NATANS - TYPE 1701 - TYPE 021N	RARE	[illegible]
8/4/80	CORVALLIS	TF EFFLUENT	ROCK	19	-	[j]	[j]	SOME - S. NATANS - H. HYDROSSIS FEW - TYPE 021N	SOME	[illegible]
		MLSS			[j]	[j]	[j]	COMMON - H. HYDROSSIS TYPE 1701 SOME - S. NATANS TYPE 021N	COMMON	[illegible]

FOOTNOTES:

[a] ANNUAL AVERAGES EXCEPT CHILTON AND OCONTO FALLS, WHICH ARE AVERAGE VALUES FOR THE FULL-SCALE STUDIES.

[b] RELATIVE INDEX. MAY NOT BE ACCURATE REPRESENTATION OF ONSITE CONDITIONS BECAUSE OF REQUIRED SAMPLE TRANSPORT.

[c] RANKING DEPENDS ON DATE:
1984: ABUNDANT, VERY COMMON, COMMON, SOME, FEW, NONE
1980: ABUNDANT, COMMON, SOME, FEW, RARE, NONE

[d] BASED ON REFERENCE 15

[e] TREATMENT PLANT IN TF/AS MODE.

[f] NO SVI DATA ON THIS DAY. NUMBER IS AVERAGE OF 5 VALUES BETWEEN 7/3/84 AND 7/19/84.

[g] TYPE 021N POSSIBLY INDICATIVE OF LOW DO, SULFIDES, AND/OR NUTRIENT DEFICIENCY.

[h] THIOTHRIX SPECIES POSSIBLY INDICATIVE OF PRESENCE OF SULFIDES, NUTRIENT DEFICIENCY, AND/OR LOW DO

[i] H. HYDROSSIS AND S. NATANS PRESENT BUT TOO FEW TO QUANTITATE.

[j] DATA NOT AVAILABLE.

[k] NO DESCRIPTION OF OPERATING CONDITION FOR THIS FILAMENT TYPE.

[l] TOO FEW - ESTIMATE RANGE.

[m] NO SVI DATA ON THIS DAY. NUMBER IS AVERAGE OF [illegible] VALUES BETWEEN 6/8/80 AND 6/19/80.

Filter BOD_5 loadings were low (9 to 28 ppd/1,000 cu ft), while SVI ranged from 21 to 146 ml/g. SVI was generally related to the overall filament abundance, with higher SVIs correlated with increases in filament abundance. Other discussions on the effect of SVI on TF/SC performance are presented in the next section. Trickling filter effluent floc size ranged from 10 to 260 μm for rock media and 50 to 1,500 μm for plastic media, although only one sample was obtained from a plant that uses only plastic media in its TFs. In all cases, floc were characterized as firm. Floc from mixed liquor samples at Medford were irregular and diffuse. Floc from mixed liquor samples at Oconto Falls were firm and compact, suggesting floc from plastic media are not as compact as those from rock media Results from Tolleson are difficult to interpret because the first-stage plastic filter is followed by a second-stage rock filter, and it is difficult to determine the controlling filter for floc formation. Although the data are limited, fundamental differences in the characteristics may exist between floc formed in plastic and rock media. Further study must be performed to clarify this issue.

The filament typing information for plant samples was used to provide information on suspected operating conditions in the TF and aerated solids contact system. Information from work by Richard, et al.,[15] in activated sludge systems was used to characterize operating conditions based on filament typing. In four of the five TF effluent samples, filaments indicated the presence of a low dissolved oxygen (DO) environment and a low food-to-microorganism (F/M) ratio. It is doubtful that these two conditions occurred in the same location in the TF. The more plausible explanation is that low DO conditions prevail near the top of the filter where BOD_5 concentrations and oxygen demands are high. Low F/M conditions probably prevail near the bottom of the filter where BOD_5 concentrations are low. A comparison between floc from TF effluent and solids contact tank mixed liquor shows filaments are usually formed first in the TF. The abundance of a specific filament in the mixed liquor may either increase or decrease depending on conditions in the aerated solids contact tank.

SOLIDS CONTACT OPERATING PARAMETERS

Designers and operators of the TF/SC process require definition of process parameters for the aerated solids contact tank to insure effective performance. This section addresses the effect of three operating parameters: (1) SRT, (2) MLSS, and (3) SVI--on TF/SC performance. SS concentration in the final effluent is used as the measure of TF/SC performance since

the TF/SC process improves effluent quality primarily by reducing final effluent SS and its related BOD_5. Results presented in this section are considered to be site specific.

Solids Retention Time

SRT--also called sludge age or mean cell residence time--has been used as a primary process control parameter for other treatment processes. Lawrence and McCarty[16] defined biological SRT as the average time a unit of biomass remains in the treatment system, that is:

$$SRT = \frac{X_T}{(\Delta X / \Delta t)_T} \quad (3)$$

where

X_T = total active microbial mass in the treatment system, mass

$(\Delta X/\Delta t)_T$ = total quantity of active microbial mass withdrawn daily, including those solids purposely wasted as well as those lost in the effluent, mass/time

This simple definition can be difficult to apply to the TF/AS or TF/SC processes because, strictly speaking, X_T includes the biomass in the TF as well as the suspended growth system. For purposes of discussion in this report, SRT will be defined as in Equation 3; but X_T will be defined as the quantity of SS in the aerated solids contact tank, and will exclude the mass of solids in the flocculator center well and secondary clarifier sludge blanket. An approximation of the relative distribution of times that solids remain in the aerated solids contact tank, flocculator center well, and sludge blanket is shown in Table 16. These calculations show that the solids spend a significant amount of time in the secondary clarifier and sometimes only a small amount of time in the aerated solids contact tank. The quantity of solids withdrawn daily will be based on SS and be equal to the mass of waste secondary sludge solids removed and secondary effluent solids lost from the system daily.

SRT had a significant effect only at Medford when approximately 2 months of TF/AS data were included (Table 17). Figure 18 shows that Corvallis final effluent SS consistently average about 9 mg/l over a broad range of SRTs. One interesting observation for the Corvallis data is higher final effluent SS

TABLE 16. APPROXIMATE DISTRIBUTION OF DETENTION TIMES FOR SOLIDS IN TF/SC PLANTS

Plant	Detention time, percent of total		
	Solids contact tank	Floc center well	Sludge blanket
Corvallis	14[a]	44	42
Medford	35	18	47
Oconto Falls	7	58	35
Tolleson	12	51	37

[a]Includes return sludge aeration and aerated solids contact times.

Note: The following assumptions were made:

1. A 0.5-ft sludge blanket was maintained.
2. The solids concentration in the center well was the same as in the solids contact tank.
3. Average plant and solids contact recycle flows were used for each plant.

TABLE 17. CORRELATIONS BETWEEN SOLIDS CONTACT OPERATING PARAMETERS AND FINAL EFFLUENT SUSPENDED SOLIDS

Correlation[a]	Statistical data[b]				
	Regression equation	n	r	F	P_F
Corvallis					
1. SRT, days	-[c]	249	0.10	0.01	0.099
2. MLSS, mg/l	y 8.3 + 0.0003x	249	0.16	6.64	0.987
3. SVI, ml/g	-[c]	249	0.05	0.57	0.549
Medford					
1. SRT, days					
a. TF/SC only	-[c]	122	0.07	0.55	0.579
b. TF/SC and TF/AS	y 8.8 1.1x	180	0.34	23.2	1.000
2. MLSS, mg/l	-[c]	122	0.15	2.93	0.911
3. SVI, ml/g	y = 15.9 - 0.083x	22	0.44	28.5	1.000
Tolleson					
1. SRT, days	-[c]	13	0.20	0.44	0.481
2. MLSS, mg/l	-[c]	30	0.32	3.12	0.912
3. SVI, ml/g	-[c]	13	0.30	2.15	0.842

[a]The independent variables (SRT, MLSS, and SVI) were correlated with the dependent variable (final effluent TSS).

[b]Independent variable (x-axis) versus dependent variable (y-axis). Units for final effluent SS are mg/l.

[c]Not shown because P_F is less than 0.95.

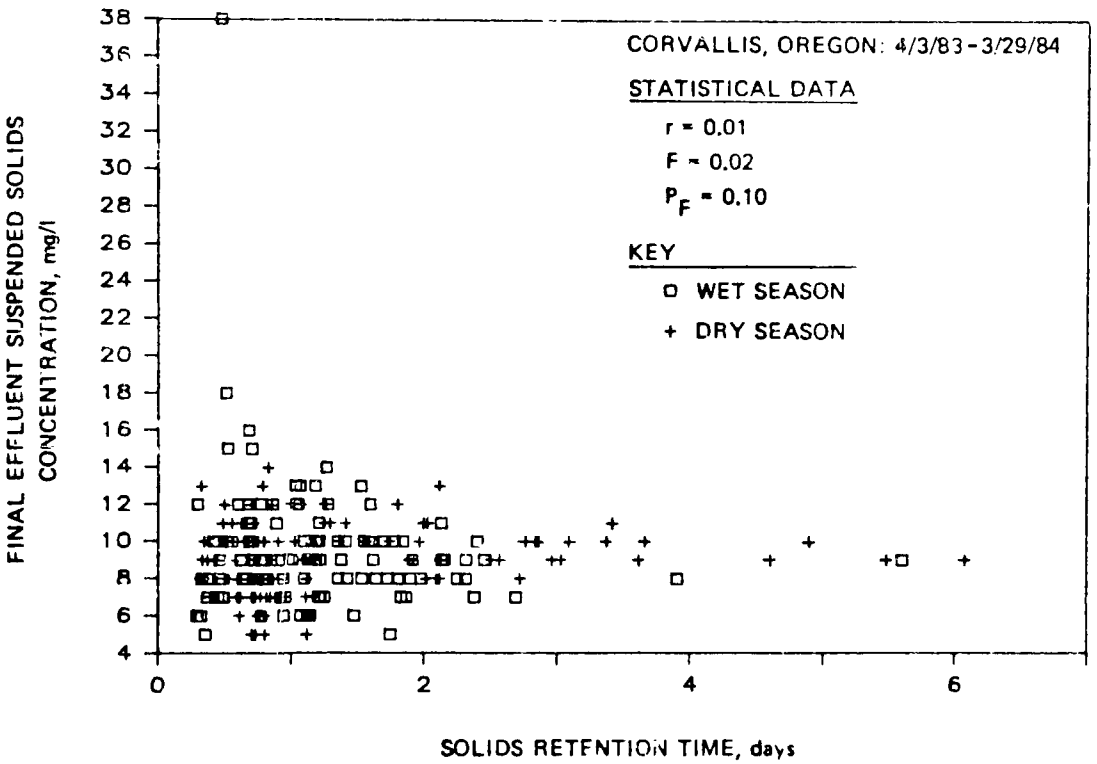


FIGURE 18. EFFECT OF SOLIDS RETENTION TIME ON FINAL EFFLUENT SUSPENDED SOLIDS AT CORVALLIS, OREGON

concentrations occur when the SRT is less than about 1 day; low effluent SS concentrations also occur in this range suggesting that at Corvallis, TF/SC can also work at low SRTs.

At Medford, effluent SS tended to decrease as SRT increased (Figure 19), although the correlation is not strong. Based on limited data at Tolleson, no significant correlation between SRT and effluent SS was obtained (Figure 20). The lack of strong correlation between SRT and effluent SS at the three plants may be due to the difficulty in measuring the true SRT. As noted earlier, the majority of the total TF/SC system solids are usually contained in the secondary clarifier center well and sludge blanket. The DO concentration and the activity of the solids in the secondary clarifier vary substantially making it difficult to estimate the true SRT.

One other interesting contrast is that Corvallis and Tolleson have rock filters preceding their aerated solids contact tanks, while Medford has a plastic filter ahead of its contact tank. It seems plausible that the insensitivity of the Corvallis and Tolleson plants may be due to better flocculation characteristics for filter solids formed in rock media. Rock media has more horizontal surface that may increase the age of the filter solids and, therefore, biopolymer concentrations. Higher biopolymer concentrations have been shown to result in better flocculation.

The Oconto Falls field investigations were used to demonstrate the effect of large changes in SRT as the plant operations mode is switched from TF/SC to the TF mode (SRT = 0). Table 13 shows that final effluent SS concentration did not vary much between the TF mode (Phase 3) and the TF/SC mode (Phases 1 and 2) even though TF loadings did not vary much. At first glance, one might conclude that the TF mode performs as well as the TF/SC mode. The cause for the lack of difference between Phase 3 and Phases 1 and 2 can be explained by comparing primary effluent and TF effluent SS values. Primary effluent SS concentrations did not vary much between phases. Major sloughing, however, occurred in Phase 2 causing TF effluent SS to exceed 1,000 mg/l and the Phase 2 average to be 189 mg/l. Despite the heavy sloughing, the Oconto Falls TF/SC plant still produced secondary effluent with an average SS concentration of 13 mg/l. During Phase 3, the average TF effluent SS concentration was only 31 mg/l making it easier to produce a secondary effluent with an average SS concentration of 11 mg/l. As a contrast, the Corvallis plant, which also has rock media and flocculator center wells, had final effluent SS concentrations of about 20 mg/l when operating in the TF mode.[14]

MLSS Concentration

The effect of MLSS concentration on effluent quality was not as dramatic as expected based on activated sludge research by

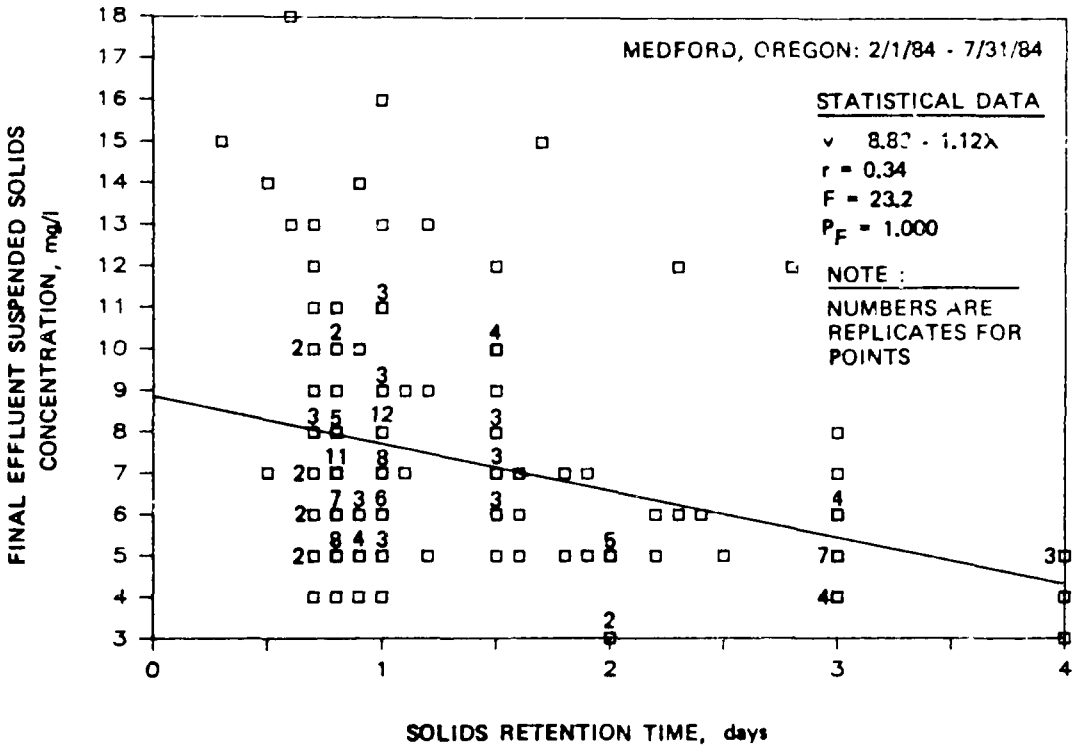


FIGURE 19. EFFECT OF SOLIDS RESIDENCE TIME ON FINAL EFFLUENT SUSPENDED SOLIDS AT MEDFORD, OREGON

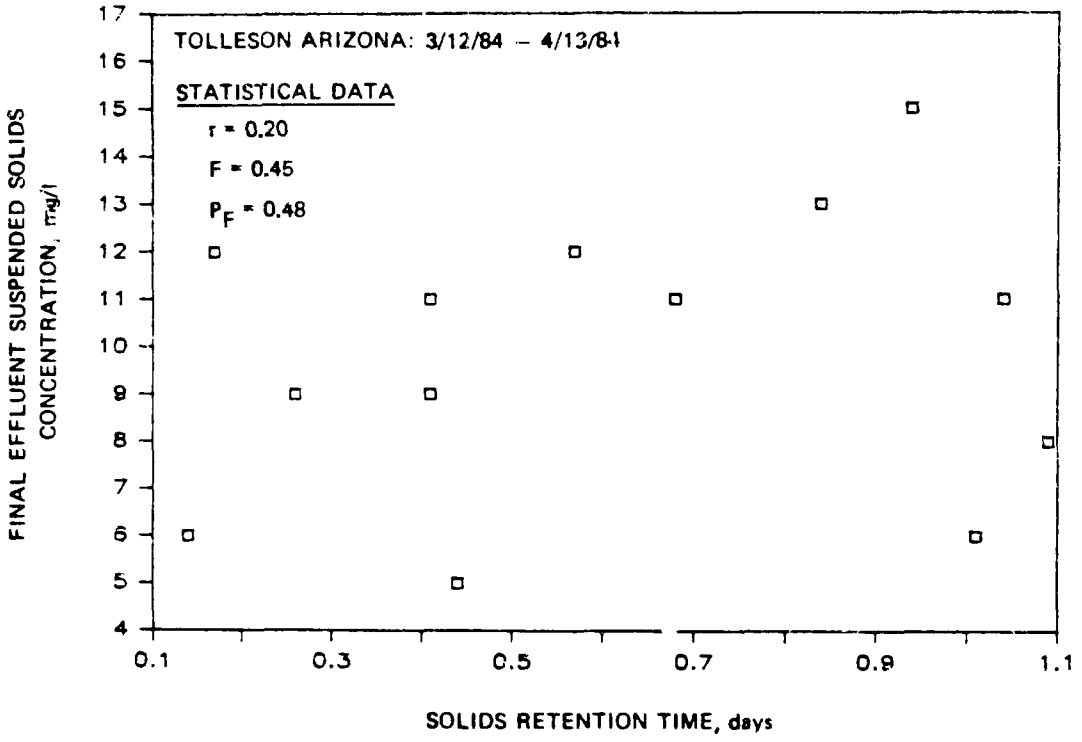


FIGURE 20. EFFECT OF SOLIDS RETENTION TIME ON FINAL EFFLUENT SUSPENDED SOLIDS AT TOLLESON, ARIZONA

Tuntoolavest, et al.,[17] and other researchers. No significant effect was measured at Medford or Tolleson, although the Tolleson data are limited. Corvallis final effluent SS increased slightly with increases in mixed liquor levels (Figure 21). Results from studies performed at Corvallis in 1980 by Norris, et al.,[14] are also presented on Figure 21. The earlier results showed significant increases in final effluent SS when mixed liquor levels were increased above 1,500 mg/l. Results from this project indicate only slight increases in final effluent SS occur.

Sludge Volume Index

Results in Table 17 indicate SVI had a significant effect on effluent quality at Medford, but not at Corvallis or Tolleson. Figure 22 shows the relationship between SVI and final effluent SS at Medford. Based on the relative distribution of detention times shown in Table 16, Medford's center well is much smaller than those at Corvallis or Tolleson. Higher SVIs at Medford may be needed to decrease the settling velocity of the solids and improve the opportunity for contact flocculation in the center well. SVI may not be critical at Corvallis or Tolleson because adequate flocculation is being provided in the large flocculator center wells.

SOLIDS CONTACT TANK SOLUBLE BOD REMOVAL

Soluble BOD_5 removal rates in the aerated solids contact tank at different TF/SC plants was quantified by developing soluble carbonaceous BOD_5 profiles. At the Medford TF/SC plant, which had the longest contact time of the plants studied, soluble carbonaceous BOD_5 profiles were developed on five different days by taking measurements at eight different points. A typical profile is shown on Figure 23.

The general form of the rate equation used to model soluble BOD_5 data is shown in Equation 4:

$$\frac{dC}{dt} = -(K_T X_V)C^n \qquad (4)$$

where

C = soluble carbonaceous BOD_5 concentration, mg/l

t = contact time, minutes

K_T = reaction rate coefficient at temperature T for order n, units depend on n

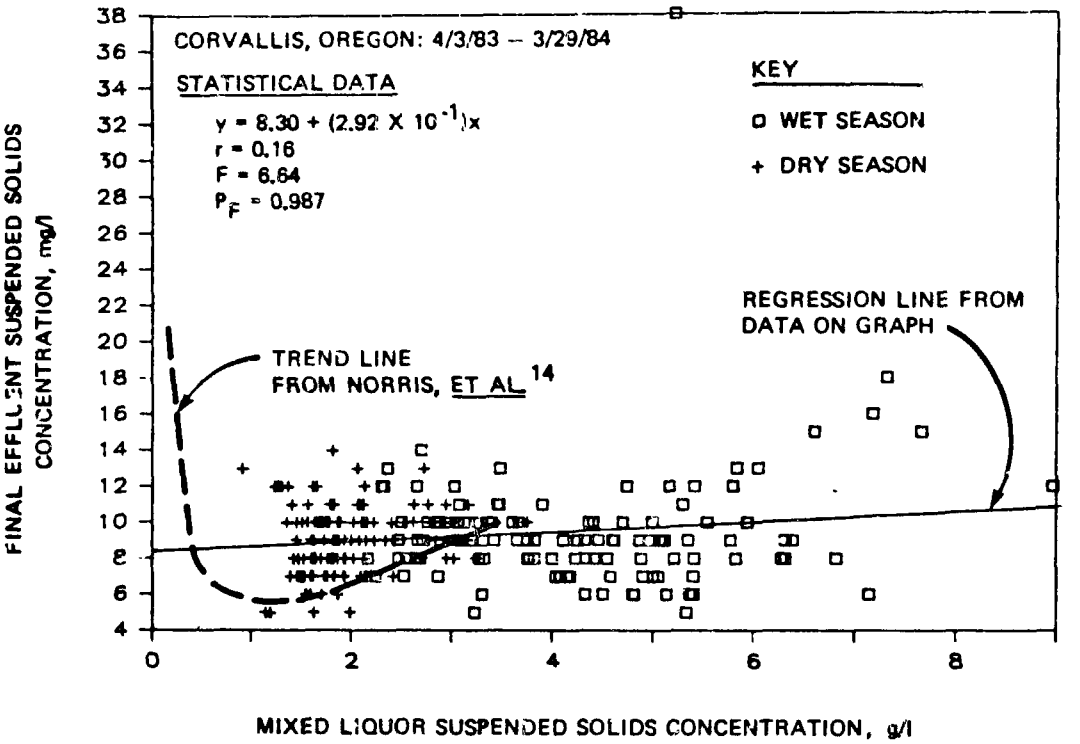


FIGURE 21. EFFECT OF MIXED LIQUOR SUSPENDED SOLIDS ON FINAL EFFLUENT SUSPENDED SOLIDS AT CORVALLIS, OREGON

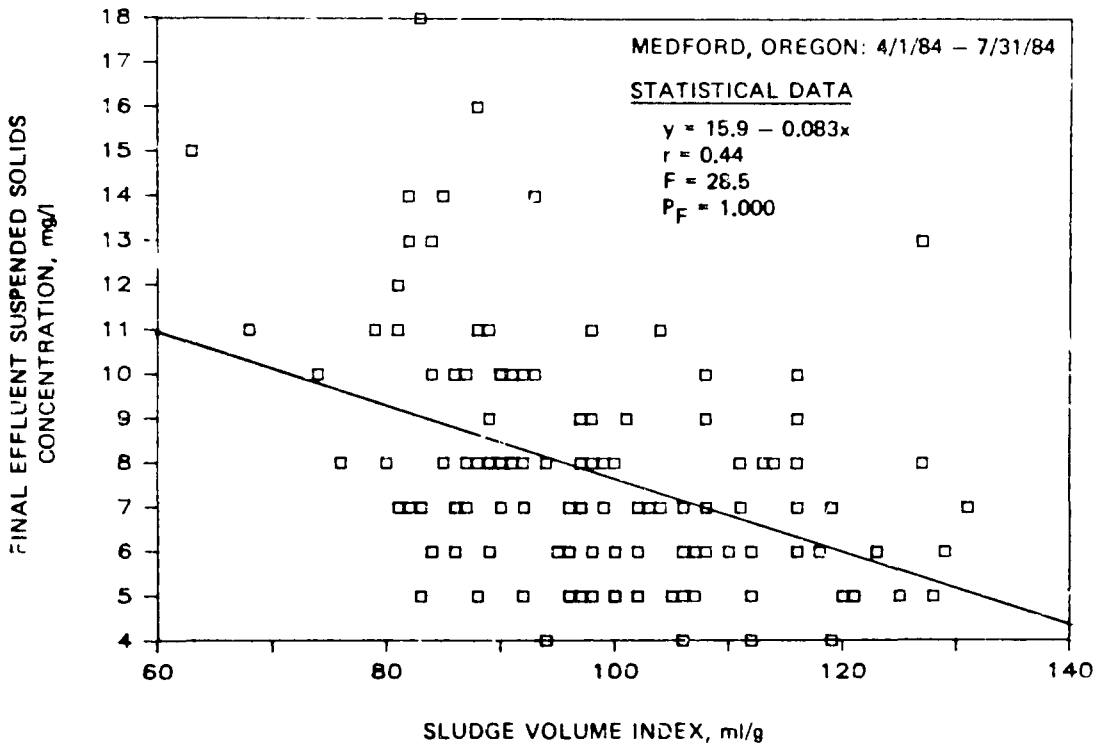


FIGURE 22. EFFECT OF SLUDGE VOLUME INDEX ON FINAL EFFLUENT SUSPENDED AT MEDFORD, OREGON

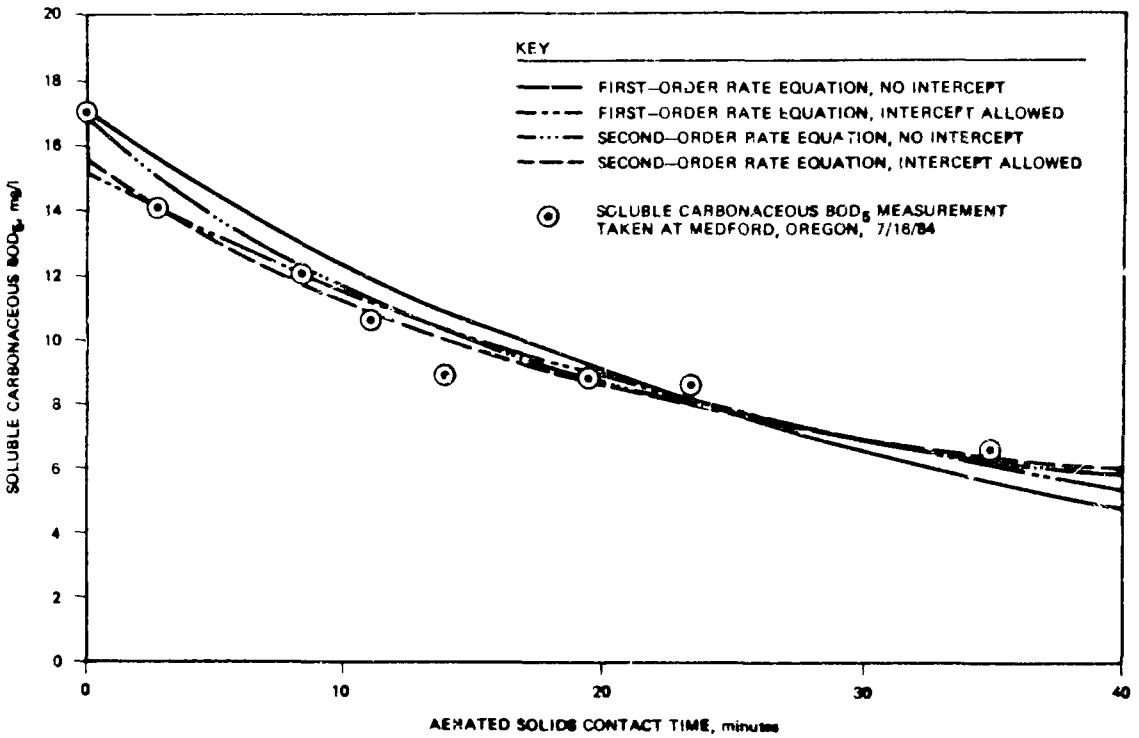


FIGURE 23. SOLUBLE BOD_5 PROFILE ALONG THE AERATED SOLIDS CONTACT TANK AT MEDFORD, OREGON

X_V = mixed liquor volatile SS concentration, mg/l

n = order of equation (n = 1 for first order, n = 2 for second order)

The linear forms of Equation 4 for first- and second-order models were fit to the data. For each of the two models, removal rate coefficients were developed with and without allowance of y-intercepts. As shown on Figure 23, each of the models fit the data well. The first- and second-order models with intercepts fit the data slightly better at the beginning of the channel than the models without intercepts because they account for the initial soluble BOD_5 uptake more accurately. However, after the first 10 minutes of contact time, the differences in predicted BOD_5 values for the different models were less than 1 mg/l. The four models were used to fit the data from each of the plant-scale and bench-scale soluble carbonaceous BOD_5 profiles, and in each case model choice made little difference. The first-order model describes the data adequately and is the simplest to apply.

Equation 4 for the first-order model can be expressed in a more convenient form for data analysis.

$$\ln \frac{C}{C_o} = [-K_{20} (\theta^{T-20}) X_V] t \qquad (5)$$

where

C_o = soluble carbonaceous BOD_5 of the mixed liquor at the beginning of the channel, mg/l

C = soluble carbonaceous BOD_5 after time t, mg/l

θ = temperature correction coefficient (assume θ = 1.035)

K_{20} = first-order reaction rate coefficient at 20 degrees C, l/mg-min

The slope of the best fit line for ln (C/C_o) plotted against t that passes through the origin is equal to the bracketed term in Equation 5. An example plot for the data collected at Medford is shown on Figure 24.

A summary of the plant-scale and bench-scale soluble BOD_5 profiles and first-order reaction rate coefficients measured at Medford is given in Table 18. Bench-scale profiles were developed to see if a small-scale, simple test could be used to model the full-scale aerated solids contact tank. The data used to develop the removal rate coefficients are given in Table D1.

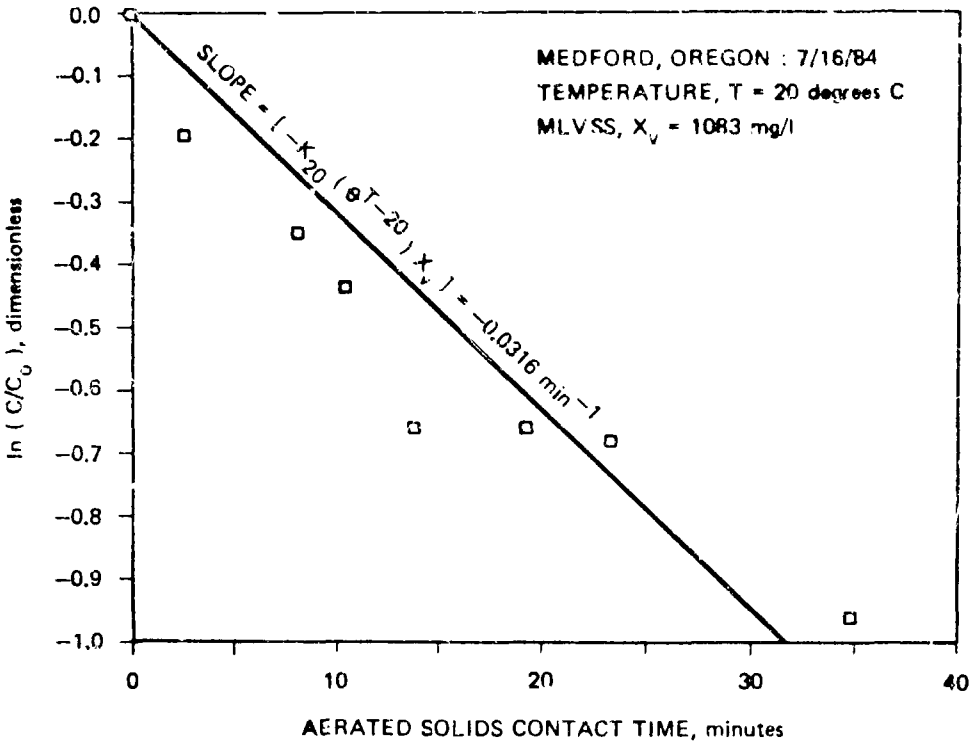


FIGURE 24. LINEAR PLOT OF SOLUBLE BOD PROFILE FOR FIRST-ORDER EQUATION AT MEDFORD, OREGON

TABLE 18. SUMMARY OF SOLUBLE BIOCHEMICAL OXYGEN DEMAND PROFILES ALONG THE MEDFORD, OREGON, SOLIDS TANK

Type of profile	Date	K20,[a] 1/mg-min	Mixed liquor volatile suspended solids, mg/l	SRT, days	Temperature, degrees C	Soluble carbonaceous BOD5, mg/l		
						Filter effluent	Beginning of contact channel	End of contact channel
Plant-scale	6/26/84	2.5×10^{-5}	1,376	0.8	21	13.2	9.3	2.5
	6/29/84	2.0×10^{-5}	1,170	0.9	18	12.0	7.5	3.0
	7/16/84	2.9×10^{-5}	1,083	0.8	20	26.0	17.0	6.5
	7/19/84	3.2×10^{-5}	940	0.8	21	7.1	5.7	2.3
	8/7/84	3.3×10^{-5}	1,066	0.7	22	31.0	21.5	5.4
Bench-scale	7/19/84	4.6×10^{-5}	810	0.8	20	17.0		2.8
	8/7/84	3.4×10^{-5}	869	0.7	20	14.4		4.2

[a]Based on first-order rate equation with best-fit line forced through origin.

It should be noted that the first soluble BOD_5 sample (sample point No. 1) was taken 8 ft downstream from the return sludge and TF influent mix point to ensure that uniform mixing had occurred. The aerated solids contact time for sample point No. 1 was assumed to be zero.

The Medford aerated solids contact channel typically removed 75 percent of the soluble carbonaceous BOD_5 in the TF effluent. The first-order reaction rate coefficients based on the plant-scale profiles ranged from 2.0×10^{-5} to 3.3×10^{-5} l/mg-min. The bench-scale reaction rate coefficients were slightly higher than the plant-scale coefficients. The probable reason is that in the bench-scale test, uniform mixing could be attained quickly so that the first sample could be collected before a significant portion of the initial BOD_5 uptake had occurred. Location 1 for the plant-scale profiles was as close as possible to the mix point of the filter effluent and return sludge; yet, soluble carbonaceous BOD data for the filter effluent and return sludge in Table 18 indicate some BOD uptake had already occurred. In four of the five profiles, soluble BOD at Location 1 was lower than predicted even when it was assumed that there was dilution of filter effluent with return sludge having a soluble BOD of zero.

It seems conceivable that the soluble BOD_5 reaction rate in the aerated solids contact tank could increase with TF effluent soluble BOD_5, since a higher filter effluent BOD_5 could indicate a larger fraction of more easily degradable organic matter. The Medford data indicated this trend may exist, although the data are limited and the trend line drawn was not statistically significant.

Soluble BOD_5 removal in the aerated solids contact tanks at Oconto Falls and Tolleson is limited because the TF effluent soluble BOD_5 concentrations are low. At Oconto Falls, the overall average soluble carbonaceous BOD_5 concentrations for the TF effluent and final effluent were 7 mg/l and 6 mg/l, respectively, for the field investigation (Table B1). At Tolleson where a two-stage TF system is used, the average soluble carbonaceous BOD_5 concentration in the second-stage filter effluent was only 1.6 mg/l.[11] Average aerated solids contact times of Oconto Falls and Tolleson are 8 and 13 minutes, respectively, which may also contribute to the low soluble BOD_5 removals.

In summary, soluble BOD_5 removal in the aerated solids contact tank can be modeled effectively with first-order reaction kinetics. The reaction rate coefficient may increase with TF effluent soluble BOD_5 concentration. Significant soluble BOD_5 removal will occur in the aerated solids contact tank only if TF effluent soluble BOD_5 concentrations are high enough (above 5 mg/l) and if sufficient contact time is provided.

AERATION RATE AND FLOCCULATION

The effect of aeration rate on flocculation was determined by varying aeration rate in sections of the aerated solids contact channel at Medford, Oregon, and developing supernatant SS profiles along the channel. Additional information on flocculation and clarifier performance was collected by measuring SS with settling (i.e., supernatant SS) and without settling, and sludge blanket depths at the Medford, Oconto Falls, and Chilton TF/SC plants.

The velocity gradient (G), which is a measure of mixing intensity, was estimated for each aeration rate at Medford, Oregon using the following equation:

$$G = \left[\frac{Q' \ w \ d}{v}\right]^{1/2} \qquad (6)$$

where

Q' = unit airflow rate, sec^{-1}

w = liquid specific weight, lb/cu ft

d = diffuser depth, ft

v = dynamic viscosity, lb-sec/sq ft

The velocity gradient was varied in the end of the aerated solids contact tank between locations E and H, a distance of 294 ft (see Figure 10 for locations). Supernatant SS concentrations decreased along the channel at high as well as low velocity gradients (Table 19). Based on replicate measurements at velocity gradients of 61 and 108 sec^{-1}, however, the decrease in supernatant SS at the lower mixing intensity was greater by a statistically significant margin.

The relatively large decrease in supernatant SS at the higher velocity gradient did not seem to agree with the work by Parker, et al.,[2] which suggested breakup rather than flocculation should occur at this mixing intensity. Velocity gradient was also varied in the middle of the aerated solids contact channel between C1 and D3 to see if the results at the end of the channel could be duplicated. Table 20 shows that breakup rather than flocculation predominated in the middle of the channel. The average increase in supernatant SS was 2.5 mg/l for the lower velocity gradient and 3.9 mg/l for the higher velocity gradient, although the difference is not statistically significant based on the three sets of data.

TABLE 19. EFFECT OF AERATION RATE ON FLOCCULATION IN THE END OF THE AERATED SOLIDS CONTACT TANK AT MEDFORD, OREGON

Date	Approximate velocity gradient, sec^{-1}	Supernatant SS at specified locations, mg/l				Supernatant SS changes,[a] mg/l
		E	F	G	H	
6/27/84	78	23.6	15.2	11.6	13.2	-10.4
	89	28.7	22.0	18.0	13.6	-15.1
6/28/84	98	14.8	16.4	9.6	10.8	-4.0
	107	21.0	13.6	14.0	12.0	-9.0
	119	20.0	15.0	12.4	12.1	-7.9
7/17/84 7/20/84	61	19.6[b]	15.0[b]	13.8[b]	11.4[b]	-8.2
7/17/84 7/19/84	108	18.5[b]	15.2[b]	14.4[b]	12.6[b]	-5.9

[a]Supernatant SS at H minus value at E.

[b]Supernatant SS values are averages based on seven separate measurements.

TABLE 20. EFFECT OF AERATION RATE ON FLOCCULATION IN THE MIDDLE OF THE AERATED SOLIDS CONTACT TANK AT MEDFORD, OREGON

Date	Approximate velocity gradient, sec^{-1}	Supernatant SS at specified locations,[a] mg/l				Supernatant SS change,[b] mg/l
		C1	C2	D2	D3	
7/8/84	52	19.8	20.3	21.2	22.3	+2.5
7/8/84	117	18.9	18.7	23.3	22.8	+3.9

[a]Supernatant SS values are averages based on three separate measurements.
[b]Supernatant SS at D3 minus value at C1.

Supernatant SS profiles along the entire aerated solids contact channel (Table 21) explain the apparent discrepancy between supernatant SS profiles at the end and in the middle of the channel. Supernatant SS always increased between sample locations D3 and E because of high turbulence at a free fall in this section of the channel. Since the free fall and concurrent breakup immediately preceded location E, flocculation rather than breakup predominated even under relatively high velocity gradients. Average supernatant SS values in Table 21 show the majority of the flocculation occurs in the beginning of the channel (between A and C1) during the first 10 minutes of aerated solids contact time. Decreases in supernatant SS between locations E and H just compensate for the increase in supernatant SS between D3 and E. These results underscore the need to minimize high turbulence in the aerated solids contact channel.

Flocculation profiles along the aerated solids contact tanks were also developed during the Chilton and Oconto Falls field investigations (Tables E-4 and B-5). Use of Kemmerer samplers to measure supernatant SS is a new technique. The results from Chilton and Oconto Falls are questionable, since the mixed liquor level in the sampler was not lowered below the upper cross support (see Figure 9) at the start of the sedimentation period. Consequently, settled solids could rest on top of the cross support and contaminate the supernatant when the sample was withdrawn.

Rapid decreases in supernatant SS were also noted by Norris, et al.,[14] in the beginning of the aerated solids contact channel at Corvallis, Oregon. At this plant, supernatant SS decreased by an average of about 40 percent in the first 3.2 minutes of aerated solids contact time. The results from Corvallis and Medford suggest that only about 12 minutes of aerated solids contact time is needed for efficient SS removal. At Medford, the additional aerated solids contact time is not wasted since it maintains the solids in an aerobic state and provides for additional soluble BOD_5 removal. At Corvallis, the biological solids are maintained in an aerobic state through the use of return sludge aeration.

Flocculation in the aerated solids contact tank and flocculator center well can be explained with Figure 25. The relationship between velocity gradient, flocculation time, and supernatant SS reduction was derived theoretically and confirmed experimentally with bench-scale flocculation experiments on activated sludge from a pilot plant.[2] A rapid decrease in supernatant SS occurs when the biological solids enter the aerated solids contact tank near point I. As the biological solids travel down the aerated solids contact tank, the rate of improvement (supernatant SS decrease) decreases until the solids reach point II at the end of the tank. The biological solids

TABLE 21. FLOCCULATION PROFILES ALONG AERATED SOLIDS CONTACT TANK AT MEDFORD, OREGON

Date	Supernatant SS at specified locations, mg/l									Supernatant SS change,[a] mg/l			
	A	B	C1	D1	D3	E	F	G	H	Beginning	Middle	End	Whole channel
										A-C1	C1-D3	D3-H	A-H
6/26/84	16.7	22.5	16.3	19.2	16.0	23.2	12.6	14.4	13.2	-0.4	-0.3	-2.8	-3.5
6/29/84	23.0	23.6	(52.4)	(55.6)	18.8	22.4	22.0	16.0	18.0	(+29.4)	(-33.6)	-0.8	-5.[illegible]
7/19/84	26.4	16.5	12.8	11.6	13.2	14.8	12.8	12.4	12.8	-13.6	+0.4	-0.4	-13.6
7/20/84	19.5	11.6	10.8	14.4	14.0	20.8	14.3	12.8	14.0	-8.7	+3.2	0	-5.3
Average										-7.6[b]	+1.1[b]	-1.0	-6.9

[a]Supernatant SS at upstream sampling point minus value at downstream point.
[b]Average excludes data from 6/29/84.

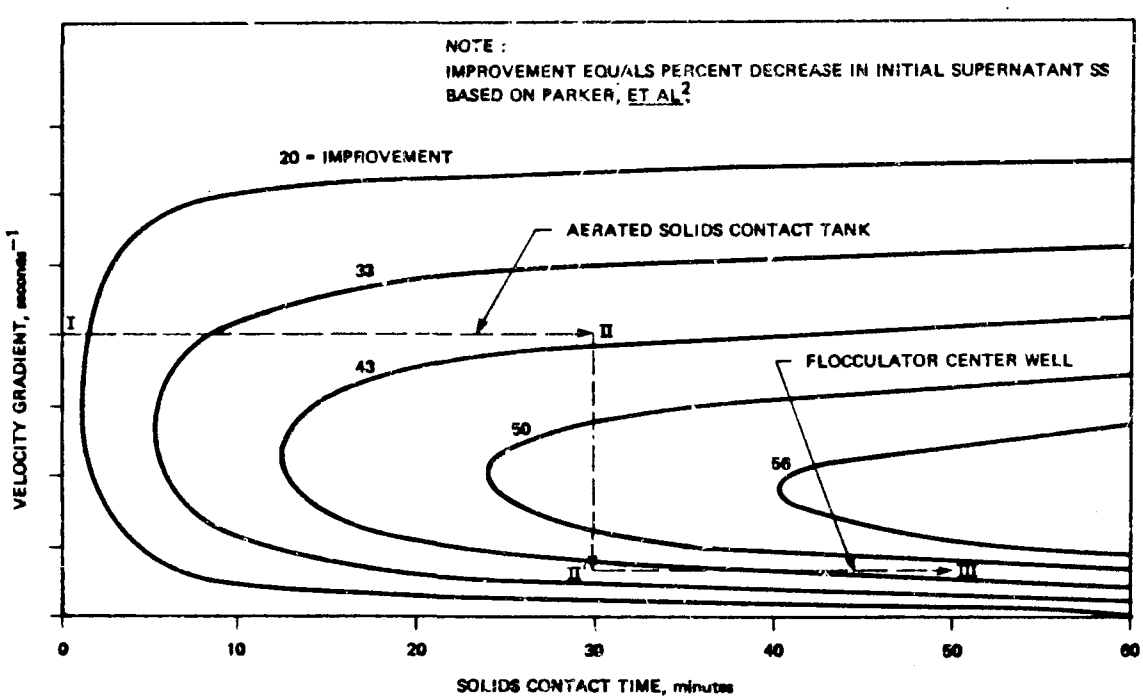


FIGURE 25. SCHEMATIC OF FLOCCULATION IN AERATED SOLIDS CONTACT TANK AND FLOCCULATOR CENTER WELL

then enter the flocculator center well (point II') where the velocity gradient is low. Further reductions in supernatant SS occur as biological solids move through the flocculator center well into the bottom of the clarifier (point III).

Secondary clarifier performance at Chilton, Oconto Falls, and Medford was evaluated by collecting supernatant SS measurements in the center wells and total suspended solids (TSS) measurements outside of the center wells. Results from the Chilton and Oconto Falls field investigations are summarized in Table 22. Supernatant SS values decreased with depth in the flocculator center well at Chilton indicating flocculation is occurring. At Oconto Falls, however, supernatant SS increased with depth, probably because the mechanical mixers in the flocculator center well are operating at a high speed and causing breakup. Although the Medford center well is only moderately sized, supernatant SS (Table 23) decreased an average of 6 mg/l between the top (location I) and bottom (location J3) of the center well.

SS were measured at various depths below the effluent launders at Chilton and Oconto Falls to provide some indication of the effect of clarifier depth on effluent quality. In all cases, the average SS increased with depth. At Medford, average SS values for samples taken just above the sludge removal draft tubes (locations K and L) were higher than for samples near the effluent launders (locations M and N), but still relatively low considering their proximity to the sludge blanket. The low SS values at K and L may be due to the low overflow rate used at Medford.

Secondary clarifier sludge blanket profiles were also developed for the Chilton, Medford, and Oconto Falls TF/SC plants. Profiles are summarized in Table 24 and show that the TF/SC plants studied operate with a minimal sludge blanket. Average sludge blanket depths ranged from 0 ft to 1.4 ft but generally lie between 0.5 ft and 1.0 ft. Low sludge blankets are maintained because an effort is made to remove the biological solids from the anoxic or anaerobic environment at the clarifier bottom and to avoid denitrification. Maintaining the solids in an aerobic state helps maintain their flocculating characteristics.

SECONDARY CLARIFIER OVERFLOW RATE

The effect of secondary clarifier overflow rate on final effluent quality was determined by comparing average daily overflow rates with final effluent SS at Corvallis and Tolleson. Figure 26 shows that overflow rate did not have a significant effect on final effluent SS at Corvallis. The Corvallis

TABLE 22. SECONDARY CLARIFIER PERFORMANCE AT CHILTON AND OCONTO FALLS, WISCONSIN

Treatment plant	Supernatant SS with floc well depth, mg/l		Suspended solids with depth below effluent launder		
	3 ft	12 ft	4 ft	8 ft	12 ft
Chilton					
Phase 1	21	14	15	21	35
Phase 2	19	8	4	12	12
Phase 3	50	34	11	14	17
Overall average	30	18	12	17	25
Oconto Falls					
Phase 1	23	32	7	13	30
Phase 2	24	23	9	11	169
Phase 3	13	28	5	5	7
Phase 4	30	31	12	18	94
Overall average	21	28	8	11	78

Note: Supernatant SS and suspended solids values are phase or overall averages for field investigations. See Appendix E and D for individual values.

TABLE 23. SECONDARY CLARIFIER PERFORMANCE AT MEDFORD, OREGON

Sample collection dates	Supernatant SS in flocwell, mg/l				Suspended solids at various locations, mg/l			
	I	J1	J2	J3	K	L	M	N
6/26/84 to 7/20/84	13.2	14.7	-	-	12.3	35.0	9.4	6.6
8/6/84 to 8/9/84	25.3	23.9	17.4	19.4	-	15.2	6.6	

Note: Supernatant SS and suspended solids values are averages for the different collection dates. See Appendix D for individual values and Figure 10 for sample locations.

TABLE 24. SLUDGE BLANKET DEPTHS AT TF/SC PLANTS

Treatment plant	Average sludge blanket depth, ft			
	Inside floc well	Outside floc well	At scum baffle	At outside wall
Chilton				
Phase 1	0.2	0.2	0.0	0.2
Phase 2	0.8	0.9	0.9	1.0
Phase 3	0.7	0.9	1.0	0.9
Overall average	0.5	0.6	0.6	0.6
Medford				
Overall average	0.8	0.88	1.3	1.4
Oconto Falls				
Phase 1	1.1	1.1	1.5	1.3
Phase 2	0.8	1.0	1.3	1.0
Phase 3	0.1	0.1	0.1	0.2
Phase 4	0.5	0.5	0.7	0.6
Overall average	0.6	0.7	0.9	0.7

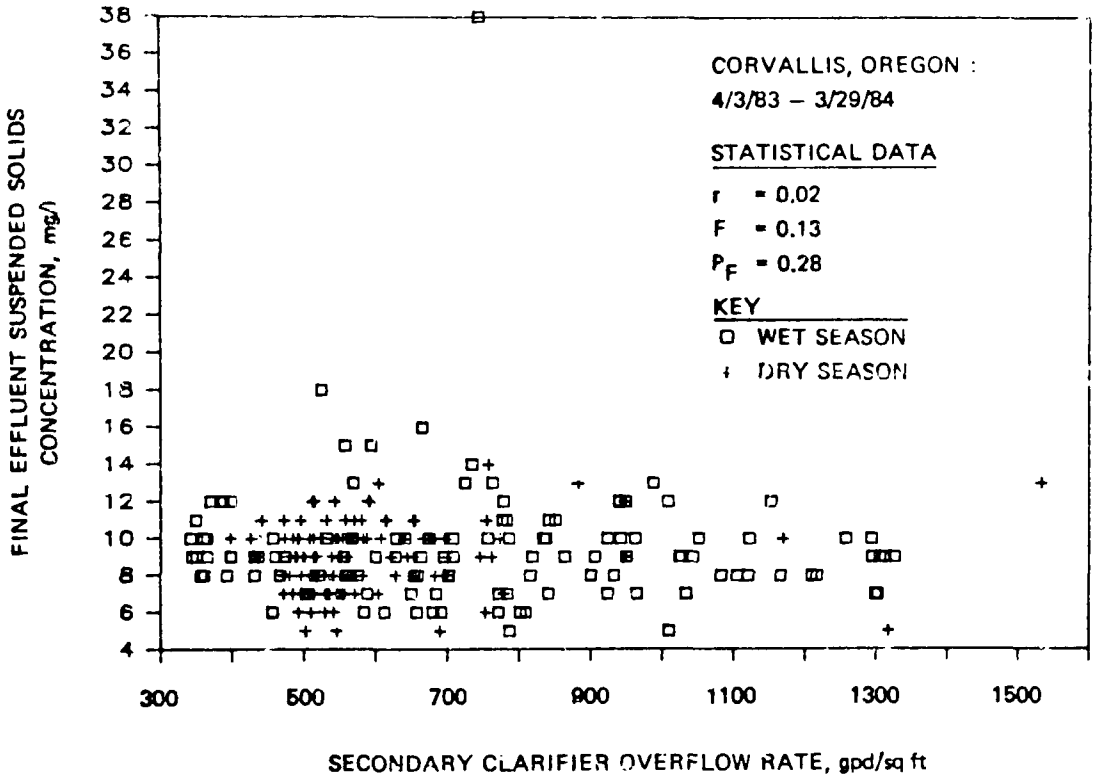


FIGURE 26. EFFECT OF SECONDARY CLARIFIER OVERFLOW RATE ON FINAL EFFLUENT SUSPENDED SOLIDS AT CORVALLIS, OREGON

TF/SC plant produced an effluent that was consistently low in final effluent SS over a wide range in overflow rates. It is interesting to note that the Corvallis plant operations staff increases the MLSS concentration in the aerated solids contact tank from 2,000 mg/l to about 4,000 mg/l during the winter,[18] which is also the time when high overflow rates occur.

At the Tolleson TF/SC plant, full-scale studies were performed under another project[11] to determine the effect of increasing the average daily overflow rate from about 350 gpd/sq ft to about 600 gpd/sq ft. Table 25 and Figure 27 show that the overflow rate increase did not increase final effluent SS significantly. High final effluent SS concentrations (greater than 40 mg/l) were measured during some days at Tolleson as shown on Figure 27, although the monthly average SS values were usually less than 10 mg/l (Table A5). High final effluent SS at Tolleson have been caused by denitrification[11] and primary treatment failures as noted earlier in this report.

The results from Corvallis and Tolleson TF/SC plants on the effect of overflow rate on effluent quality generally do not agree with those reported in the literature.[17,19] The insensitivity to overflow rate is most likely due to the flocculation features and other characteristics of the Corvallis and Tolleson secondary clarifiers. Both sets of clarifiers have flocculator center wells, inboard effluent launders, suction header sludge removal systems, and high sidewater depths.

The insensitivity of the clarifiers may also due in part to the conditioning of the mixed liquor solids in the aerated solids contact tank as well as in the flocculator center wells. Inboard launders avoid the carryover of solids from density currents along the walls of the clarifiers. Suction header sludge removal systems quickly remove settled solids from the secondary clarifiers so that carry-over of solids from denitrification is minimized and the settled solids are quickly returned to an aerobic environment. Higher sidewater depths increase clarifier detention time and provide a larger distance between the sludge blanket and effluent launders. Chapman[19] noted that deeper clarifiers are less sensitive to changes in overflow than shallow clarifiers.

COAGULANT ADDITION

SS and total phosphorus concentrations and removal efficiencies for the different field investigation phases at Oconto Falls are shown in Table 26. The effect of coagulant addition on TF/SC performance can be determined primarily by comparing results from Phase 1 (TF/SC with ferric chloride addition) and Phase 2 (TF/SC without ferric chloride addition).

TABLE 25. SUSPENDED SOLIDS REMOVAL AND SECONDARY CLARIFIER OPERATIONS SUMMARY FOR TOLLESON FULL-SCALE STUDIES

Parameter	Period 1[a]	Period 2[b]
Flow, mgd	6.8	6.7
Final clarifier overflow rate, gpd/sq ft		
Average	360	705
90th percentile of daily peaks	-	1,315[c]
Final clarifier solids loading rate, lb TSS/sq ft/day	7.8	13.2
Suspended solids, mg/l		
Primary effluent	62	133
First-stage filter effluent	64	67
Intermediate clarifier effluent	46	45
Second-stage filter effluent	44	45
Final effluent	11	9
Mixed liquor		
Suspended solids, mg/l	1,700	1,570
Volatile fraction, percent	80	84
Sludge volume index	124	108
Return activated sludge		
Suspended solids, mg/l	3,350	5,650
Flow, percent of influent flow	76	39

[a]March 1 through March 11, 1984.
[b]March 12 through April 12, 1984.
[c]March 12 through April 3, 1984.

Note: Results from Reference 11.

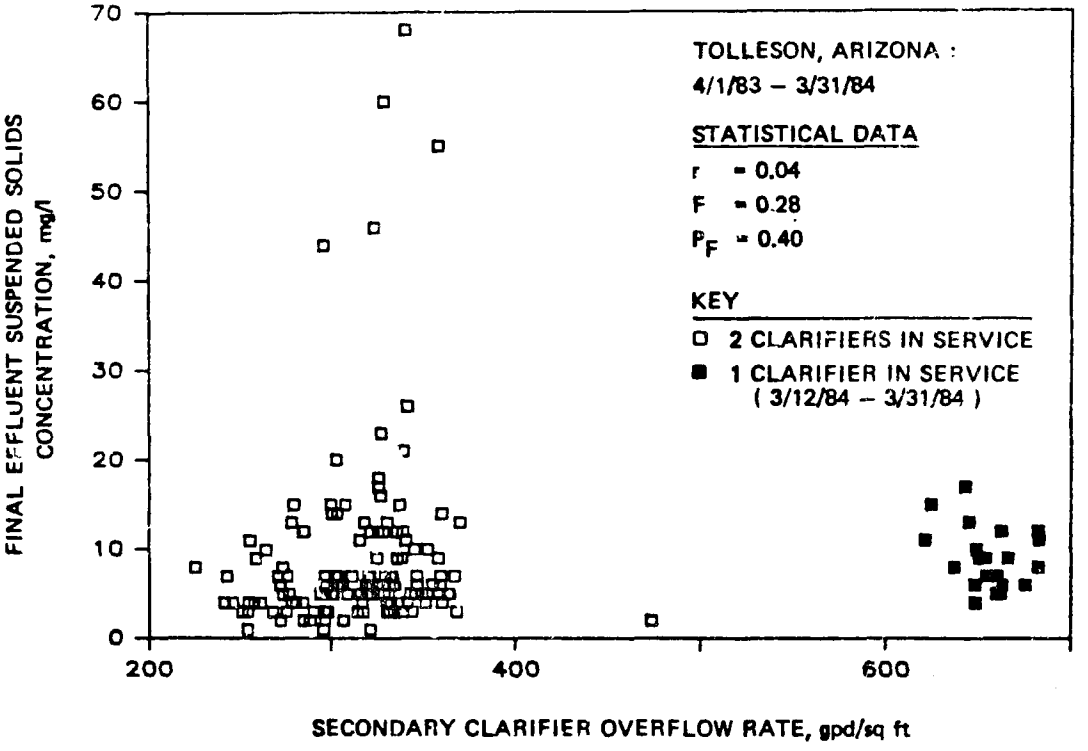


FIGURE 27. EFFECT OF SECONDARY CLARIFIER OVERFLOW RATE ON FINAL EFFLUENT SUSPENDED SOLIDS AT TOLLESON, ARIZONA

TABLE 26. EFFECT OF COAGULANT ADDITION ON SUSPENDED SOLIDS AND PHOSPHORUS CONCENTRATIONS AND REMOVALS AT OCONTO FALLS, WISCONSIN

Parameter[a]	Phase 1		Phase 2		Phase 3		Phase 4	
	Suspended solids	Total phosphorus	Suspended solids	Total phosphorus[b]	Suspended solids	Total phosphorus[b]	Suspended solids	Total phosphorus[b]
Concentration, mg/l								
Influent	136	3.69	191	4.03	238	6.15	152	4.64
Primary effluent	71	4.03	57	2.79	55	3.43	56	3.19
Trickling filter effluent	69	4.04	189	4.91	31	3.32	86	3.81
Secondary effluent	10	0.76	1.	1.65	11	2.82	18	2.71
Removal efficiency, percent								
Primary treatment	48	-9	70	31	77	44	63	31
Trickling filter	3	[illegible]	-232	-76	44	3	-54	-19
Solids contact tank and clarifier	86	81	93	66	65	15	79	29
Plant	93	79	91	59	95	54	88	42

[a]Phase averages for Oconto Falls field investigation.
[b]Total phosphorus concentrations expressed in mg/l as P.

Results from Phase 3 (TF process) and Phase 4 (TF/SC with one filter) are also useful since coagulant was also not added in these phases.

Increases and decreases in total phosphorus generally followed the same pattern as SS. For instance, SS in the TF effluent in Phases 2 and 4 were significantly higher than the primary effluent SS because of TF sloughing. Concurrent increases in total phosphorus concentrations, therefore, were also measured across the TF. Coagulant addition to the solids contact tank in Phase 1 produced higher combined total phosphorus removals in the solids contact tank and secondary clarifier and in the plant than in Phase 2 or in Phases 3 and 4.

It is difficult to determine the effect of coagulant addition on SS removal because of the effect that TF sloughing in Phase 2 had on the Phase 2 results. The combined SS removal efficiency for the solids contact tank and clarifier is slightly lower in Phase 1 than in Phase 2, although the SS concentration in the secondary effluent is lower in Phase 1. The Phase 2 removal efficiency is probably higher for the solids contact tank and clarifier because it is easier to attain a higher percent removal when the influent SS concentration is high. In conclusion, coagulant addition may improve SS removal, although the field investigation results do not provide firm support for this conclusion.

Coagulant addition could also conceivably affect the flocculant characteristics of the microorganisms in the mixed liquor. Since the coagulant is inorganic, the TF/SC process could require a higher MLSS concentration or larger aerated solids contact tank to attain an equivalent biological mass for effective flocculation. The field investigation data, however, do not support this hypothesis as the average MLSS concentration for Phase 1 (1,813 mg/l) was less than or equal to averages for Phase 2 (1,829 mg/l) or Phase 4 (2,425 mg/l), while secondary effluent SS were the lowest in Phase 1.

SUMMARY DISCUSSION

The TF/SC process is composed of a series of distinct but interdependent unit processes. The purpose of this section is to summarize the results from the special studies and to discuss their relationships to and implications on the overall performance of the TF/SC process. The TF/SC process, although related to some conventional processes, has some significant differences. Generally, the majority of the soluble BOD_5 removal occurs in the TF, while the suspended growth system (aerated solids contact tank) is used as a polishing unit to remove SS and its associated BOD_5. Some soluble BOD_5 is removed in the aerated solids contact tank if sufficient contact time is provided.

Based on the TF/SC plants studied in this project, TF BOD_5 loading rate does not exert a strong influence on final effluent quality when average loading is less than 40 ppd/1,000 cu ft. A more significant variable is SS concentration entering and leaving the TF. TF influent and effluent SS were correlated with final effluent SS. One does not know whether fine solids in the primary effluent are passing through the system or whether their characteristics are changed. In either case, they seem to produce some adverse effect, although not large, on the final effluent SS concentration.

The effect of media type on TF/SC performance seems to be significant. Microscopic examinations showed that TF solids formed in rock media filters tend to be more compact and less diffuse than those formed in plastic media filters. This statement, however, is based on limited data and requires further study. The implication is that TF effluent solids from a rock media filter may be easier to flocculate and require less aerated solids contact time than solids formed in plastic media filters. SRT, which is related to the size of the aerated solids contact tank, did not exert a significant influence on the performance of TF/SC plants with rock media filters preceding the aerated solids contact tank. Some effect was noted, however, for the one treatment plant studied with a plastic media filter preceding the aerated solids contact tank. One other difference between rock and plastic media noted in this project was that rock media had higher soluble BOD_5 removal rate coefficients in the TF than plastic media. The oxygen transferred per unit of media surface and hydraulic residence time may be higher for rock media than plastic media.

MLSS concentration and SVI generally did not exert a strong influence on final effluent quality. The implication is that the aerated solids contact system can be operated over a wider range of mixed liquor levels than originally believed based on earlier work at Corvallis, Oregon. SVI exerted a significant influence on final effluent quality at one treatment plant, probably because this plant lacked a large flocculator center well.

Results from project work in Medford and earlier work at Corvallis show that the majority of the SS flocculation in the aerated solids contact tank occurs within the first 12 minutes of contact time. This result does not imply that in all cases only 12 minutes of aerated solids contact time is required. If soluble BOD_5 removal is needed in the aerated solids contact tank, more than 10 minutes of contact time must be provided. Sufficient attention must also be paid to ensure the biological solids are maintained in an aerobic state by providing additional aerated solids contact time or return sludge aeration. Results from studies at Medford show the aerated solids contact tank can remove a significant fraction of filter effluent soluble BOD_5

and that removal is adequately described by first-order reaction kinetics. Soluble BOD_5 removal in the contact tank may be a function of TF effluent quality.

Secondary clarifiers employed at the TF/SC plants were relatively insensitive to changes in average daily overflow rate. Final effluent SS concentrations remained consistent over a wide range in overflow rates. This consistent performance is probably due to a number of clarifier features including high sidewater depths, inboard effluent launders, rapid sludge removal mechanisms, and flocculator center wells; and to maintenance of a low sludge blanket. Coagulant addition for phosphorus removal, required in some regions, did not adversely affect TF/SC operation.

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APPENDIX A

TREATMENT PLANT OPERATIONS DATA

TABLE A1 - CORVALLIS PLANT OPERATIONS DATA

Parameter	Month												High	Low	Average
	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar			
Influent Flow															
Average, mgd	12.24	7.40	7.30	6.15	6.18	5.71	5.55	15.24	17.90	13.39	16.60	12.68	17.90	5.55	10.53
Influent Characteristics															
BOD, mg/l	90	140	128	112	123	141	188	100	48	70	79	70	188	48	100
Suspended solids, mg/l	149	186	173	188	155	172	191	134	112	124	125	135	191	112	154
pH	6.8	7.4	7.3	7.2	7.4	7.4	7.3	7.0	6.8	6.9	6.9	6.8	7.4	6.8	7.1
Temperature, °C	15	18	20	20	22	22	21	17	14	14	13	13	22	13	17
Primary Effluent															
BOD, mg/l	66	90	87	78	72	94	114	56	35	49	56	48	114	35	70
Suspended solids, mg/l	75	82	74	68	63	68	66	56	58	56	64	64	82	56	66
Trickling Filter Effluent															
BOD, mg/l	25	34	32	28	29	39	38	33	26	26	22	22	39	22	30
SBOD, mg/l	6	5	6	5	5	8	8	6	4	4	3	3	8	3	5
Suspended solids, mg/l	63	72	61	60	57	59	56	55	59	54	59	58	72	54	59
Return Secondary Sludge															
Suspended solids, mg/l	13,075	8,091	8,100	6,345	5,437	5,415	10,293	13,703	16,139	17,190	16,523	15,352	17,15[illegible]	5,415	11,312
Mixed Liquor															
Suspended solids, mg/l	3,110	2,150	1,940	1,768	1,557	1,675	2,948	3,571	4,2[illegible]8	4,777	4,852	4,982	4,982	1,557	3,127
Secondary Effluent															
Suspended solids, mg/l	10	12	10	11	10	13	12	10	10	9	13	9	13	9	11
Effluent Characteristics															
BOD, mg/l	5	8	7	7	5	9	8	7	6	7	6	6	9	5	7
CBOD, mg/l	4	6	5	5	5	7	6	5	5	5	4	4	7	4	5
Suspended solids, mg/l	9	10	9	9	7	10	10	9	9	9	13	9	13	7	9
pH	6.9	6.8	6.7	7.0	7.0	7.0	7.1	6.9	6.8	6.8	6.8	6.7	7.1	6.7	6.9

NOTE: -Data reported from April 1983 thru March 1984.
-BOD = Five-day total BOD.
-SBOD = Soluble BOD.
-CBOD = Carbonaceous BOD.

TABLE A2 - MEDFORD PLANT OPERATIONS DATA

Parameter	Month							High	Low	Average
	Jan	Feb	Mar	Apr	May	June	July			
Influent Flow										
Average, mgd	10.00	11.90	9.90	9.90	8.20	8.30	9.00	9.90	8.20	8.95
Influent Characteristics										
BOD, mg/l	132	112	135	142	153	173	159	173	142	157
Suspended solids, mg/l	113	100	112	119	135	159	138	159	119	138
pH	7.4	7.3	7.3	7.4	7.4	7.3	7.2	7.4	7.2	7.3
Temperature, ^{o}C	13	13	15	16	18	19	22	22	16	19
Primary Effluent										
BOD, mg/l	66	62	66	76	82	90	76	90	76	81
Suspended solids, mg/l	35	35	38	32	38	38	29	38	29	34
Ammonia, mg/l	26	25	27	28	30	28	20	30	20	26
Trickling Filter Effluent										
BOD, mg/l	53	64	83	67	81	65	51	81	51	66
Suspended solids, mg/l	46	70	99	66	89	89	39	89	39	71
Ammonia, mg/l	21	20	19	16	17.1	15.7	12	17.1	12	15.20
Return Secondary Sludge										
Suspended solids, mg/l	6,000	6,000	7,400	6,700	6,300	5,800	5,827	6,700	5,800	6,157
Mixed Liquor										
Suspended solids, mg/l	1,360	1,320	1,529	1,622	1,868	1,496	1,475	1,868	1,475	1,615
Effluent Characteristics										
BOD, mg/l	13	18	17	14	22	23	16	23	14	19
CBOD, mg/l	3	7	10	6	8	11	6	11	6	8
Suspended solids, mg/l	3	15	8	7	9	9	6	9	6	8
Ammonia, mg/l	7	13	15	15.2	16.1	14.5	9.7	16.1	9.7	13.9
pH	7.1	7.2	7.2	7.3	7.3	7.2	7.2	7.3	7.2	7.3

NOTE: -Data reported from January thru July 1984.
-Plant in trickling filter/activated sludge (TF/AS) mode up to March 20, 1984, then changed to trickling filter/solids contact (TF/SC) mode.
-High, Low, and Average results based on April thru July data only.
-BOD = Five-day Total BOD.
-CBOD = Carbonaceous BOD.

TABLE A3 - NORCO PLANT OPERATIONS DATA

Parameter	Month												High	Low	Average
	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar			
Influent Flow															
Average, mgd	0.468	0.473	0.494	0.488	0.528	0.567	0.509	0.516	0.456	0.482	0.446	0.455	0.567	0.446	0.491
Influent Characteristics															
BOD, mg/l	324	309	343	379	321	319	298	297	260	232	360	309	379	232	317
Suspended solids, mg/l	366	344	391	357	319	314	293	317	322	335	412	452	452	293	352
Return Secondary Sludge							*	**							
Suspended solids, mg/l	13,331	14,340	10,777	14,421	10,630	3,237	491	15,661	17,722	20,856	18,469	16,072	20,856	491	13,001
Mixed Liquor							*	**							
Suspended solids, mg/l	1,370	1,554	1,281	1,423	948	444	109	1,873	2,061	2,021	1,505	1,332	2,061	109	1,327
Effluent Characteristics															
BOD, mg/l	15	16	19	17	21	29	32	29	22	20	19	20	32	16	22
Suspended solids, mg/l	6	10	13	7	9	15	19	17	16	18	15	15	19	6	13
Ammonia, mg/l	11.99	12.18	13.16	13.2	13.51	11.84	12.46	18	21.4	20.7	22.19	22.77	22.77	11.84	16.12
pH	7.6	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.6	7.7	7.6	7.5	7.7	7.5	7.7

NOTE: -Data reported from April 1983 thru March 1984.
-BOD = Five-day total BOD.
* = Aeration tank taken out of service; results based on four days of operation.
** = Results based on seven days of operation.
Effluent characteristics are after tertiary filtration.

TABLE 44 - OCONTO FALLS PLANT OPERATIONS DATA

Parameter	Month												High	Low	Average
	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar			
Influent Flow															
Average, mgd	0.433	0.463	0.368	0.320	0.280	0.331	0.370	0.325	0.320	0.338	0.407	0.388	0.463	0.280	0.358
Influent Characteristics															
BOD, mg/l	121	119	142	142	165	147	125	150	179	179	154	133	179	119	146
Suspended solids, mg/l	103	107	111	115	128	110	100	118	151	142	123	108	151	100	118
Temperature, ^{o}C	9.8	107	13.3	17.2	17.8	19.4	17.2	14.7	11.9	9.6	8.9	8.2	19.4	8.2	13.2
Effluent Characteristics															
BOD, mg/l	21.3	18.9	17.1	16.8	14.2	17.3	16.0	16.6	25.0	30.6	23.2	31.7	31.7	14.2	20.9
Suspended solids, mg/l	15.7	17.8	11.9	3.0	6.1	8.0	9.0	10.4	13.2	16.3	13.7	22.6	22.6	6.1	12.8
pH	7.5	7.4	7.3	7.3	7.2	7.3	7.4	7.3	7.4	7.2	7.3	7.4	7.5	7.2	7.3

NOTE: -Data reported from April 1983 thru March 1984.
-BOD = Five-day total BOD.

TABLE 85 - TOLLESON PLANT OPERATIONS DATA

Parameter	Month												High	Low	Average
	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar			
Influent Flow															
Average, mgd	6.34	6.20	5.68	5.01	5.27	5.87	6.23	6.44	6.29	6.74	6.28	6.28	6.74	5.01	6.05
Influent Characteristics															
BOD, mg/l	284	350	271	248	222	247	245	277	320	315	316	224	350	222	277
Suspended solids, mg/l	192	254	229	223	204	213	202	216	193	208	255	300	300	192	224
pH	7.2	7.2	7.2	7.1	7.0	6.8	6.6	6.8	7.1	6.9	6.8	6.6	7.2	6.6	6.9
Primary Effluent															
BOD, mg/l	182	373	142	178	149	136	107	207	175	161	147	115	373	107	173
Suspended solids, mg/l	82	400	67	153	79	57	59	234	63	70	79	106	400	57	121
Intermediate Clarifier Effluent															
BOD, mg/l	24.0	38.9	18.3	24.6	12.1	10.4	14.1	27.3	16.5	25.4	42.5	19.9	42.5	10.4	22.8
Suspended solids, mg/l	10.4	29.4	21.3	36.0	15.8	9.9	11.9	45.9	15.6	25.5	26.0	36.0	45.9	9.9	23.6
Mixed Liquor															
Suspended solids, mg/l	1,120	1,621	1,133	937	848	571	551	979	931	1,020	1,327	1,466	1,621	551	1,042
Effluent Characteristics															
BOD, mg/l	6.7	15.4	6.4	5.9	4.6	3.5	4.3	9.4	5.8	9.9	8.6	5.3	15.4	3.5	7.2
Suspended solids, mg/l	4.3	11.6	7.2	7.5	5.4	4.0	4.5	20.2	6.6	11.1	9.1	11.0	20.2	4.0	8.5

NOTE: -Data reported from April 1982 thru March 1984.
-BOD = Five-day total BOD.

APPENDIX B

OCONTO FALLS FIELD INVESTIGATION DATA

TABLE B1 OCONTO FALLS FLOW AND BOD DATA continued.

Date	Flow, mgd				Total 5-day BOD, mg/l					Soluble 5-day BOD, mg/l					Carbonaceous 5-day BOD, mg/l			Sol. Carb. 5-day BOD, mg/l		
	Infl.	Filter Recyc.	S.C. Recyc.	Sec. Waste	Raw Infl.	Prim. Effl.	T.F. Effl.	Sec. Effl.	Final Effl.	Raw Infl.	Prim. Effl.	T.F. Effl.	Sec. Effl.	Final Effl.	T.F. Effl.	Sec. Effl.	Final Effl.	T.F. Effl.	Sec. Effl.	Final Effl.
02-Jul-84	0.378	0.604	0.188	0.0087																
03-Jul-84	0.355	0.637	0.188	0.0037	127	78	72	25	20	63	34	12.0	8.2	8.6	42	14.0	15.0	8.6	6.6	8.6
04-Jul-84	0.293	0.605	0.169	0.0037																
05-Jul-84	0.337	0.614	0.179		90	84	71	22	14	40	27	10.0	5.7	6.3	54	13.0	10.0	7.0	4.3	5.5
06-Jul-84	0.341	0.619	0.179																	
07-Jul-84	0.320	0.637	0.287	0.0032																
08-Jul-84	0.295	0.601	0.229	0.0049	112	61	20	24	16	38	22	8.2	4.4	5.4	27	9.5	9.1	8.5	3.6	6.6
09-Jul-84	0.357	0.626	0.230	0.0017																
10-Jul-84	0.433	0.601	0.251	0.0019	310	79	38	29	19	39	17	8.1	4.3	5.9	25	13.0	12.0	7.6	3.2	4.0
11-Jul-84	0.385	0.172	0.079	0.0668																
PHASE III																				
11-Jul-84																				
12-Jul-84	0.380		0.000	0.0097	134	45	18	14	19	43	18	9.9	7.5	9.0	18	13.0	18.0	8.6	7.1	7.9
13-Jul-84	0.391	0.589	0.000	0.0991																
14-Jul-84	0.388	0.511	0.000	0.0025																
15-Jul-84	0.342	0.415	0.000	0.0015	82	40	18	16	11	22	16	7.0	4.3	6.7	12	8.9	11.0	7.1	4.1	5.1
16-Jul-84	0.401	0.536	0.000	0.0901																
17-Jul-84	0.326	0.547	0.000	0.0995																
18-Jul-84	0.324	0.562	0.000	0.0075	165	70	38	25	12	35	30	12.0	6.0	9.4	31	14.0	14.0	8.4	6.4	7.5
19-Jul-84	0.310	0.554	0.000	0.1041	117	52	32	25	12	23	25	6.2	4.3	5.7	17	9.4	8.7	6.3	3.2	6.0
20-Jul-84	0.314	0.578	0.000	0.0936																
21-Jul-84	0.274	0.531	0.000	0.0020																
22-Jul-84	0.284	0.509	0.000	0.0730																
23-Jul-84	0.342	0.562	0.000	0.0068	142	54	46	15	10	42	21	8.0	8.7	6.2	20	10.0	11.0	6.1	6.4	4.4
24-Jul-84	0.299	0.550	0.000	0.0955	156	62	37	17	18	40	33	11.0	5.1	6.2	15	8.9	9.6	8.2	4.3	5.5
25-Jul-84	0.288	0.545	0.000	0.0042																
26-Jul-84	0.339	0.541	0.000	0.0080	203	64	44	31	20	44	29	8.0	6.0	7.7	20	12.0	12.0	6.0	4.9	6.3
27-Jul-84	0.330	0.586	0.000	0.0921																
28-Jul-84	0.290	0.543	0.000	0.0016																
29-Jul-84	0.292	0.547	0.000	0.0780	190	43	44	14	12	98	17	5.9	4.0	5.7	15	6.0	8.4	4.2	2.9	5.6
30-Jul-84	0.324	0.564	0.000	0.0777																
31-Jul-84	0.305	0.563	0.000	0.0036	133	43	50	22	16	43	18	7.0	5.6	7.2	19	11.0	11.0	6.0	5.0	7.1
01-Aug-84	0.306	0.557	0.000	0.0037																
02-Aug-84	0.402	0.557	0.000	0.0908	200	64	57	36	27	40	30	8.3	6.2	9.5	46	12.0	16.0	6.9	5.0	6.4
03-Aug-84																				

continued.

TABLE B1 OCONTO FALLS FLOW AND BOD DATA continued.

Date	Flow, mgd				Total 5-day BOD, mg/l					Soluble 5-day BOD, mg/l					Carbonaceous 5-day BOD, mg/l			Sol. Carb. 5-day BOD, mg/l		
	Infl.	Filter Recyc.	S.C. Recyc.	Sec. Waste	Raw Infl.	Prim. Effl.	T.F. Effl.	Sec. Effl.	Final Effl.	Raw Infl.	Prim. Effl.	T.F. Effl.	Sec. Effl.	Final Effl.	T.F. Effl.	Sec. Effl.	Final Effl.	T.F. Effl.	Sec. Effl.	Final Effl.
PHASE IV																				
03-Aug-84	0.397	0.331	0.220	0.1010																
04-Aug-84	0.364	0.279	0.224																	
05-Aug-84	0.365	0.262	0.223		140	78	58	29	18	29	39	17.0	9.4	8.6	29	12.0	15.0	4.6	5.6	7.6
06-Aug-84	0.387	0.273	0.191	0.0020																
07-Aug-84	0.455	0.246	0.212	0.0019	151	62	40	39	31	29	22	10.0	9.2	10.0	32	16.0	17.0	9.2	5.6	7.0
08-Aug-84	0.509	0.183	0.279	0.0016																
09-Aug-84	0.437	0.177	0.241	0.0006	92	55	49	23	21	18	27	11.0	7.8	9.1	29	15.0	14.0	7.8	6.2	7.0
10-Aug-84	0.429	0.305	0.250	0.0043																
11-Aug-84	0.373	0.279	0.228	0.0036																
12-Aug-84	0.361	0.281	0.218	0.0027	109	43	59	38	19	44	29	9.4	6.9	6.9	29	9.8	13.0	7.0	4.1	6.7
13-Aug-84	0.386	0.277	0.221	0.0033																
14-Aug-84	0.370	0.277	0.217	0.0026	98	49	61	35	23	23	19	9.5	7.6	7.7	28	18.0	16.0	9.3	6.6	6.6
15-Aug-84	0.353	0.275	0.219	0.0026																
16-Aug-84	0.352	0.273	0.232	0.0026	145	54	92	21	21	20	30	13.0	9.0	12.0	61	20.0	21.0	10.0	7.0	8.0
Averages																				
Phase I	0.342	0.618	0.147	0.0038	114	74	51	14	12	34	30	6.3	4.9	5.0	27	9.2	6.7	5.2	3.5	4.0
II	0.395	0.622	0.214	0.0064	139	66	100	23	19	36	20	9.3	4.9	6.9	61	11.1	12.1	7.8	4.3	6.7
III	0.326	0.545	0.000	0.0076	153	54	38	22	17	45	25	8.3	5.9	7.3	21	10.6	12.0	6.8	4.9	5.2
IV	0.396	0.266	0.227	0.0107	123	57	60	31	22	27	28	11.7	8.2	9.4	35	15.1	16.0	8.0	5.9	7.3
Overall	0.366	0.533	0.144	0.0086	135	62	67	22	18	36	24	8.8	5.7	7.1	39	11.3	12.2	7.1	4.6	6.2

Note: S.C. = Solids Contact.
T.F. = Trickling Filter.

TABLE 32 OCONTO FALLS SUSPENDED SOLIDS CONCENTRATION, VOLATILE SUSPENDED SOLIDS PERCENT, MIXED LIQUOR PARAMETERS, SLUDGE BLANKET DEPTHS, AND FERRIC CHLORIDE QUANTITIES.

Date	Suspended Solids, mg/l							Volatile Suspended Solids, percent							Mixed Liquor Parameters			Sludge Blanket Depth, feet				FeCl3, gal.
	Raw Infl.	Prim. Effl.	T.F. Effl.	R.S.S.	Mix. Liq.	Sec. Effl.	Final Effl.	Raw Infl.	Prim. Effl.	T.F. Effl.	R.S.S.	Mix. Liq.	Sec. Effl.	Final Effl.	30-Minute Settleability	SVI, ml/g	Color	Location A	B	C	D	
PHASE I																						
28-May-84	79		95			13	6	81.0		72.6			61.5	58.0								
29-May-84	149	107	76	9,000	2,070	10	11	85.0	78.0	69.7	55.2	57.2	58.0	63.6	140	60	black	0.5	1.5	1.2	1.5	16
30-May-84				7,300	2,429						55.9	54.5			160	66	black	1.5	0.8	1.2	1.2	16
31-May-84	158	66	58			9	10															16
01-Jun-84				7,560	1,720						55.6	57.4						1.2	1.0	1.2	1.2	16
02-Jun-84																						16
03-Jun-84	106	68	52			8	6	85.0	55.6	73.1			75.0	100.0								12
																						16
04-Jun-84				9,433	1,600						47.0	58.0			90	56	dk. brn.	1.5	0.5	1.5	1.0	16
05-Jun-84	132	70	51			9		77.1	65.7	68.6			66.7									12
06-Jun-84				8,833	1,700						51.7	49.0			110	65	dk. brn.	0.9	1.4	2.0	1.2	16
07-Jun-84	220	69	61			10	10	74.6	64.7	65.6			70.0	72.2								16
08-Jun-84				8,550	1,367						48.0	58.9			75	55	brown	1.2	1.3	1.9	1.5	16
09-Jun-84																						16
10-Jun-84	100	43	86			9		85.0	65.3	72.7			77.0									16
11-Jun-84				6,900	1,250						54.4	62.0			70	54	black	0.8	1.2	1.0	0.9	16
PHASE II																						
11-Jun-84																						0
12-Jun-84	258	100	248			19		72.0	64.0	69.3			66.4									0
13-Jun-84				5,500	2,514						65.4	67.3			80	32	black	1.0	1.2	1.5	0.2	0
14-Jun-84	186	65	210			14	16	74.1	69.2	69.5			65.7	58.0								0
15-Jun-84				4,940	2,533						68.0	66.7			90	36	black	1.0	1.5	1.2	0.4	0
16-Jun-84																						0
17-Jun-84																						0
																						0
18-Jun-84	132	22	220	12,000	4,640	16	16	75.0	55.0	67.3	66.0	54.6	75.0	53.0	120	25	black	1.0	1.0	1.9	1.2	0
19-Jun-84	97	58	1050			16	14	77.3	76.0	69.5			73.0	71.4								0
20-Jun-84				8,540	2,230						65.6	65.1			100	45	black	0.2	0.2	1.5	1.2	0
21-Jun-84	137	49	74			13	9	77.4		63.5	64.9	70.0		64.0								0
22-Jun-84				3,400	615													1.2	1.2	1.4	1.2	0
23-Jun-84																						0
24-Jun-84	96	22	74			13	7	87.5		68.9			69.2	57.1								0
																						0
25-Jun-84				2,630	585						68.1	64.1			59	85	black	1.9	2.2	2.5	2.0	0
26-Jun-84	187	64	93			11	10	82.9	71.9	77.4			58.9	66.7								0
27-Jun-84											69.1	77.6			45		black	1.2	1.0	1.0	1.0	0
28-Jun-84	132	59	141			12	9	88.3	72.9	72.3			66.7	55.6								0
29-Jun-84				4,660	1,000						65.7	64.0			40	37	brown	0.5	0.5	1.2	1.2	0
30-Jun-84																						0
01-Jul-84	120	38	111			12	6	84.2		77.5			70.0	66.6								0

TABLE 12 OCONTO FALLS SUSPENDED SOLIDS CONCENTRATION, VOLATILE SUSPENDED SOLIDS PERCENT, MIXED LIQUOR PARAMETERS, SLUDGE BLANKET DEPTHS, AND FERRIC CHLORIDE QUANTITIES continued.

Date	Suspended Solids, mg/l							Volatile Suspended Solids, percent							Mixed Liquor Parameters			Sludge Blanket Depth, feet				$FeCl_3$, gal.
	Raw Infl.	Prim. Effl.	T.F. Effl.	R.S.S.	Mix. Liq.	Sec. Effl.	Final Effl.	Raw Infl.	Prim. Effl.	T.F. Effl.	R.S.S.	Mix. Liq.	Sec. Effl.	Final Effl.	30-Minute Settleability	SVI, ml/g	Color	Location A	B	C	D	
02-Jul-84				1,520	660						69.7	66.7			25	38	brown	1.0	1.2	0.9	0.9	0
03-Jul-84	63	62	65			8	7	90.4	77.4	72.3			62.5	65.7								0
04-Jul-84				1,320	700						69.7	72.8			45	64	brown	0.1	0.1	0.1	0.1	0
05-Jul-84	113	51	72			10	11	88.5	76.4	77.8			63.6									0
06-Jul-84				8,280	1,960						72.4	73.8			80	41	brown	0.1	0.1	0.5	0.5	0
07-Jul-84																						0
08-Jul-84	115	67	47			17	14	85.2	75.0	72.3			76.5	71.4								0
																						0
09-Jul-84				7,540	2,915						72.6	72.9			100	34	brown	0.3	0.3	0.5	0.8	0
10-Jul-84	856	89	54	5,040	1,857	16	19	68.7	73.0		72.2	71.6	67.5	73.6								0
11-Jul-84															95	51	brown					0
PHASE III																						
11-Jul-84	186	61												64.7				0.3	0.3	0.2	0.2	0
12-Jul-84			23			10	17	79.6	78.7	67.8			88.8									0
13-Jul-84																		0.1	0.1	0.1	0.1	0
14-Jul-84																						0
15-Jul-84	115	44	21			7	8	95.2	66.2	76.2			85.7	75.0								0
																						0
16-Jul-84																		0.0	0.0	0.0	0.0	0
17-Jul-84																						0
18-Jul-84	188	52	21			10	12	82.4	69.2	66.7			68.0	66.7				0.5	0.5	0.5	0.5	0
19-Jul-84	178	57	28			23	22	83.5	78.9	71.4			65.2	77.3								0
20-Jul-84																		0.0	0.0	0.2	0.3	0
21-Jul-84																						0
22-Jul-84																						0
																						0
23-Jul-84	284	92	34			8	12	71.8	68.3	67.6			62.5					0.0	0.0	0.2	0.2	0
24-Jul-84	292	54	24			8	7	42.4	48.1	66.7			62.5	14.0								0
25-Jul-84																		0.0	0.0	0.0	0.0	0
26-Jul-84	280	80	29			14	13	77.1	70.0	48.2			57.1	46.1								0
27-Jul-84																		0.0	0.0	0.0	0.0	0
28-Jul-84																						0
29-Jul-84	332	32	30			5.7	7	61.4	100.0	75.0			82.4	71.4								0
																						0
30-Jul-84																		0.0	0.0	0.0	0.4	0
31-Jul-84	244	27	43			12	13	68.3	44.4	69.0			66.7	17.7								0
01-Aug-84																		0.0	0.0	0.0	0.2	0
02-Aug-84	252	57	60			15	13	68.5	63.2	66.7			64.0	72.0								0
03-Aug-84																						0

TABLE E2 DECATUR FALLS SUSPENDED SOLIDS CONCENTRATION, VOLATILE SUSPENDED SOLIDS PERCENT, MIXED LIQUOR PARAMETERS, SLUDGE BLANKET DEPTHS, AND FERRIC CHLORIDE QUANTITIES continued.

Date	Suspended Solids, mg/l							Volatile Suspended Solids, percent							Mixed Liquor Parameters			Sludge Blanket Depth, feet				FeCl3, gal.
	Raw Infl.	Prim. Effl.	T.F. Effl.	R.S.S.	Mix. Liq.	Sec. Effl.	Final Effl.	Raw Infl.	Prim. Effl.	T.F. Effl.	R.S.S.	Mix. Liq.	Sec. Effl.	Final Effl.	30-Minute Settleability	SVI, ml/g	Color	Location A	B	C	D	
PHASE IV																						
03-Aug-84																		0.0	0.6	0.2	0.2	0
04-Aug-84																						0
05-Aug-84	226	42	63			12	14	84.0	71.4	72.2			75.7	78.6								0
																						0
06-Aug-84				8,480	3,083						71.4	70.3			200	65	black	1.3	1.2	1.5	1.2	0
07-Aug-84	134	56	51			21	22	88.1	55.3	68.6			61.0	77.2								0
08-Aug-84				9,920	2,660						71.7	70.3			170	64	black					0
09-Aug-84	130	35	46			11	11	82.3	80.6	71.7			72.7	63.6								0
10-Aug-84				10,640	3,050						70.4	67.8			150	49	gray	0.4	0.4	0.8	0.8	0
11-Aug-84																						0
12-Aug-84	157	41	89			11	21	82.9	80.4	64.0				76.2								0
																						0
13-Aug-84				5,050	1,230						67.7	72.3			60	49	gray	0.6	0.6	0.6	0.6	0
14-Aug-84	158	112	71			28	24	72.9	27.7	71.8			78.5	78.8								4
15-Aug-84				5,280	2,100						72.8	69.8			90	43	black	0.2	0.4	0.4	0.4	0
16-Aug-84	112	51	175			23	23	75.8	76.4	70.8			69.6	65.2								
Averages																						
Phase I	136	71	69	8,446	1,813	10	10	81.4	76.4	70.4	61.5	52.2	66.8	71.5	115	62		1.1	1.1	1.5	1.3	15.7
II	191	57	109	5,572	1,829	13	12	79.0	75.1	71.5	67.6	70.5	74.3	68.6	70	45		0.8	1.0	1.3	1.0	0.0
III	238	55	31			11	12	73.2	68.7	69.6			68.6	55.3				0.1	0.1	0.1	0.2	0.0
IV	152	56	46	7,639	2,425	18	19	79.3	65.3	69.7	70.6	69.9	75.7	71.9	134	54		0.5	0.5	0.7	0.6	0.0
Overall	187	58	105	6,765	1,949	13	13	77.0	71.3	70.4	64.6	66.0	71.4	66.0	95	51		0.6	0.7	0.9	0.7	2.6

Note: FeCl3 = Ferric Chloride added as coagulant.
T.F. = Trickling filter.
R.S.S. = Return Secondary Sludge.
Mix. Liq. = Mixed Liquor.

Location of Sludge Blanket Depths: A = 1-ft inside flocculation center wall skirt.
B = 1-ft outside flocculation center wall skirt.
C = at scum baffle.
D = 1-ft from outside wall.

TABLE A3 OCONTO FALLS TEMPERATURE, pH, AND DISSOLVED OXYGEN MEASUREMENTS.

Date	Temperature, degrees C		pH		Dissolved Oxygen Profile, mg/l									
	Raw Infl.	Final Effl.	Raw Infl.	Final Effl.	Raw Infl.	Prim. Effl.	T.T. Effl.	S.C. Tank	Floc. well depth 1'	5'	9'	Sludge Blank.	Effl. Weir	Final Effl.
PHASE I														
28-May-84														
29-May-84	13.0	[illegible]	[illegible]		5.4	4.9	6.2	4.4	1.0	0.6	0.6	0.4	1.2	1.0
30-May-84	13.0	13.0	6.7		6.2	3.4	7.2	4.2	0.7	0.5	0.3	0.2	0.9	0.9
31-May-84														
01-Jun-84	12.5	13.0	6.4	7.6	6.8	1.9	7.2	4.1	0.5	0.2	0.2	0.2	0.8	1.0
02-Jun-84														
03-Jun-84														
04-Jun-84	12.5	14.0	7.3	6.8	[illegible]	1.5	7.1	3.6	0.6	0.3	0.3	0.4	0.9	1.1
05-Jun-84														
06-Jun-84	13.0	15.0	7.4	7.2	[illegible]	2.3	7.4	4.3	0.6	0.5	0.2	0.2	0.9	1.0
07-Jun-84														
08-Jun-84	13.5	15.0	7.5	7.3	6.2	2.6	7.2	4.6	0.7	0.5	0.4	0.2	1.0	1.0
09-Jun-84														
10-Jun-84														
11-Jun-84	14.3	14.5	7.4	7.0	5.2	1.9	6.9	5.5	1.2	1.0	0.9	0.1	0.9	1.4
PHASE II														
11-Jun-84														
12-Jun-84														
13-Jun-84	14.0	15.0	7.4	7.6	5.4	4.1	7.5	4.0	0.6	0.5	0.4	0.2	1.9	[illegible]
14-Jun-84														
15-Jun-84	14.0	15.0	7.5	7.5	5.5	2.5	8.1	7.6	1.4	1.4	1.0	1.0	1.2	1.9
16-Jun-84														
17-Jun-84														
18-Jun-84	14.0	15.0	7.9	7.6	6.3	4.9	8.3	5.6	1.0	0.4	0.4	0.0	0.5	0.6
19-Jun-84														
20-Jun-84	15.0	15.0	8.1	8.0	6.2	5.4	7.9	7.5	2.4	2.0	2.0	0.3	1.4	1.3
21-Jun-84														
22-Jun-84	15.0	15.0	7.9	7.9	5.6	5.8	8.4	8.8	4.4	4.0	3.9	1.6	3.1	2.7
23-Jun-84														
24-Jun-84														
25-Jun-84	14.5	15.0	7.8	7.6	4.4	2.2	7.1	4.2	2.7	2.5	2.6	2.6	2.5	2.2
26-Jun-84														
27-Jun-84	15.0	16.9	8.0	7.8	5.1	2.1	6.9	[illegible]	1.4	1.4	0.9	1.2	0.8	0.7
28-Jun-84														
29-Jun-84	15.0	16.0	7.8	7.8	4.9	2.1	7.6	4.9	1.0	0.7	0.6	0.6	1.0	1.0
30-Jun-84														
01-Jul-84														

continued

TABLE B3 OCONTO FALLS TEMPERATURE, pH, AND DISSOLVED OXYGEN MEASUREMENTS continued.

Date	Temperature, degrees C		pH		Dissolved Oxygen Profile, mg/l									
	Raw Infl.	Final Effl.	Raw Infl.	Final Effl.	Raw Infl.	Prim. Effl.	T.F. Effl.	S.C. Tank	Floc. 1'	well 5'	depth 9'	Sludge Blank.	Effl. Weir	Final Effl.
02-Jul-84	16.5	16.5	7.9	7.6	4.1	1.8	7.7	7.3	4.3	3.9	3.7	3.3	3.3	2.6
03-Jul-84														
04-Jul-84	14.5	17.0	8.2	7.7	4.6	1.6	7.9	8.2	1.9	1.6	1.2	1.2	1.0	1.2
05-Jul-84														
06-Jul-84	16.0	16.5	7.9	7.7	4.1	1.2	7.9	7.2	1.2	1.0	0.7	0.4	1.7	1.4
07-Jul-84														
08-Jul-84														
09-Jul-84	16.0	17.0	7.8	7.7	4.1	1.7	6.8	6.3	0.7	0.6	0.4	0.3	1.2	0.9
10-Jul-84														
11-Jul-84	16.5	17.5	7.8	7.7	5.5	3.1	8.4	5.6	0.9	0.6	0.5	0.2	1.1	1.0
PHASE III														
11-Jul-84														
12-Jul-84														
13-Jul-84	17.0	17.5	7.7	7.7	4.7	2.8	9.1	6.0	3.4	3.2	3.2	3.2	1.0	1.2
14-Jul-84														
15-Jul-84														
16-Jul-84	16.0	17.5	7.7	7.9	4.7	1.3	8.4	6.1	3.8	3.4	3.3	3.4	2.7	2.2
17-Jul-84														
18-Jul-84	17.0	17.5			5.0	1.6	8.4	6.3	3.1	3.0	3.0	2.1	2.0	2.0
19-Jul-84														
20-Jul-84	17.5	18.0	7.8	7.8	4.7	1.2	8.8	6.2	4.3	4.0	3.8	0.5	2.2	2.2
21-Jul-84														
22-Jul-84														
23-Jul-84	18.0	18.5	7.8	7.8	3.6	1.5	8.1	6.2	3.2	3.2	3.0	1.2	2.0	2.4
24-Jul-84														
25-Jul-84	18.0	18.5	7.7	7.8	3.1	1.7	7.9	6.3	2.9	2.9	2.7	2.2	2.2	2.4
26-Jul-84														
27-Jul-84	17.5	18.5	7.9	7.8	4.7	2.3	7.8	6.2	4.0	3.4	2.7	2.0	1.6	1.7
28-Jul-84														
29-Jul-84														
30-Jul-84	17.5	18.5	7.9	7.8	3.8	1.2	8.9	6.5	4.2	3.8	3.8	2.8	2.6	2.2
31-Jul-84														
01-Aug-84	17.5	18.5	7.8	7.8	3.7	1.2	6.0	6.1	3.5	3.0	2.6	0.2	3.6	2.6
02-Aug-84	18.0	18.0	7.5	7.6										
03-Aug-84														

continued

TABLE B3 OCONTO FALLS TEMPERATURE, pH, AND DISSOLVED OXYGEN MEASUREMENTS continued.

Date	Temperature, degrees C		pH		Dissolved Oxygen Profile, mg/l									
	Raw Infl.	Final Effl.	Raw Infl.	Final Effl.	Raw Infl.	Prim. Effl.	T.F. Effl.	S.C. Tank	Floc. 1'	well depth 5'	9'	Sludge Blank.	Effl. Weir	Final Effl.
PHASE IV														
03-Aug-84					4.2	1.4	6.2	6.1	3.2	4.2	4.9	0.4	3.9	2.8
04-Aug-84														
05-Aug-84														
06-Aug-84	13.0	19.0	7.9	7.9	3.8	1.9		3.2	0.4	0.4	0.4	0.2	1.0	1.0
07-Aug-84														
08-Aug-84	16.0	19.0	7.8	7.8	5.2	3.2		6.6	0.5	0.2	0.2	0.2	0.2	0.2
09-Aug-84														
10-Aug-84	18.0	18.5	7.7	7.8	4.1	1.9		4.9	0.2	0.2	0.2	0.2	0.7	0.4
11-Aug-84														
12-Aug-84														
13-Aug-84	17.0	18.5	7.6	7.7	4.8	2.1		7.2	1.3	1.2	1.2	0.4	1.0	0.8
14-Aug-84														
15-Aug-84	16.0	18.5	7.6	7.7	3.3	1.1		6.6	0.4	0.4	0.0	0.0	0.9	0.6
16-Aug-84														
Averages														
Phase I	12.9	13.7	7.2	7.2	6.1	2.8	7.0	4.2	0.7	0.4	0.3	0.3	1.0	1.0
II	15.0	15.8	7.8	7.7	5.0	2.9	7.7	6.5	1.9	1.7	1.5	1.1	1.6	1.5
III	17.4	18.1	7.7	7.7	4.2	1.6	8.1	6.2	3.6	3.3	3.1	2.0	2.2	2.1
IV	17.8	18.7	7.7	7.8	4.2	1.9	6.2	5.8	1.3	1.1	1.0	0.2	1.3	1.0
Overall	15.7	16.5	7.7	7.6	4.9	2.4	7.6	5.6	2.0	1.7	1.6	1.0	1.7	1.4

Note: T.F. = Trickling Filter.
S.C. = Solids Contact.

TABLE IVA OCOINTO FALLS NITROGEN AND PHOSPHORUS MEASUREMENTS.

Date	Total Kjeldahl Nitrogen, mg/l as N				Ammonia Nitrogen, mg/l as N				Oxidized Nitrogen, mg/l as N				Total Phosphorus, mg/l as P							Ortho-Phosphorus, mg/l as P				
	Raw Infl.	Prim. Effl.	T.F. Effl.	Sec. Effl.	Raw Infl.	Prim. Effl.	T.F. Effl.	Sec. Effl.	Raw Infl.	Prim. Effl.	T.F. Effl.	Sec. Effl.	Raw Infl.	Prim. Effl.	T.F. Effl.	R.A.S.	Rec. Liq.	Sec. Effl.	Final Effl.	Raw Infl.	Prim. Effl.	T.F. Effl.	Sec. Effl.	Final Effl.
PHASE I																								
28-May-84	24.6		23.6	16.7	16.90		5.02	2.03	0.05		1.14	0.05	2.98		7.32			6.05	0.09	2.23		1.96	0.35	0.23
29-May-84	27.5	40.3	15.7	14.7	17.10	24.30	17.59	13.10			0.05	0.05				63.9	57.2	0.97	1.02					
30-May-84																115.0	73.2							
31-May-84	37.9	25.0	18.7	15.1	15.60								1.03	6.75	2.72			1.04	1.04					
01-Jun-84																111.0	63.0							
02-Jun-84																								
03-Jun-84	28.5	25.6	15.6	11.6	9.43	14.00	9.36	9.23	0.05	0.05	0.05	0.05	3.95	4.25	3.73			0.46	0.49	[illegible]	1.00	1.70	0.16	0.14
04-Jun-84																65.5	72.6							
05-Jun-84	26.0	27.0	22.7	15.7	11.90	11.90	9.10	10.40			0.05	0.05	4.03	3.03	3.40			0.39						
06-Jun-84																72.2	57.5							
07-Jun-84	24.3	21.2	13.9	10.3	13.20	13.20	9.09	9.69			0.05	0.05	4.53	2.03	2.95			0.73	0.97					
08-Jun-84																134.0	87.6							
09-Jun-84																								
10-Jun-84	22.2	21.2	13.9	12.3	15.60	14.40	8.31	9.50	14.05	0.05	1.52	1.25	3.99	2.69	4.14			0.57		1.69	0.92	1.03	0.16	
11-Jun-84																								
PHASE II																								
11-Jun-84																131.4	58.4							
12-Jun-84	25.6	20.3	20.6	15.2	14.00	13.60	9.20	11.60		0.05	0.53	0.05	4.74	3.00	4.73			1.41						
13-Jun-84																108.0	60.9							
14-Jun-84	22.1	18.1	21.4	11.7	14.70	12.50	8.51	8.97			1.12	1.19	4.50	3.30	5.05			1.25	1.36					
15-Jun-84																93.9	70.0							
16-Jun-84																								
17-Jun-84																								
18-Jun-84	15.9	11.3	17.4	8.25	6.75	6.00	3.23	2.44	0.05	0.05	2.10	0.05	2.55	1.54	5.50	107.6	110.5	1.09	1.03	0.35	0.74	0.27	0.31	0.60
19-Jun-84	13.2	15.4	46.6	8.16	8.44	5.03	2.51	6.92			4.92	1.70	2.69	2.42	10.60			1.05	0.90					
20-Jun-84																120.4	71.6							
21-Jun-84	23.9	15.0	9.0	7.30	13.40	10.40	4.81	5.67		0.05	5.20	4.35	4.17	2.54	2.04			1.24	1.21					
22-Jun-84																91.2	54.4							
23-Jun-84																								
24-Jun-84	15.4	13.6	10.7	6	6.10	10.30	5.07	5.93	0.40	1.50	7.90	5.00	4.14	2.23	2.04			1.71	1.59	1.50	1.21	1.21	0.13	2.12
25-Jun-84																79.4	17.5							
26-Jun-84	29.3	17.6	16.1	8.04	13.90	9.10	5.34	7.05			4.22	4.69	4.02	2.04	3.59			1.92	1.05					
27-Jun-84																73.4	80.1							
28-Jun-84	24.3	20.0	20.1	11.7	13.60	12.30	7.32	8.44			8.51	9.23	3.26	2.60	4.50			2.05	1.90					
29-Jun-84																137.7	89.6							
30-Jun-84																								
01-Jul-84	20.1	16.4	14.3	8.44	13.60	10.70	5.14	6.13	0.05	0.05	10.40	11.00	3.53	2.75	3.04			1.08	1.03	1.40	1.30	1.77	1.47	1.02

continued.

TABLE IX: COCHITI FALLS NITROGEN AND PHOSPHORUS MEASUREMENTS continued.

Date	Total Kjeldahl Nitrogen, mg/l as N				Ammonia Nitrogen, mg/l as N				Oxidized Nitrogen, mg/l as N				Total Phosphorus, mg/l as P								Ortho-Phosphorus, mg/l as P				
	Raw Infl.	Prim. Effl.	T.F. Effl.	Sec. Effl.	Raw Infl.	Prim. Effl.	T.F. Effl.	Sec. Effl.	Raw Infl.	Prim. Effl.	T.F. Effl.	Sec. Effl.	Raw Infl.	Prim. Effl.	T.F. Effl.	R.S.S.	Alu. Liq.	Sec. Effl.	Final Effl.	Raw Infl.	Prim. Effl.	T.F. Effl.	Sec. Effl.	Final Effl.
02-Jul-84																53.4	22.2							
03-Jul-84	19.3	21.4	14.4	7.85	14.20	13.90	6.92	5.74	0.07	0.05	8.31	7.85	3.44	3.32	7.94			2.19	2.13					
04-Jul-84																48.5	21.9							
05-Jul-84	23.4	20.8	11.3	7.19	12.80	14.40	6.99	6.53	0.05		11.10	11.00	4.25	3.30	4.17			2.22	2.16					
06-Jul-84																127.1	50.3							
07-Jul-84																								
08-Jul-84	31.1	25.2	13.8	7.71	16.80	15.20	6.46	6.46	6.00	0.05	11.60	9.35	3.07	3.05	5.98			2.24	2.16	2.04	1.63	1.95	2.04	2.04
09-Jul-84																125.6	55.9							
10-Jul-84	35.3	32.3	15.3	6.65	14.40	13.80	10.70	9.96	0.05		4.95	2.44	6.20	3.10	1.80	104.8	34.3	1.20	0.92					
11-Jul-84																								
PHASE III																								
11-Jul-84				15.2	12.30	11.50	9.76	10.50	0.05		3.69	3.43												
12-Jul-84	22.1	21.1	7.8										3.41	2.42	2.99			1.09	1.50					
13-Jul-84																								
14-Jul-84																								
15-Jul-84	23.7	18.6	14.9	12.1	15.02	14.30	6.75	9.42	0.05	0.05	6.46	4.22	4.10	3.56	3.20			2.24	1.82	1.10	0.78	1.07	0.66	1.40
16-Jul-84																								
17-Jul-84																								
18-Jul-84	36.2	23.3	17.3	8.11	18.90	17.10	9.76	13.10			6.00	5.20	5.35	3.05	2.84			2.30	2.25					
19-Jul-84	25.5	22.8	16.2	13.8	21.00	18.70	10.70	14.90	0.05		4.40	3.89	4.16	3.30	2.78			2.31	2.25					
20-Jul-84																								
21-Jul-84																								
22-Jul-84																								
23-Jul-84	36.6	24.4	14.9	15.5	25.00	16.20	12.50	10.30	1.32	0.05	3.10	6.79	5.92	3.63	3.29			2.05	2.93	2.00	2.10	1.60	2.13	1.50
24-Jul-84	29.4	23.5	15.2	14.8	13.50	14.20	6.77	10.50			3.42	2.10	5.72	3.35	3.02			1.00	2.64					
25-Jul-84																								
26-Jul-84	34.7	29.8	15.7	16.1	19.70	21.00	9.46	10.20	1.11	0.70	2.23	4.24	6.01	3.93	2.81			2.02	2.67					
27-Jul-84																								
28-Jul-84																								
29-Jul-84	44.3	32.9	15.9	13.5	21.70	18.20	8.49	10.50	0.56	3.69	2.71	5.29	6.24	3.29	3.57			1.76	1.29	1.35	2.70	1.39	1.00	1.05
30-Jul-84																								
31-Jul-84	29.2	21.6	17.0	16.1	34.20	18.20	13.50	14.10	1.25	4.17	3.40	4.30	6.15	3.51	3.94			3.64	3.29					
01-Aug-84																								
02-Aug-84	33.2	22.4	16.3	16	15.50	15.50	9.00	17.00			3.97	6.33	6.01	4.11	4.71			4.09	3.01					
03-Aug-84																								

continued

TABLE 84 OCCOKITO FALLS NITROGEN AND PHOSPHOROUS MEASUREMENTS continued.

Date	Total Kjeldahl Nitrogen, mg/l as N				Ammonia Nitrogen, mg/l as N				Oxidized Nitrogen, mg/l as N				Total Phosphorus, mg/l as P							Ortho-Phosphorus, mg/l as P				
	Raw Infl.	Prim. Effl.	T.F. Effl.	Sec. Effl.	Raw Infl.	Prim. Effl.	T.F. Effl.	Sec. Effl.	Raw Infl.	Prim. Effl.	T.F. Effl.	Sec. Effl.	Raw Infl.	Prim. Effl.	T.F. Effl.	R.A.S.	Mix. Liq.	Sec. Effl.	Final Effl.	Raw Infl.	Prim. Effl.	T.F. Effl.	Sec. Effl.	Final Effl.
PHASE IV																								
04-Aug-84																								
05-Aug-84	25.6	22.3	15.4	12.5	16.30	13.60	8.77	9.07	0.05	0.05	2.16	3.76	5.71	2.81	5.18			3.32	2.89	1.23	1.59	1.85	2.27	2.14
06-Aug-84																	43.4							
07-Aug-84	25.4	21.0	18.2	19.3	13.70	14.80	14.30	13.40			6.62	2.92	4.64	3.24	2.94			2.64	2.76					
08-Aug-84																88.7	44.4							
09-Aug-84	25.6	14.8	15.6	14.1	12.10	11.50	9.61	13.30	0.05	0.05	1.83	9.42	3.99	2.59	2.90			2.14	2.06					
10-Aug-84																141.6	56.5							
11-Aug-84																								
12-Aug-84	28.5	38.1	28.4	17.6	12.40	14.10	12.00	9.60	0.90	0.05	8.14	1.53	4.78	3.31	3.34			2.66	2.25	2.09	1.70	1.07	1.83	1.44
13-Aug-84																98.5	33.9							
14-Aug-84	26.5	29.3	28.7	19.2	13.00	14.00	12.70	17.60			1.40	0.76	3.04	2.75	3.25			2.50	2.09					
15-Aug-84																102.6	36.9							
16-Aug-84	29.9	23.0	16.4	18.6	11.90	12.60	11.60	15.40			6.09	2.16	4.07	4.46	5.27			3.00	2.01					
Averages																								
Phase I	26.3	26.7	17.7	13.0	14.23	15.72	9.15	8.99	0.33	0.05	0.46	0.25	3.69	4.03	4.04	94.6	63.4	0.76	0.00	1.91	1.40	1.56	0.23	0.19
II	23.3	18.4	17.8	8.8	12.47	11.63	6.38	7.76	0.95	0.27	6.10	5.35	4.03	2.79	4.91	101.8	49.7	1.65	1.59	1.37	1.22	1.30	0.99	1.10
III	31.5	24.1	15.1	14.1	20.04	15.67	9.96	12.19	0.61	1.71	3.95	4.60	6.15	3.43	3.32			2.02	2.67	2.24	1.09	2.05	2.23	1.96
IV	25.6	21.9	19.2	16.9	13.70	13.57	11.36	12.90	0.30	0.00	3.21	1.53	4.64	3.19	3.01	105.9	43.0	2.71	2.40	1.66	1.65	1.06	2.05	1.79
Overall	26.5	22.1	17.3	12.6	15.14	13.76	8.73	9.97	0.62	0.60	4.05	3.67	4.60	3.23	4.12	100.7	52.1	1.90	1.97	1.77	1.51	.65	1.29	1.30

Note: Oxidized Nitrogen = Sum of Nitrite and Nitrate Nitrogen.
T.F. = Trickling Filter.
R.A.S. = Return Suspended Solids.
Mix. Liq. = Mixed Liquor.

TABLE B5 NIAGARA FALLS FLOCCULATION, SECONDARY CLARIFIER TOTAL SUSPENDED SOLIDS, AND SOLUBLE BOD PROFILES.

Date	T.F. Effl., mg/l		Solids Contact Tank, mg/l				Flocculator Center Well, mg/l				Secondary Clarifier TSS, mg/l			5-Day BOD Profile, mg/l									
			Location A		Location B		3" depth		12" depth		depth below effl. launder			Soluble 5-day BOD					Soluble Carbonaceous 5 day BOD				
	SSS	TSS	SSS	MLSS	SSS	MLSS	SSS	MLSS	SSS	MLSS	4"	8"	12"	#1	#2	#3	#4	#5	#1	#2	#3	#4	#5
PHASE I																							
30-May-84											7	10	20										
31-Jun-84							27	438	42	550													
03-Jun-84	33	44	41	2517	38	2717																	
04-Jun-84											6	16	39										
06-Jun-84	25	69	32	690	15	2720	19	350	21	250													
08-Jun-84														14.0		8.6	7.3	5.9	9.1		4.3	3.3	2.4
PHASE II																							
11-Jun-84											10	5	150										
13-Jun-84														17.0	17.0	15.0	15.0	11.0	8.9	9.1	8.1	8.4	7.3
15-Jun-84	67	255	42	1853	40	2888	32	587	31	255													
18-Jun-84											12	18	333										
20-Jun-84														18.0	11.0	9.2	9.5	6.8	6.4	8.6	4.6	8.0	4.5
22-Jun-84	23	54	27	647	26	567	24	256	14	180													
27-Jun-84														26.0	28.0	17.0	16.0	11.0	11.0	8.4	9.8	8.2	6.0
29-Jun-84	56	288					18	380															
02-Jul-84														16.0	13.0	16.0	19.0	13.0	13.0	11.0	12.0	12.0	7.2
06-Jul-84	31	63	26	1640	21	1710	22	380	24	272	6	9	17										
09-Jul-84																							
11-Jul-84	11	17	32	1550	63	1750	27	412	70	350													
PHASE III																							
13-Jul-84														12.0	13.0	12.0	14.0	12.0	19.0	12.0	11.0	12.0	12.0
16-Jul-84											6.3	5.3	4.7										
20-Jul-84	5	8			9	16	5	8	6	7				14.0		16.0		15.0	12.0		13.0		11.0
25-Jul-84											5.5	4.5	6.5										
27-Jul-84	13	19	10	14	11	13	8	10	7	9.7				15.0	14.0	14.0	14.0	12.0	8.1	8.4	8.8	9.0	5.9
30-Jul-84											3.7	4.7	10										
01-Aug-84	10	44	17	4[illegible]	22	90	11	24															
PHASE IV																							
03-Aug-84														12.0		16.0	18.0	16.0	8.5		7.9	18.0	7.3
10-Aug-84	27	47	22	2640	29	2680	30	670	38	540	4	10	31	17.3	15.0	13.0	15.0	13.0	12.0	10.0	11.0	10.0	10.0
15-Aug-84	25	64	24	1970	17	1670	30	570	24	355	16	25	156										
17-Aug-84														17.0	18.0	13.0	17.0	14.0	11.0	8.5	9.3	9.4	9.8
Averages																							
Phase I	29	57	37	1684	27	2719	23	414	32	400	7	13	30	14.0		8.6	7.3	5.9	9.1		4.3	3.3	2.4
II	38	135	32	1223	38	1529	25	355	35	244	9	11	169	17.3	15.3	14.3	14.9	10.5	9.8	9.3	8.6	9.2	6.3
III	12	24	14	28	14	42	8	14	7	8	5	5	7	13.7	13.5	14.0	14.0	13.0	18.0	18.2	18.9	12.5	5.6
IV	26	56	23	2385	19	2175	30	620	31	446	12	18	94	15.3	16.5	14.0	16.7	14.3	18.5	9.3	9.4	12.5	9.8
Overall	28	81	27	1276	26	1457	21	324	28	269	8	11	78	15.5	15.1	13.6	14.5	11.8	18.0	9.5	9.1	9.6	7.6

Notes: T.F. = Trickling Filter.
SSS = Total suspended solids in the supernatant after 30 minutes of settling.
TSS = Total suspended solids.
MLSS = Mixed Liquor Suspended Solids.
SBOD = Soluble Five-day BOD.
SCBOD = Soluble Carbonaceous Five-day BOD.

Solids Contact Sample Locations

A: 6-ft below surface in upflow section.
B: 15-ft below surface in downflow section.

Five-day BOD Sample Locations.

#1 - trickling filter effluent.
#2 - 6-ft below surface of upflow section of solids contact tank..
#3 - 2-ft below surface of downflow section of solids contact tank..
#4 - 16-ft below surface of downflow section of solids contact tank..
#5 - 4-ft below surface in flocculator center well.

TABLE C1 Flow and BOD Data at TOLLESON.

Date	Flow, mgd				Number of Clarifiers In-Serv.	Total 5-day BOD, mg/l					Soluble 5-day BOD, mg/l		Suspended Solids, mg/l							Primary Sludge Data			Avg Sludge Blanket Depth,* feet		Temp., deg. C	pH
	Raw Infl.	I.C. Return	TF/SC Waste	P.C. Sludge		Raw Infl.	P.C. Infl.	P.C. Effl.	I.C. Effl.	Final Effl.	P.C. Infl.	P.C Effl.	Raw Infl.	I.C. Return	TF/SC Waste	P.C. Infl.	P.C. Effl.	I.C. Effl.	Final Effl.	Conc. percent	D.M.S	R.F. gpm	Primary Clarifier Sc	Sc	Raw Infl.	Raw Effl.
PHASE I																										
10-May-84	7.900	3.900	0.023	0.068	7	284	188	159	35	11	101.0	67.0	324	0c	1225	316	136	70	17	4.2	70	30			32.0	
11-May-84	8.300	3.900	0.638	0.074	3															4.3	70	30			29.0	7.3
12-May-84	8.085				3																					
13-May-84	7.600	3.900	0.326	0.058	3	89	87	55	14	2	32.0	24.0	232	38	1325	160	56	10	12		70	30				
14-May-84	9.000	3.900	0.158	0.038	3															4.3	80	30			29.0	7.2
15-May-84	8.500	0.800	0.479	0.052	3	225	222	110	34	10	79.0	60.0	240	169	1870	412	64	33	16	4.6	80	30			29.0	7.3
16-May-84	8.500	0.600	0.767	0.029	3															3.7	85	30			30.0	7.1
17-May-84	6.400	6.700	0.693	0.035	3	275	300	159	32	15	97.0	90.0	285	383	1050	300	132	70	15	3.6	85	30			31.0	
18-May-84	9.700	0.700	0.288	0.061	3															3.7	85	25			32.0	7.3
19-May-84	10.000	0.700	0.036	0.047	3															3.7	90	25			32.0	
20-May-84	7.900	0.700	0.048	0.032	3	173	102	90	15	12	29.0	44.0	252	133	1009	152	104	20	13	4.3	90	25			30.0	
21-May-84	9.160	0.756	0.020	0.020	3															4.5	95	25			30.0	
22-May-84	8.413	0.750	0.043	0.025	3	332	342	193	24	13	102.0	87.0	292	260	1834	300	168	10	13	4	95	30			32.0	7.2
23-May-84	8.659	0.750	0.013	0.029	3															4.6	95	35			31.0	7.2
24-May-84	8.762	0.750	0.010	0.017	3	278	347	120	29	12	78.0	58.0	348	862	2971	416	168	45	8	4.6	100	40			30.0	6.8
25-May-84	8.095	0.750	0.006	0.022	3															4.5	100	45			30.0	
26-May-84	7.248	0.750	0.000	0.014	3															4.6	100	45			30.0	
27-May-84	6.327	0.750	0.013	0.086	3								192	8581	4650	1192	872	49	48	2.7	100	45			30.0	
28-May-84	7.007	0.900	0.023	0.092	3															3.1	85	15			30.0	
29-May-84	7.375	1.497	0.071	0.035	3	284	249	106	16	12	73.0	87.0	352	494	6970	304	276	50	22	3.2	85	15			29.0	7.1
PHASE II																										
26-Jun-84	7.076				2								296	1942	2376	344	124	17	9	1.8	50	10			33.0	6.5
27-Jun-84	5.692	1.948	0.036	0.153	2															1.7	50	10	3.70	2.60	33.0	6.5
28-Jun-84	5.130	1.836	0.056	0.047	2	330	310	150	12	7	100.0	84.0	344	338	3844	280	32	27	13	3.3	50	10	3.67	2.20	34.0	
29-Jun-84	7.687	1.632	0.074	0.099	2															3.5	50	10	3.33	1.33	33.0	
30-Jun-84	5.353	0.873	0.041	0.097	2																0	10	1.60	0.67	34.0	
01-Jul-84	5.165	0.842	0.071	0.078	2	130	110	80			32.0	30.0	284	74	2769	200	280	13	11	4.5	0	10	0.10	0.27	34.0	
02-Jul-84	5.689	0.748	0.107	0.040	2															1.3	0	10	0.10	0.03	35.0	
03-Jul-84	5.951	0.748	0.048	0.057	2	260	220	120			85.0	76.0								3.2	25	15	0.00	0.10	34.0	7.4
04-Jul-84	6.681	0.748	0.085	0.039	2															4.2	35	18	0.07	0.00	35.0	
05-Jul-84	6.554	0.748	0.023	0.338	2	230	220	120			86.0	72.0								4.1	45	18	0.06	0.00	34.0	
06-Jul-84	5.014	0.663	0.007	0.051	2															3.6	45	18	0.00	0.07	35.0	
07-Jul-84	6.433	0.748	0.003	0.016	2																		0.57	1.23	36.0	

continued

TABLE C1 Flow and BOD Data at [illegible] continued

Date	Flow, mgd: Raw Inf.	I.C. Return	TF/SC waste	P.C. Sludge	Number of Clarifiers	Total 5-day BOD, mg/l: Raw Inf.	P.C. Inf.	P.C. Eff.	I.C. Eff.	Final Eff.	Soluble 5-day BOD, mg/l: P.C. Inf.	P.C. Eff.	Suspended Solids, mg/l: Raw Inf.	I.C. Return	TF/SC waste	P.C. Inf.	P.C. Eff.	I.C. Eff.	Final Eff.	Primary Sludge Data: Conc. percent	D.R.S.	R.F. min	Avg Sludge Blanket Depth, feet: Primary Clarif. #2	Primary Clarif. #3	Temp. deg C: Raw Inf.	pH: Raw Inf.
08-Jul-84	6.566	0.7[illegible]	0.069	0.089	2	138	148	55			33.6	33.0	252	259	1943	396	68	36	12	2.8	25	10	0.70	1.32	24.0	
09-Jul-84	6.174	0.811	0.025	0.067	2															3.2	25	10	0.45	0.80	34.0	
10-Jul-84	6.044	1.456	0.084	0.06[illegible]	2	198	120	140			55.0	54.0	252	82	1181	180	-	5		4.2	25	10	0.35	0.[illegible]3	33.0	6.2
1[illegible]-Jul-84	6.01[illegible]	1.025	0.04[illegible]	0.04[illegible]	2															4.2	25	10	0.13	0.05	33.0	
[illegible]-Jul-84	7.035	1.025	0.0[illegible]5	0.033	2	210	190	110			67.0	71.0	284	42	1646	208	48	10	4	4.3	45	10	0.28	0.05	35.0	
13-Jul-84	7.080	1.176	0.023	0.058	2															4.2	55	10	0.28	0.5	33.0	
14-Jul-84	7.092	1.997	0.015	0.1[illegible]	2															3.7	55	10	0.00	0.07	34.0	
15-Jul-84	6.310	1.297	0.033	0.05[illegible]	2	97	100	58			28.0	25.0	144	236	4320	132	64	9	5		55	10			34.0	
16-Jul-84	6.997	1.958	0.059	0.036	2															3.8	55	10	0.00	0.23	34.0	
17-Jul-84	6.657				2								288	132	2609		70	10	9								7.1
Averages																										
[illegible]	6.199	1.455	0.177	0.044	1.8	243	231	135	25	11	74.1	64.6	288	1222	2637	396	22	41	18	4.0	87	31			29.9	7.2
[illegible]	6.393	1.151	0.040	0.062	2.0	197	181	185	12	7	68.0	55.8	239	564	347	277	185	16	9	3.4	36	15	0.81	0.54	34.0	6.7
Overall	7.249	1.299	0.107	0.053	2.5	220	206	120	22	10	67.4	60.2	260	913	2613	344	166	29	14	3.7	61	23	0.81	0.54	32.[illegible]	7.0

Note: P.C. = Primary Clarifier
I.C. = Intermediate Clarifier.
D.R.S. = Density meter Setting.
R.F. = Sludge Removal Frequency.
Density meter setting determines the maximum sludge concentration allowed at the primary sludge shutoff point.
Meter scale ranges from 0 to 100, with 100 receiving the highest sludge concentration.

APPENDIX D

MEDFORD FIELD INVESTIGATION DATA

TABLE D1 MEDFORD AERATED SOLIDS CONTACT SOLUBLE CARBONACEOUS 5-DAY BOD PROFILES.

Parameter	Aerated Solids Contact Soluble Carbonaceous 5-Day BOD Profiles						
	Plant-Scale					Bench-Scale	
	26-Jun-84	29-Jun-84	16-Jul-84	19-Jul-84	07-Aug-84	19-Jul-84	07-Aug-84
Operating Parameters							
Plant Flow, mgd	9.5	9.6	11.5	11.5	10.5	(a.)	(a.)
Return Secondary Sludge Flow, mgd	3	2.9	3.2	2.9	3	(a.)	(a.)
Waste Temperature, degrees C	21	18	20	21	22	20	20
MLVSS, mg/l	1376	1170	1083	940	1066	810	869
Sample Collection Starting Time	09:32 am	01:55 pm	03:03 pm	11:56 am	03:75 pm	09:57 am	10:43 am
Sample Collection Ending Time	11:22 am	33:26 pm	04:28 pm	01:09 pm	04:48 pm	10:41 am	11:25 am
Profile Data (b.)							
Carbonaceous 5-Day BOD							
TF Effluent	22.0	22.3	47.0	22.0	55.0	28.0	30.3
Soluble Carbonaceous 5-Day BOD					21.0		6.0
Return Secondary Sludge							
TF Effluent	13.2	12.0	26.0	7.1	31.0	12.0	14.4
01	9.3	7.5	17.0	5.7	21.5	8.0	10.6
02	6.6	6.7	14.0	4.8	17.6	5.8	8.1
03	4.4	5.4	12.0	3.8	14.3	4.7	6.5
04	5.7	4.8	11.0	3.2	10.6	3.9	6.0
05	4.3	5.0	8.8	3.4	9.4	3.4	5.3
06	3.7	4.8	8.8	2.8	8.3	3.1	4.4
07	3.3	3.9	8.6	2.6	7.2	2.9	4.3
08	2.5	3.0	6.5	2.3	5.4	2.8	4.2
Dissolved Oxygen							
TF Effluent	6.2	7.5	6.6	7.3	7.0		3.6
01	3.6	5.5	4.3	6.1	5.2	6.0	4.6
02	2.6	4.6	3.2	4.6	3.3	6.3	4.1
03	1.6	3.3	1.6	3.2	1.2	6.7	5.1
04	3.3	3.4	1.6	3.5	1.4	6.9	5.1
05	1.8	3.3	1.8	3.6	1.2	7.0	5.4
06	4.1	3.4	1.8	3.9	1.5	7.4	5.8
07	4.7	4.1	1.9	4.7	1.5	7.3	5.9
08	3.7	2.8	0.1	4.7	0.3	7.5	6.0

Footnotes: (a.) A 10:3 ratio of trickling filter effluent to return secondary sludge was used in the bench-scale tests.

(b.) Sample numbers represent points along the aerated solids contact tank for the plant-scale, SCBOD profiles and the contact times for the bench scale SCBOD profiles.

	Sample numbers							
	1	2	3	4	5	6	7	8
Plant-Scale								
Cumulative Contact Tank Volume, 1000 gal.	11	38	96	118	152	208	249	320
Bench-Scale								
Solids Contact Time, min:sec.								
19-Jul-84	0:00	4:59	10:35	16:05	21:09	26:09	32:04	37:19
07-Aug-84	0:00	6:18	.42	16:59	21:45	26:54	32:04	37:05

TABLE D2 FLOCCULATION PROFILES ALONG WHOLE LENGTH OF AERATED SOLIDS CONTACT TANK AT NEWFORD.

DATE	(a.) Approximate Velocity Gradient, 1/sec.	Aerated Solids Contact Tank Sampling Locations.																	
		A		B		C1		D1		D3		E		F		G		H	
		SSS	MSS	SSS	MLSS	SSS	MLSS	SSS	MLSS	SSS	MLSS	SSS	MLSS	SSS	MLSS	SSS	MLSS	SSS	MLSS
26-Jun-84	96	16.7	36.0	22.5	680	16.3	1610	19.2	1642	16.0	1411	23.2	1700	12.6	1643	14.4	1500	13.2	1729
29-Jun-84	96	23.0	29.1	23.6		52.4	1430	53.6	1430	18.8	1430	22.4	1360	22.0	1360	16.0	1360	18.0	1290
19-Jul-84	108	26.4	29.5	16.5	1340	12.8	1790	11.6	1815	13.2		14.8	1840	12.8	1840	12.4	1840	12.8	1840
20-Jul-84	61	19.5	33.5	11.6		10.8	1450	14.8	1390	14.0		20.8	1330	14.3	1335	12.8	1335	14	1340

Footnote (a.) Approximate velocity gradient between sampling locations E and H.

Note: SSS = Supernatant suspended solids in mg/l after 30 minutes of settling.
MLSS = Mixed liquor suspended solids in mg/l.

TABLE D3 FLOCCULATION PROFILES IN END OF AERATED SOLIDS CONTACT TANK AT MEDFORD.

DATE	(a.) Approximate Velocity Gradient, 1/sec.	Aerated Solids Contact Tank Sampling Locations.											
		E			F			G			H		
		SSS	MLSS	DO	SSS	MLSS	DO	SSS	MLSS	DO	SSS	MLSS	DO
27-Jun-84	78	23.6	1250		15.2	1280		11.6	1300		13.2	1330	
27-Jun-84	89	28.7	930		22.0	850		18.0	840		13.6	1440	
28-Jun-84	98	14.8	1700		16.4	1710		9.6	1710		10.8	1700	
28-Jun-84	107	21.0	1270		13.6	1270		14.0	1300		12.0	1260	
28-Jun-84	119	20.0	1440		15.0	1440		12.4	1420		12.1	1470	
17-Jul-84	61	16.0	1780	2.8	14.8	1745	1.7	17.6	1745	0.1	10.8	1710	0.1
17-Jul-84	108	20.0	1460	2.7	14.4	1530	2.1	13.9	1530	1.7	13.1	1600	1.5
17-Jul-84	61	21.6	1530	3.9	16.0	1420	3.1	13.6	1420	1.6	11.6	1310	
17-Jul-84	108	18.4	1280	2.8	14.4	1300	2.2	13.2	1300	2.0	13.2	1320	1.4
17-Jul-84	61	22.4	1330	1.5	16.4	1400	0.7	16.4	1400	0.1	12.4	1470	0.2
17-Jul-84	108	20.8	1450	1.8	18.0	1395	1.7	18.0	1395	0.6	13.6	1340	0.9
18-Jul-84	61	17.6	1450	3.9	12.0	1425	3.7	9.6	1425	2.4	7.6	1400	1.2
18-Jul-84	108	18.0	1320	4.4	15.2	1295	4.0	14.8	1295	3.8	10.8	1270	3.9
18-Jul-84	61	18.8	1270	4.9	15.2	1300	4.5	13.2	1300	3.3	10.8	1330	2.4
18-Jul-84	108	19.2	1250	4.6	14.8	1240	3.6	13.2	1240	3.2	11.0	1230	3.2
18-Jul-84	61	20.0	1250	4.2	16.0	1280	1.9	13.6	1280	1.7	12.8	1310	1.0
18-Jul-84	108	18.4	1330	3.6	16.8	1365	3.2	15.6	1365	3.2	13.6	1400	2.5

Footnote (a.) Approximate velocity gradient between sampling locations E and H.

Note: SSS = Supernatant suspended solids in mg/l after 30 minutes of settling.
MLSS - Mixed liquor suspended solids in mg/l.
DO = Dissolved oxygen concentration in mg/l.

TABLE D4 FLOCCULATION PROFILES IN MIDDLE OF AERATED SOLIDS CONTACT TANK AT MEDFORD.

DATE	(a.) Approximate Velocity Gradient, 1/sec.	Aerated Solids Contact Tank Sampling Locations											
		C1			C2			D2			D3		
		SSS	MLSS	DO	SSS	MLSS	DO	SSS	MLSS	DO	SSS	MLSS	DO
08-Aug-84	52	21.2	1180	2.6	14.4	-	1.6	13.6	-	0.9	21.2	1820	0.8
09-Aug-84	117	16.6	1170	2.7	16.4	-	2.5	18.8	-	2.6	22.0	1150	2.8
18-Aug-84	52	18.8	1270	2.[illegible]	18.0	-	1.8	22.0	-	0.8	19.6	1130	0.5
30-Aug-84	117	18.4	[illegible]	2.1	21.6	-	1.5	27.6	-	0.8	2[illegible].8	1190	1.0
08-Aug-84	52	21.2	1280	2.1	28.0	-	0.6	28.0	-	0.1	26.0	1260	0.1
08-Aug-84	117	21.6	1240	1.7	18.[illegible]	-	0.8	23.6	-	1.4	25.5	1280	1.0

Footnote (a.) Approximate velocity gradient between sampling locations E and H.

Note: SSS = Supernatant suspended solids in mg/l after 30 minutes of settling.
MLSS = Mixed liquor suspended solids in mg/l.
DO = Dissolved oxygen concentration in mg/l.

TABLE D5 CLARIFIER SUSPENDED SOLIDS MEASUREMENTS AT MEDFORD.

Date	Clarifier Sampled	Clarifiers In-Service	Clarifier Sample Locations									
			I		J1		J2	J3	K	L	M	N
			SSS	MLSS	SSS	MLSS	SSS	SSS	TSS	TSS	TSS	TSS
26-Jun-84	2	1,2,4	16.8	1633	15.2	970			21.2	58.9	21.2	10.5
27-Jun-84	2	1,2,4	12.8	1310	19.5	1310			12.0	78.8	17.0	11.2
28-Jun-84	2	1,2,4	11.2	1370	10.4	1210			11.6	56.6		7.7
29-Jun-84	2	1,2,4	16.0	910	17.2	270			7.6	10.8	5.3	5.0
19-Jul-84	4	1,3,4	12.3		12.8				8.0	14.8	6.5	5.0
20-Jul-84	4	1,3,4	10.7		12.8				9.6	16.0	3.1	3.2
20-Jul-84	3	1,3,4	12.8		15.2				16.4	9.6	3.1	3.8
06-Aug-84	2	1,2,3	31.9	1336	32.1	975		20.5		22.8	8.8	
09-Aug-84	2	1,2,3	21.6	1360	16.4	1200	14.8	18.0		12.0	4.5	
09-Aug-84	2	1,2,3	22.4	1300	20.8	1120	20.0	19.6		10.8	6.5	

Note: SSS = Supernatant suspended solids in mg/l after 30 minutes of settling.
MLSS = Mixed liquor suspended solids in mg/l.
TSS = Total suspended solids in mg/l.

TABLE D6 CLARIFIER SLUDGE BLANKET PROFILES AT MIDFORD.

Date	Clarifier Sampled	Sludge Blanket Depth In Feet At Specified Sample Locations					
		I	II	III	IV	V	VI
26-Jun-84	2	(a.)	0.0	0.8	1.2	1.8	4.5 (b.)
27-Jun-84	2	(a.)	0.6	1.0	1.0	0.9	3.8 (b.)
28-Jun-84	2	4.0	0.7	0.4	0.9	1.0	0.6
29-Jun-84	2	(a.)	0.9	0.4	0.8	0.8	1.1 (b.)
19-Jul-84	4	(a.)	0.0	0.5	1.0	1.0	0.8
20-Jul-84	4	3.0	2.0	2.0	1.2	1.5	1.2
20-Jul-84	3	0.5	0.9	1.0	1.5	0.7	1.0
06-Aug-84	2	(a.)	0.7	1.4	1.3	0.5	1.3
09-Aug-84	2	0.7	1.0	1.1	1.4	1.3	0.5
09-Aug-84	2	0.2	0.5	1.0	1.2	1.1	0.8

Footnotes (a.) Mixed from top to bottom.
(b.) Bands of concentrated solids also noted above blanket.

APPENDIX E

CHILTON FIELD INVESTIGATION DATA

TABLE E1 CHILTON FLOW AND BOD DATA.

Date	Flow, mgd			Total 5-day BOD, mg/l					Soluble 5-Day BOD mg/l			Carb. 5-Day BOD mg/l			Sol. Carb. 5-Day BOD mg/l		
	Raw Infl.	S.C. Recyc.	Sec. Waste	Raw Infl.	Prim. Effl.	T.F. Effl.	Sec. Effl.	R.S.S.	Prim. Effl.	T.F. Effl.	Sec. Effl.	Prim. Effl.	T.F. Effl.	Sec. Effl.	Prim. Effl.	T.F. Effl.	Sec. Effl.
PHASE I																	
01-Jul-84	0.466	0.161	0.02048														
02-Jul-84	0.641	0.216	0.02039			407	10.0			14.0	1.6					9.3	1.5
03-Jul-84	0.546	0.218	0.02035					1763									
04-Jul-84	0.516	0.177	0.02031	337	182	271	5.5		131	18.3	3.6	150.0	120.0	3.5	90.0	12.6	4.2
05-Jul-84	0.690	0.224	0.02032	302				1032									
06-Jul-84	0.903	0.259	0.01688		222	272	20.0		81.0	14.0	2.5	92.0	67.0	5.8	67.0	9.7	2.4
07-Jul-84	0.435	0.000	0.01490					519									
08-Jul-84	0.450	0.178	0.01412														
09-Jul-84	0.634	0.406	0.01257		237	146	11.0		32.0	3.3	1.0	64.0	153.0	3.6	33.0	3.0	1.0
10-Jul-84	0.679	0.452	0.00200	333				402									
11-Jul-84	0.617	0.412	0.00000	420													
12-Jul-84	0.528	0.356	0.00000	245													
13-Jul-84	0.662	0.443	0.00000														
14-Jul-84	0.511	0.345	0.00000														
15-Jul-84	0.442	0.298	0.00000														
* 16-Jul-84	0.630	0.421	0.00000														
17-Jul-84	0.564	0.443	0.00900	332													
* 18-Jul-84	0.492	0.295	0.01321	100		636	10.0	1630		19.0	2.5		104.0	8.0		9.2	1.0
19-Jul-84	0.460	0.250	0.01444	355													
20-Jul-84	0.517	0.234	0.01498		116	218	2.8	717	66.0	6.8	1.3	72.0	81.0	1.2	54.0	1.8	1.0
21-Jul-84	0.372	0.161	0.01379														
22-Jul-84	0.352	0.155	0.01433														
* 23-Jul-84	0.601	0.253	0.01499		291	120	6.0	880	47.0	7.5	1.4	65.0	46.0	2.9	45.0	4.7	1.6
24-Jul-84	0.546	0.231	0.01147	315													
25-Jul-84	1.751	0.489	0.00053	221	136	163	3.0	786	71.0	5.0	1.4	103.0	45.0	1.9	64.0	2.3	1.0
26-Jul-84	0.549	0.146	0.00735	141													
* 27-Jul-84	0.616	0.273	0.00833		108	185	3.2	750	58.0	5.5	1.1	76.0	78.0	1.3	38.0	6.3	1.6
28-Jul-84	0.996	0.501	0.00840														
29-Jul-84	0.365	0.197	0.00735														
* 30-Jul-84	0.615	0.321	0.00740		66	205	3.6	540	35.0	5.4	1.8	56.0	82.0	1.5	25.0	2.5	0.5
31-Jul-84	1.102			134													

continued.

TABLE E1 CHILTON FLOW AND BOD DATA continued.

Date	Flow, mgd			Total 5-day BOD, mg/l					Soluble 5-Day BOD mg/l			Carb. 5-Day BOD mg/l			Sol. Carb. 5-Day BOD mg/l		
	Raw Infl.	S.C. Recyc.	Sec. Waste	Raw Infl.	Prim. Effl.	T.F. Effl.	Sec. Effl.	R.S.S.	Prim. Effl.	T.F. Effl.	Sec. Effl.	Prim. Effl.	T.F. Effl.	Sec. Effl.	Prim. Effl.	T.F. Effl.	Sec. Effl.
PHASE II																	
* 01-Aug-84	0.530	0.279	0.00759	307	180	197	4.8	452	91.0	15.0	2.1	114.0	103.0	3.4	94.0	11.0	1.1
02-Aug-84	0.552	0.290	0.00762	207													
03-Aug-84	0.608	0.318	0.00791		109	261	6.3		77.0	11.0	3.7	81.0	120.0	2.3	63.0	9.2	2.3
04-Aug-84	0.438	0.233	0.00726					638									
05-Aug-84	0.732	0.378	0.00767														
06-Aug-84	0.622	0.325	0.00752														
* 07-Aug-84	0.696	0.361	0.00754	242	140	142	4.6	390	48.0	8.0	2.3	67.0	76.0	2.1	42.0	4.2	1.7
* 08-Aug-84	0.591	0.309	0.00751	316	132	174	4.2	762	17.0	6.3	1.2	73.0	89.0	2.4	12.0	2.3	1.3
09-Aug-84	0.587	0.307	0.00750	171													
10-Aug-84	0.571	0.299	0.00752		62	278	3.8	480	6.9	1.9	1.0	46.0	78.0	1.0	1.0	1.0	1.0
11-Aug-84	0.436	0.233	0.00783														
PHASE III																	
12-Aug-84	0.566	0.296	0.00720														
13-Aug-84	0.623	0.325	0.00748														
* 14-Aug-84	0.369	0.298	0.00746	86	142	74	18.0		9.0	2.8	2.5	10.0	24.0	7.2	4.8	1.6	1.4
* 15-Aug-84	0.526	0.277	0.00739	152	234	168	12.0	948	16.0	3.7	2.6	37.0	79.0	6.4	21.0	3.3	1.7
16-Aug-84	0.540	0.274	0.00854	227				788									
17-Aug-84	0.599	0.314	0.00882		86	113	14.0		41.0	5.1	4.6	68.0	24.0	6.2	35.0	3.8	3.5
18-Aug-84	0.591	0.365	0.00863					485									
19-Aug-84	0.686	0.315	0.00764														
* 20-Aug-84	0.520	0.274	0.00834		156	165	7.3		10.0	3.8	1.4	39.0	44.0	3.9	6.9	3.8	1.0
* 21-Aug-84	0.596	0.311	0.00832					1160									
* 22-Aug-84	0.531	0.279	0.00830	168													
23-Aug-84	0.498	0.263	0.00838	189													
Averages																	
Phase I	0.626	0.284	0.0105	270	170	262	7.5	902	48.9	9.9	1.8	84.8	86.2	3.3	52.0	6.2	1.6
II	0.578	0.303	0.0076	249	109	214	4.6	548	48.0	8.4	2.1	76.2	93.2	2.2	42.4	5.5	1.5
III	0.563	0.294	0.0080	164	145	130	12.8	823	19.0	4.4	2.8	38.5	42.8	5.9	16.9	3.1	1.9
Overall	0.603	0.290	0.0094	241	146	222	7.9	792	41.6	8.3	2.1	71.4	78.5	3.6	40.9	5.4	1.6

Note: * High concentrations of metals in raw effluent caused inhibition in BOD test.
T.F. = Trickling Filter.
R.S.S. = Return Secondary Sludge.

TABLE E2 CHILTON SUSPENDED SOLIDS CONCENTRATION, VOLATILE SUSPENDED SOLIDS PERCENT, MIXED LIQUOR PARAMETERS, AND SLUDGE BLANKET DEPTHS.

Date	Suspended Solids, mg/l						Volatile Suspended Solids, percent					Mixed Liquor Parameters		Sludge Blanket Depth, feet			
	Raw Infl.	Prim. Effl.	T.F. Effl.	Sec. Effl.	R.S.S.	MLSS	Prim. Effl.	T.F. Effl.	Sec. Effl.	R.S.S.	MLSS	30-Minute Settleability	SVI	Inside Floc Well	Outside Floc Well	At Scum Baffle	At Side Wall
PHASE I																	
01-Jul-84												150					
02-Jul-84			2534	14				48.4	57.1								
03-Jul-84					8300	4750				48.7	48.0	100	21	1.2	1.2		1.5
04-Jul-84	308	130	3585	29			15.3	47.2	27.6								
05-Jul-84	482				5500	3460				45.9	46.8	60	17	0.2	0.2		0.2
06-Jul-84		94	1326	15			53.2	48.1	53.3								
07-Jul-84					3040	2500				46.4	48.4	45	17	0.0	0.0		0.0
08-Jul-84																	
09-Jul-84		72	990	21			33.3	50.0	52.3								
10-Jul-84	272				3320	2740				44.2	46.1			0.0	0.0	0.0	0.0
11-Jul-84	284																
12-Jul-84	468																
13-Jul-84												40					
14-Jul-84												45					
15-Jul-84																	
16-Jul-84		128	1200	15			50.0	44.2	46.7			70					
17-Jul-84	220				7500	3643				45.7	44.7	80	22	0.0	0.0	0.0	0.0
18-Jul-84	220		1490	7				45.9	15.4			85					
19-Jul-84	420				8543	3010				46.6	46.3	90	30	0.0	0.0	0.0	0.0
20-Jul-84		100	1090	5			64.0	47.7	60.0			75					
21-Jul-84					5140	3260				47.5	47.6			0.0	0.0	0.0	0.0
22-Jul-84																	
23-Jul-84		108	530	10			40.7	39.6	15.0			95					
24-Jul-84	236				1470	625				44.2	44.8	90	144	0.0	0.0	0.0	0.0
25-Jul-84	268	160	1540	3			42.5	49.3	20.0			70					
26-Jul-84	232				6125	2190				48.2	46.6	65	30				
27-Jul-84		116	1030	2			44.0	41.9	12.5			60					
28-Jul-84					4800	2300				48.0	47.8	70	30	0.0	0.0	0.0	0.0
29-Jul-84												70					
30-Jul-84		140	1460	5			45.7	46.6	17.0			80					
31-Jul-84	240				5400	2500				48.5	48.8	80	32				

continued.

TABLE E2 CHILTON SUSPENDED SOLIDS CONCENTRATION, VOLATILE SUSPENDED SOLIDS PERCENT, MIXED LIQUOR PARAMETERS, AND SLUDGE BLANKET DEPTHS continued.

Date	Suspended Solids, mg/l						Volatile Suspended Solids, percent					Mixed Liquor Parameters		Sludge Blanket Depth, feet			
	Raw Infl.	Prim. Effl.	T.F. Effl.	Sec. Effl.	R.S.S.	MLSS	Prim. Effl.	T.F. Effl.	Sec. Effl.	R.S.S.	MLSS	30-Minute Settleability	SVI	Inside Floc Well	Outside Floc Well	At Scum Baffle	At Side Wall
PHASE II																	
01-Aug-84	395	156	1200	5			48.7	49.0	52.1								
02-Aug-84	176				4320	1560				49.5	46.8	50	32	1.0	1.0	1.0	1.5
03-Aug-84		104	1620	4			38.8	45.6	37.5								
04-Aug-84					3180	1720				45.9	45.3	50	29	1.0	1.0	1.0	1.0
05-Aug-84																	
06-Aug-84																	
07-Aug-84	228	124	850	6	2650	1600	41.9	45.9	43.3	49.2	47.6	45	27	0.5	0.5	0.5	0.5
08-Aug-84	298	82	950	5			51.2	45.2	26.0								
09-Aug-84	700				5920	2470				38.2	40.0	65	26	0.5	0.5	0.5	0.5
10-Aug-84		90	1150	5			50.0	47.0	28.0								
11-Aug-84					4050	3575				40.7	49.7	80	22	1.2	1.5	1.5	1.5
PHASE III																	
12-Aug-84																	
13-Aug-84																	
14-Aug-84	272	63	870	22	9833	5112	46.0	41.4	41.8	46.5	45.0	140	27	1.0	1.2	1.0	1.2
15-Aug-84	356	88	540	14			31.8	41.7	21.4								
16-Aug-84	320				8271	4083				47.0	47.2	95	19	0.2	0.5	0.8	0.8
17-Aug-84		130	348	11			73.8	49.4	54.5								
18-Aug-84					2833	1710				50.9	48.3	50	29	0.5	0.5	0.9	0.9
19-Aug-84																	
20-Aug-84		94	540	11			54.2	47.4	45.4								
21-Aug-84		52	268	15	8740	4220	54.9	53.7	50.0	54.8	50.2	90	21	1.2	2.0	2.0	1.2
22-Aug-84	264	43	1293	8	8200	4300	53.0	50.0		49.8	47.9	105	84	0.4	0.5	0.5	0.5
23-Aug-84	312				4560	5040				47.0	47.3	80	16				
Averages																	
Phase I	298	116	1521	12	5391	2826	43.3	45.5	34.3	46.7	46.9	76	38	0.2	0.2	0.0	0.2
II	359	111	1154	5	4026	2201	44.5	46.5	35.8	44.7	47.5	58	27	0.6	0.9	0.9	1.0
III	305	83	643	14	6940	4211	52.3	47.3	42.6	48.7	47.6	93	33	0.7	0.9	1.0	0.9
Overall	313	105	1198	11	5583	3062	46.3	46.2	36.7	46.8	47.2	76	34	0.5	0.6	0.6	0.6

Note: T.F. = Trickling Filter.
R.S.S. = Return Secondary Sludge.

TABLE E3 CHILTON TEMPERATURE, pH, AND DISSOLVED OXYGEN MEASUREMENTS.

Date	Temperature, degrees C		pH		Dissolved Oxygen Profile, mg/l														
	Raw Infl.	Final Effl.	Raw Infl.	Final Effl.	Raw Infl.	Prim. Effl.	T.F. Effl.	T.F./R.S.S. M's Point	Influent of Aeration Tanks #1	#2	#3	#4	S.C. Channel Infl.	Effl.	Flow Center Well Depth 1'	5'	9'	Sludge Blank.	Sec. Effl.
PHASE I																			
01-Jul-84			7.9	7.7															
02-Jul-84			7.8	8.1															
03-Jul-84	17.5	19.0	8.0	8.0	3.4	3.7	7.2		4.4	6.6	8.7	8.1	7.7	7.1				3.9	5.3
04-Jul-84			7.8	7.6															
05-Jul-84	17.0	18.5	7.8	8.0	2.8	1.8	7.1		5.0	7.6	9.1	8.9	8.1	7.4				3.4	6.1
06-Jul-84			7.9	7.9															
07-Jul-84	16.5	17.5	8.0	7.8	1.7	1.3	8.8		8.2	8.8	11.2	10.2	9.3	9.1				5.0	6.0
08-Jul-84			7.9	8.0															
09-Jul-84			7.9	8.1															
10-Jul-84	17.5	18.5	8.0	7.9	3.7	6.8	8.3	7.4	7.7	10.3	11.1	10.1	8.1	8.2	5.2	5.0	5.0	3.1	5.7
11-Jul-84			7.8	8.0															
12-Jul-84			7.8	7.9															
13-Jul-84			7.8	7.7															
14-Jul-84			7.7	7.6															
15-Jul-84			7.6	7.7															
16-Jul-84			7.9	8.1															
17-Jul-84		20.0	7.8	7.5		4.8	6.5	4.8	3.2	5.6	8.6	8.6	8.8	8.7	6.2	6.0	6.0	3.0	6.8
18-Jul-84			7.9	7.7															
19-Jul-84		19.5	7.7	6.9		4.9	6.5	2.8	1.0	2.8	7.4	8.7	8.2	7.7	6.1	6.3	6.5	5.6	7.9
20-Jul-84			7.9	8.1															
21-Jul-84		19.5	7.7	8.0		4.8	7.7	5.7	7.2	5.3	9.0	8.9	8.3	8.0	5.7	5.0	5.1	5.5	6.8
22-Jul-84			7.7	8.2															
23-Jul-84			7.8	8.0															
24-Jul-84		21.0	7.9	7.8		6.2	7.7	6.5	7.2	4.0	9.4	6.6	7.9	8.0	6.4	6.4	6.4	5.7	6.8
25-Jul-84			7.8	8.1															
26-Jul-84			7.9	7.7															
27-Jul-84			7.8	8.1															
28-Jul-84	18.5	19.0	7.7	7.9	2.9	4.4	6.1	3.5	1.2	3.3	8.1	9.2	9.0	7.0	7.4	6.8	6.8	6.4	9.0
29-Jul-84			7.7	7.8															
30-Jul-84			7.8	8.2															
31-Jul-84			8.1	7.7															

continued.

TABLE E3 CHILTON TEMPERATURE, pH, AND DISSOLVED OXYGEN MEASUREMENTS continued.

Date	Temperature, degrees C		pH		Dissolved Oxygen Profile, mg/l														
	Raw Infl	Final Effl	Raw Infl.	Final Effl.	Raw Infl.	Prim. Effl.	T.F. Effl.	T.F./R.S.S. Mix Point	Influent #1	of Aeration #2	Tanks #3	#4	S.C. Infl.	Channel Effl.	Floc. 1'	Center Well 5'	Depth 9'	Sludge Blank.	Sec. Effl.
PHASE II																			
01-Aug-84																			
02-Aug-84		20.5	7.7	7.7		4.0	6.6	6.0			6.8	7.6	7.2	6.1	5.0	5.0	5.0	4.8	6.7
03-Aug-84																			
04-Aug-84		20.5	7.7	7.6		4.2	6.8	6.0			9.8	9.8	8.8	6.8	3.8	3.8	3.6	3.6	5.2
05-Aug-84																			
06-Aug-84																			
07-Aug-84		21.5	7.6	7.3		4.0	6.5	5.8			7.2	7.0	6.7	7.1	5.4	5.4	5.0	5.1	5.0
08-Aug-84																			
09-Aug-84		21.0	8.0	7.6		3.8	5.9	5.0			5.3	5.6	4.9	5.6	5.0	5.0	5.0	4.8	6.0
10-Aug-84																			
11-Aug-84	14.5	20.0	7.9	8.3	4.3	4.8	6.9	7.5			9.4	9.3	7.0	7.6	5.5	5.4	5.4	5.4	6.8
PHASE III																			
12-Aug-84																			
13-Aug-84																			
14-Aug-84		20.0	7.7	7.8		3.8	7.6	7.9					4.9	4.2	1.4	1.3	1.1	1.2	1.8
15-Aug-84																			
16-Aug-84		20.0				5.3	7.6	7.7					5.0	4.6	2.2	2.0	2.0	2.0	2.5
17-Aug-84																			
18-Aug-84	21.0	20.0	7.8	7.7	8.9	3.8	7.1	7.4					5.1	3.9	1.5	1.5	1.2	1.2	2.2
19-Aug-84																			
20-Aug-84																			
21-Aug-84		20.5	8.1	7.8		5.0	7.3	7.5					4.6	4.4	2.0	1.9	1.2	1.2	2.7
22-Aug-84		21.0	7.8	7.5		5.1	8.2	8.3					3.6	3.6	0.9	0.2	0.2	0.4	1.9
23-Aug-84																			
Averages																			
Phase I	17.4	19.2	7.8	7.9	2.9	4.3	7.3	5.1	5.1	6.0	9.2	8.8	8.4	7.9	6.2	5.5	6.0	4.7	6.9
II	18.5	20.7	7.8	7.7	4.3	4.2	6.5	6.1			7.7	7.9	6.9	6.6	4.9	4.9	4.8	4.7	5.9
III	21.0	20.3	7.9	7.7	8.9	4.6	7.6	7.8					4.8	4.1	1.6	1.4	1.1	1.2	2.2
	18.1	19.9	7.8	7.8	2.8	4.3	7.2	6.2	5.1	6.0	8.7	8.5	7.0	6.6	4.4	4.2	4.1	3.8	5.4

Note: T.F. = Trickling Filter.
R.S.S. = Return Secondary Sludge.

TABLE E4 CHILTON -FLOCCULATION AND SECONDARY CLARIFIER TOTAL SUSPENDED SOLIDS.

Date	T.F., mg/l		T.F./R.S.S. mg/l		Solids Contact Channel mg/l								Flocculator Center Well, mg/l				Secondary Clarifier TSS, mg/l		
					location #1		location #2		location #3		location #4		3' depth		12' depth		depth below effl. launder		
	SSS	TSS	SSS	MLSS	SSS	MLSS	SSS	MLSS	SSS	MLSS	SSS	MLSS	SSS	MLSS	SSS	MLSS	4'	8'	12'
PHASE I																			
06-Jul-84																	19	26	64
10-Jul-84																	24	30	36
17-Jul-84	106	992	86	4160	35	3483	37	3940	35	3517	38	4014	16	80	18	368			
19-Jul-84																			
21-Jul-84																	2	8	6
28-Jul-84	66	675	41	1986	10	2100	10	5000	11	2363	11	3320	25	760	9	232			
PHASE II																			
02-Aug-84																			
04-Aug-84	61	1750	60	2500	20	1700	44	9600	42	11840	27	2175	27	82	8	20			
07-Aug-84	55	2586	60	2320	26	2640	35	2520	29	7100	34	2400	10	640	7	200	4	12	12
09-Aug-84																			
PHASE III																			
16-Aug-84	76	1020	75	570	84	3540			76	3967	84	4667	40	790	35	260			
18-Aug-84																	8	12	17
21-Aug-84																	13	16	17
22-Aug-84	105	1750	130	1930	105	4070	84	4100	78	5125	56	3[illegible]	60	1175	33	143			
Averages																			
Phase I	86	839	64	3073	22	2792	23	4470	23	2940	25	3667	21	170	14	300	15	21	35
II	58	2130	60	2410	23	2170	40	6060	36	9470	31	2280	19	361	8	150	4	12	12
III	91	1325	100	1250	95	3805	80	4100	77	4546	70	4084	50	1083	34	202	11	14	17
Overall	78	1451	75	2244	47	2922	41	5048	45	5652	42	3346	30	538	18	217	12	17	25

Note: T.F. = Trickling Filter.
R.S.S = Return Secondary Sludge.
SSS = Total Suspended Solids in Supernatant After 30 Minutes Settling.
TSS = Total Suspended Solids.
MLSS = Mixed Liquor Suspended Solids.

TABLE E5 CHILTON SOLUBLE AND SOLUBLE CARBONACEOUS 5-DAY BOD PROFILES.

Date	Soluble 5-Day BOD Profile, mg/l									Soluble Carbonaceous 5-Day BOD Profile, mg/l								
	T.F. Effl.	T.F./R.S.S. Mix Point	Influent to Aeration Tanks #1	#2	#3	#4	S.C. Channel beg'nng	middle	end	T.F. Effl.	T.F./R.S.S. Mix Point	Influent to Aeration Tanks #1	#2	#3	#4	S.C. Channel beg'nng	middle	end
PHASE I																		
06-Jul-84																		
10-Jul-84																		
17-Jul-84																		
13-Jul-84	30.0	36.0	14.0	3.0	3.3	2.2	2.8		3.3	26.0	28.0	14.0	2.9	1.7	1.0	1.0		1.0
21-Jul-84																		
28-Jul-84	5.3	2.9	11.0	11.0	2.0	2.1	2.2		4.5	12.0	6.5	1.1	3.5	2.3	7.1	4.1		5.0
PHASE II																		
02-Aug-84	16.0	10.0			7.2	6.0	5.3		3.9	14.0	7.0			5.1	3.9	4.0		3.7
04-Aug-84																		
07-Aug-84																		
03-Aug-84	7.5	3.7			2.0	1.6	1.5		1.9	7.0	2.0			1.4	1.6	1.5		1.7
PHASE III																		
16-Aug-84																		
18-Aug-84	16.0	8.0					10.0	3.2	9.0	11.0	5.7					4.4	5.2	3.4
21-Aug-84																		
22-Aug-84	11.0	15.0					2.4	2.0	2.9	7.7	10.0					2.5	2.7	1.4
Averages																		
Phase I	17.7	19.5	7.5	2.0	2.7	2.2	2.5		3.9	19.0	17.3	7.5	3.2	2.0	4.1	2.6		3.0
II	11.0	6.9			4.6	3.0	3.4		2.9	10.9	5.4			3.3	2.0	2.0		2.7
III	13.5	11.5					6.2	3.5	6.0	9.4	7.9					3.5	4.0	2.4
Overall	14.3	12.6	7.5	2.0	3.6	3.0	4.0	3.5	4.3	13.1	10.2	7.5	3.2	2.6	3.4	2.9	4.0	2.7

Note: T.F. = Trickling Filter.
R.S.S = Return Secondary Sledge.
S.C. = Solids Contact.

APPENDIX F

QUALITY ASSURANCE/QUALITY CONTROL PROJECT PLAN*

QUALITY ASSURANCE PROJECT PLAN FOR POST CONSTRUCTION EVALUATION OF TRICKLING FILTER/SOLIDS CONTACT PROCESS

PROJECT TITLE: POST CONSTRUCTION EVALUATION OF TRICKLING FILTER/SOLIDS CONTACT PROCESS

PROJECT OFFICER: Mr. James Kreissl

PROJECT DIRECTOR: Mr. Arthur H. Benedict

PERFORMING ORGANIZATION: Brown and Caldwell

DURATION: January 10, 1984 to September 30, 1984

TYPE OF PROJECT: Task Order Contract 68-03-1818, Work Assignment 3

SUPPORTING ORGANIZATION: (LABORATORY AND DIVISION) Municipal Environmental Research Laboratory

APPROVALS:
Project Manager: Mr. Arthur H. Benedict
Extramural QA Officer: Mr. Larry L. Schaleger
Project Officer: Mr. James Kreissl
Project Officer's immediate supervisor: Mr. Carl A. Brunner
MERL QA Officer: Mr. Larry Khamphake

*Appendix F is taken from Appendix A of Work Assignment 3 Revised Work Plan for Task Order Contract 68-03-1818, June 6, 1984.

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Mr. Larry L. Schaleger, Extramural QA Officer, Brown and Caldwell

Mr. Sheldon Stone, Laboratory Director, Robert E. Lee & Associates

1.0 PROJECT DESCRIPTION

The purpose of Work Assignment 3 is to provide technical support to the U.S. Environmental Protection Agency (USEPA) for post construction evaluations (PCE) of selected trickling filter/solids contact (TF/SC) facilities in North America. A main objective of PCEs is to identify and rank cause-effect performance relationships for selected innovative/alternative (I/A) technologies. Performance relationships include those related to meeting final discharge limits, as well as those impacting non-I/A unit processes. PCEs are accomplished by investigating several operating facilities and identifying deficiencies or superior attributes common to the particular I/A technology being evaluated. Major areas of investigation include design, construction, operation and control (including start-up), sampling-testing procedures, laboratory facilities, management/administration, and major equipment characteristics.

Special studies may also be performed to resolve outstanding questions of national interest focusing on specific areas of design and operation of the I/A technology. The primary emphasis of the PCE for TF/SC will be the special studies which include field investigations at four treatment plants. At this time, field investigations are planned for treatment plants in Tolleson, Arizona; Oconto Falls, Wisconsin; Chilton, Wisconsin; and Medford, Oregon. The quality assurance project plan has been developed for these field investigations.

2.0 PROJECT ORGANIZATION AND RESPONSIBILITIES

The project organization and lines of authority are shown on Figure A-1. Larry Schaleger will be the quality assurance officer for the work assignment. He will assure the collection of valid measurement data and perform routine assessments of quality assurance/quality control laboratory data. Brown and Caldwell will supervise field investigations at Medford, Oregon; while, Jack Muir will supervise field investigations at Tolleson, Arizona. Robert E. Lee & Associates will supervise and perform field investigations at Oconto Falls and Chilton, Wisconsin.

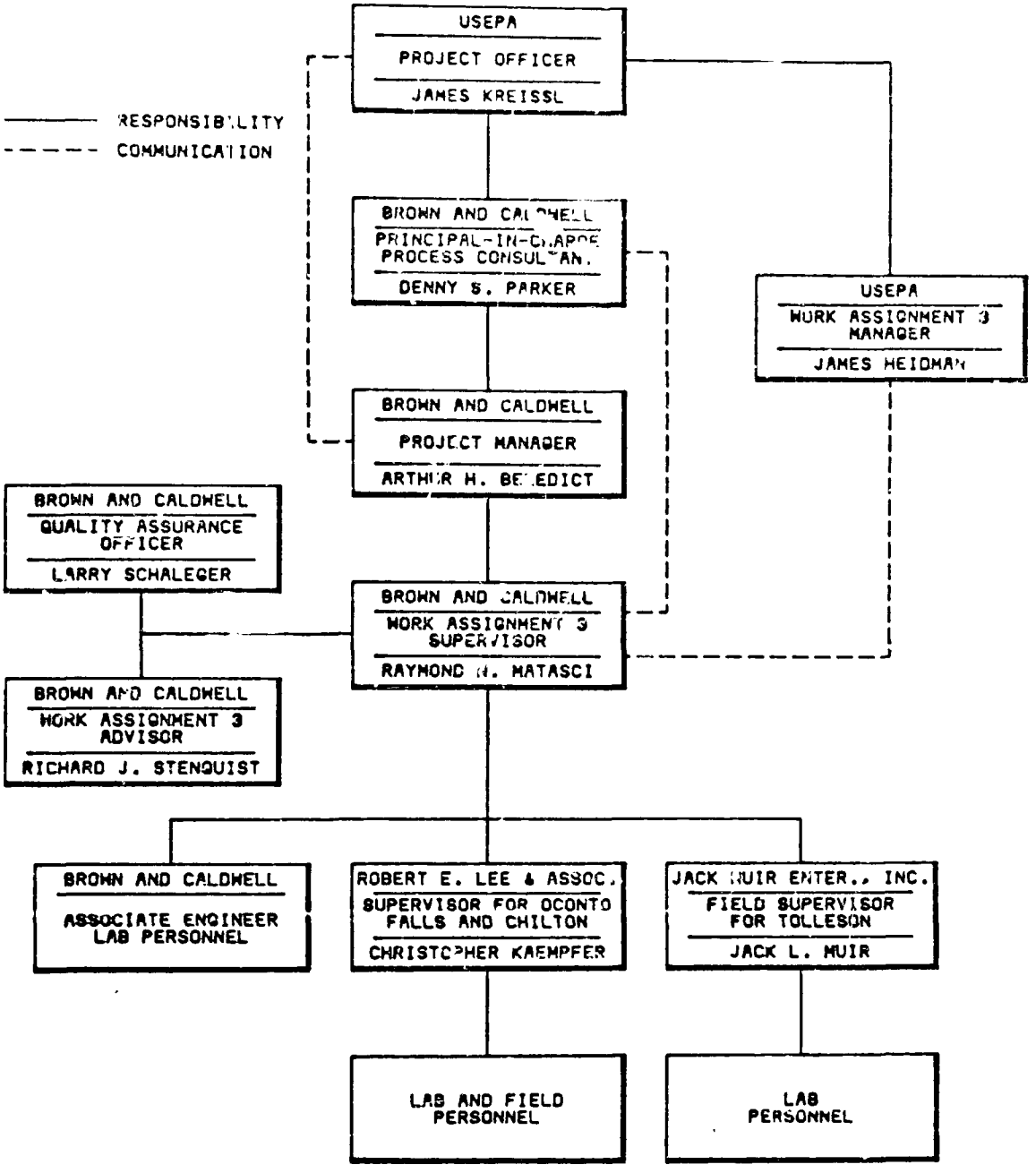

Figure F-1 USEPA Innovative/Alternative Technology Support Work Assignment 3 Organization Chart

3.0 QUALITY ASSURANCE OBJECTIVES

The quality assurance (QA) objectives for precision, accuracy, and completeness for each of the analytical parameters of interest are discussed here.

3.01 Analytical Parameters

The parameters to be monitored will vary, depending on specific plant requirements. They will be selected from the following four groups:

1. Biological oxygen demand (BOD)
2. Solids: total, suspended, volatile suspended
3. Phosphorus: total, orthophosphate
4. Nitrogen: ammonia, total Kjeldahl (TKN), nitrate, nitrite

3.02 Precision, Accuracy, and Completeness

Project QA objectives are summarized in Table A-1. Test methods, accuracy, precision, and completeness are shown in this table for each parameter to be measured.

3.03 Comparability

Because several different laboratories will be conducting analyses for the project, it is essential that the data be comparable from one laboratory to the next. This will be tested in two ways. First, common methodology will be established. This will include such details as specifying filters for determining suspended solids and soluble BODs. Second, at least one round of check samples will be sent to each laboratory for interlaboratory comparison. The results will be judged on the basis of the precision and accuracy objectives of Table A-1.

Table A-1 QA Objectives

Measurement parameter	Method	Accuracy, percent	Precision		Completeness, percent
			RSD,[a] percent	Concentration,[b] mg/l	
Biological oxygen demand (BOD)	Oxygen depletion	±10	±20	<[c]	90
Suspended solids	Gravimetric	-	±10	250	90
Total solids	Gravimetric	±10	±5 percent or ±4 mg	<[c]	90
Phosphorus	Total or ortho; ascorbic acid	±5	±5	1	90
Ammonia	Distillation with titrimetric finish	±5	±20 ±5	1 10	90
Total Kjeldahl nitrogen	Digestion, distillation, titrimetric finish	+5 to -15	±20 ±5	1 10	90 90
Nitrate nitrogen	Brucine sulfate	±10	±20	1.0	90
Nitrate and nitrite nitrogen	Devarda's or cadmium reduction	+5 to -15	±10	10	90
K	Flame AAS	±20	±20	100	90
Ca	Flame AAS	±20	±20	100	90
Mg	Flame AAS	±20	±20	100	90
Cd	Flame or furnace AAS	±20	±25	0.1	90
Cr	Flame or furnace AAS	±40	±25	1.0	90
Cu	Flame or furnace AAS	±40	±20	1.0	90
Hg	Cold vapor AAS	±20	±50	0.001	90
Pb	Flame or furnace AAS	±40	±50	1.0	90
Zn	Flame or furnace AAS	±20	±20	10	90
Temperature	Thermometer or probe	±5	±5	-	90
Length	Steel tape	±5	±5	-	90
Volume	Calculated from length measurements	±10	±10	-	90
Weight	Scale	±5	±10	-	90
Particle size	Screening	±10	±10	-	90
Oxygen content	Oxygen meter	±1, absolute	±10	5 to 20	90
Coliform	Multiple-tube fermentation	-	Determine on case-by-case basis	-	90
Salmonella	Biochemical/serological	-	<d	-	90

[a]RSD—relative standard deviation.
[b]Approximate concentration where RSD applies.
[c]Applies to all concentrations.
[d]Detectable/nondetectable.

4.0 SAMPLING PROCEDURES

Sampling procedures must include provisions to insure proper collection, preservation, and representativeness. Collection and representativeness are discussed in this section, while preservation methods are presented in Section 5.02. In this work assignment, sampling will be performed using a variety of methods.

Two types of samples will be collected--grabs and composites. Grab samples will be collected for mixed liquor and sludge streams. Composite samples will be collected for liquid streams with all samples being composited over a 24-hour period. The composite samples will be flow-proportional and be the manual or automatic type. Manual composites will be collected every one or two hours by field personnel or by discrete samplers. In each case, the 24-hour composites are developed by inspecting the plant flow charts and proportioning sample volume for each time increment according to the average flow over the same increment. Automatic composites will be collected with existing plant automatic samplers that develop flow-proportional composites.

Every effort will be made to insure that representative samples will be collected by choosing sampling points where streams are well mixed. These points can be just downstream of flumes or in areas of hydraulic mixing or aeration. Samples will be collected in the middle of channels at 0.4 to 0.6 depths from the bottom. In the case of primary sludges, three grab samples taken from the beginning, middle and end of the sludge removal cycle will be composited to provide a representative sample. Kemmerer samplers, which collect in situ samples, will be used to assess the state of flocculation along the mixed liquor channels and in the clarifier. These samplers consist of 2-liter plexiglass cylinders with ends that can be closed after the cylinders are filled with sample. These samples will receive a minimum of disturbance since they are not pumped or drawn through small orifices.

5.0 SAMPLE CUSTODY

The purpose of sample custody procedures is to document the identity of a sample and its handling from the time of collection until its ultimate disposal. The requirements for on-site laboratories will be less rigorous in general than those for commercial laboratories, although certain minimum requirements must be met.

5.01 Labeling and Chain-of-Custody Records

Each sample collected must be identified as to sample type, sampling location, date, and time of collection. A sample identification number must be assigned and the name of the person responsible for collection must be indicated on the sample container label. Additional information regarding preservatives, analyses requested, and special circumstances should also be noted on the label at the time of collection. Samples relinquished to a commercial laboratory will also be accompanied by an appropriate chain-of-custody record form for purposes of sample tracking.

5.02 Sample Preservation

For purposes of collection, preservation and storage, the analyses can be divided into three groups: BOD, solids, and phosphorus-nitrogen.

BOD - Samples should be tested immediately if possible. Storage at 4° C for a period not to exceed 24 hours is acceptable.

Solids (Residues) - Preservation of the sample is not practical; analysis should begin as soon as possible. When short storage times (less than 24 hours) are necessary, refrigeration at 4° C is recommended to minimize microbiological decomposition of solids. These samples are also suitable for pH measurements.

Phosphorus-Nitrogen - Analysis should be started within 24 hours. If this is not possible, the samples should be filtered, acidified to a pH of ≤ 2 with H_2SO_4 and stored in glass at 4° C.

6.0 ANALYTICAL PROCEDURES

The analytical methods to be used for project monitoring purposes are listed in Table A-2. Most of the procedures are taken from "Standard Methods for the Examination of Water and Wastewater."[1]

Table F-2 Methods for Analysis of Solid and Aqueous Samples

Measurement parameter	Reference[a]	Description	Approximate detection limit[b,d]
Solids (residues)			
Total	209A	Gravimetric	5 mg
Total volatile solids	209E	Gravimetric	5
Total suspended	209D	Gravimetric	10
Volatile suspended	209E	Gravimetric	25
Phosphorus			
Total	424C, F	Digestion; ascorbic acid colorimetric	.05
Ortho	424F	Ascorbic acid colorimetric	.05
Nitrogen			
Ammonia (I)	417A, B	Distillation; Nesslerization	0.2
Ammonia (II)	417A, D	Distillation; titrimetric	1.0
TKN	420; 417D	Digestion; distillation; titrimetric finish	1.0
Nitrate	EPA 325.1[c]	Brucine sulfate	0.1
Nitrate plus nitrite (I)	418E, 419	DeVarda's alloy reduction	2
Nitrate plus nitrite (II)	418C	Cadmium reduction; colorimetric finish	0.10
Biochemical oxygen demand	507	Oxygen depletion	0.5
Metals[e]			
Digestion	3010,3020	Acid digestion	-
K	322A	AAS	.05
Ca	311A	AAS	0.2
Mg	318A	AAS	.001
Cd	7130,7131	AAS	.002
Cr	7190,7191	AAS	.003
Cu	7210,7211	AAS	.002
Hg	7471	Cold vapor AAS	0.0001
Pb	7420,7421	AAS	.020
Zn	7950,7951	AAS	.002
Microbiological			
Total coliform	908	Multiple-tube fermentation	N/A
Fecal coliform	908C	Modified multiple-tube fermentation	N/A
Salmonella	912A	Concentration, selective enrichment and growth, biochemical test, serological confirmation	

[a]Methods are from Reference 1 unless otherwise indicated.

[b]Units expressed in mg/l unless otherwise noted.

[c]Reference 2.

[d]For the analysis of solids, e.g., compost or sludge, the numerical detection limit will typically be 50 times higher, and the units are expressed as mg/kg.

[e]Reference 4. Detection limits refer to flame AAS. Much lower limits are possible in the case of the heavy metals if graphite furnace AAS is employed.

7.0 INTERNAL QUALITY CONTROL CHECKS AND FREQUENCY

Each laboratory participating in the monitoring project will set up its own internal quality control (QC) program specific to the project. The program will consist of the analysis of replicates, spiked samples, laboratory control standards, and spiked reference standards, in addition to daily blank and calibration standards.

7.01 Biochemical Oxygen Demand

Each group of samples for BOD analysis--total or soluble, inhibited or uninhibited--will be done in duplicate at two different concentrations at the minimum, or in triplicate at three different concentrations at the maximum. In addition, analyses will also be performed for the following:

1. Dilution water blank.

2. Glucose-glutamic acid laboratory control standard, freshly prepared, in duplicate.

3. Seed blanks (settled primary effluent) at a concentration to give a BOD in the range of 0.5 to 1.5 mg/l in duplicate.

Analyses on dilution water blanks will be performed with each group of samples; while, analyses on control standards and seed blanks will be performed on a weekly basis. Control charts will be established for the accuracy of the laboratory control standard and for the precision of all replicate determinations. The American Public Health Administration recommendation of 200± 37 mg/l for the glucose-glutamic acid standard will be used as the basis for corrective action.

7.02 Solids (Residues)

Blanks and matrix replicates will be analyzed with each sample set, the proportion of matrix replicates will be one replicate for every 10 to 15 samples. Control charts for precision will be established for each of the three residues--total suspended solids, volatile suspended solids, and total solids.

7.03 Phosphorus

Calibration standards will be prepared and analyzed to generate a calibration curve embracing the range of concentrations to be measured. Blanks, calibration standards, blank spikes, matrix spikes, and matrix replicates should be analyzed with each sample

set. Spike recoveries and replicate analyses will be conducted on every tenth to fifteenth sample. Control charts will be established for recovery and replicate precision data.

7.04 Ammonia and TKN

These methods involve digestion (TKN only), distillation, and a colorimetric or titrimetric finish. The internal QC will be the same as that for phosphorus.

7.05 Nitrate and Nitrite

The brucine sulfate method determines nitrate alone, using colorimetry. Cadmium reduction takes nitrate to nitrite, also determined colorimetrically. DeVarda's alloy reduces both species to ammonia, which is then determined with either a titrimetric or colorimetric finish. In every case, blanks, calibration standards, blank spikes, matrix spikes, and matrix replicates will be analyzed with each sample set. Matrix spike recovery and replicate analyses will be performed on every tenth to fifteenth sample or with every set of less than ten samples. Control charts will be established on the basis of matrix spike recovery and replicate analyses.

7.06 Performance and System Audits

Performance check samples will be sent out to participating laboratories near the beginning of the project for the purposes of making a preliminary assessment of method equivalency, accuracy, and precision. Each check sample will be analyzed in duplicate and the results reported to the quality assurance officer who will compute statistics and compare these to those reported by the EPA in its round-robin studies.

Several of the laboratories involved in this project regularly participate in these EPA round-robin studies. The laboratory at Tolleson is certified by the Arizona State Department of Health Services. Certification for Robert E. Lee Laboratories within the State of Wisconsin is pending. No independent QA system audits are contemplated unless a serious QC problem is uncovered in the course of the project.

7.07 Preventive Maintenance

All major analytical equipment to be used for the project at each laboratory is under service contracts. Balances are calibrated annually.

General measures to be followed include the running of distilled water blanks to check on sterility and of positive controls to check on method selectivity. If necessary, the methods can be tested by obtaining specific cultures from the American Type Culture Collection.

7.08 Performance and System Audits

Performance check samples will be sent out to participating laboratories near the beginning of the project for the purposes of making a preliminary assessment of method equivalency, accuracy, and precision. Each check sample will be analyzed in duplicate and the results reported to the quality assurance officer who will compute statistics and compare these to those reported by the EPA in its round-robin studies.

The laboratories involved in this project regularly participate in the EPA's round-robin performance check sample studies. No independent QA system audits are contemplated unless a serious QC problem is uncovered in the course of the project.

7.09 Preventive Maintenance

All major analytical equipment to be used for the project at each laboratory is under service contracts. Balances are calibrated annually.

8.0 ASSESSMENT OF QUALITY ASSURANCE/QUALITY CONTROL DATA

Precision and accuracy will generally be evaluated by means of QC charts based on the internal QC data submitted to the quality assurance officer on a monthly basis. A preliminary assessment will be based on the results for a set of performance samples to be sent to the laboratories involved.

8.01 Accuracy

Matrix spike recovery data will be used to track accuracy. If a real sample is spiked with the compound to be determined at a level equal to or greater than that in the unspiked sample, then the percent recovery is calculated as follows:

$$\% R = \frac{C_s - C_u}{C_o} \times 100$$

where

C_s = amount measured in the spiked sample

C_u = amount measured in unspiked sample

C_o = amount of spike

For example, if the concentrations of ammonia in a solution are measured at 2 and 6, before and after spiking with 5 milligrams per liter (mg/l), then the percent recovery is (6-2) x 100/5 = 80 percent.

After a number of data points have been obtained, preferably 20, the standard deviation(s) is computed. Upper and lower control limits are set at $\pm 3S$; upper and lower warning limits are set at $\pm 2S$.

Subsequent data is plotted on the control chart. A datum outside the range of R $\pm 3S$ requires that corrective action be taken. A datum within the warning range of R $\pm 2S$ and R $\pm 3S$ tells the analyst to be especially watchful for systematic errors.

8.02 Precision[3]

Replicate data is used to evaluate precision. After a number of duplicates have been reported, preferably at least 20, upper and lower control limits on precision are computed as follows:

Let $R = C_2 - C_1$, where C_1 and C_2 are concentration values for a pair of duplicates. The $\bar{R}$ is the average of R over 20 or more duplicate determinations within a defined concentration range. The upper control limit (UCL) on R then is given by $3.27\ \bar{R}$. The lower limit is zero. The range over which a particular $\bar{R}$ is measured must be specified, since $\bar{R}$ is range-dependent. That is, precision at concentrations near the detection limit is not as good as precision obtained at much higher concentrations.

In principle, separate control charts need to be constructed for each range of measurements, e.g., 0 to 1, 1 to 10, and 10 to 100 mg/l. This will not be needed if the range of values of a parameter is fairly narrow.

9.0 CORRECTIVE ACTION

The control chart serves as an alert system for unsatisfactory or unexpected results. Any result falling outside of control limits, generally set at ±3 standard deviations from the mean or true value for spike recoveries or an equivalent measure for precision, indicates the need for corrective action. Any such result must be brought to the immediate attention of the QA coordinator.

The nature of the corrective action may take any number of forms, depending upon the perceived seriousness of the particular situation. In some cases, an isolated outlier cannot be explained. If prior and subsequent QC data fail to indicate a systematic error, then the result may simply be ignored. In no case, however, will more than 5 percent QC outliers be tolerated.

In the more usual case, the out-of-control situation will require a series of corrective measures designed to reestablish analytical validity. All analysis is stopped until the problem is identified and resolved. The best determination is made of when the problem first occurred; data collected after this critical point is discarded. If possible, all analyses since the last valid control check will be repeated. Analyses performed after the resolution of the problem must be accompanied by a higher percentage of spikes and replicates, say 5 percent rather than 10 percent until the QA coordinator is satisfied that the problem has been completely solved.

10.0 QUALITY ASSURANCE COORDINATION AND REPORTING

Quality assurance report forms for each parameter will be provided to each laboratory. At the end of each month, the completed forms will be mailed to the QA coordinator for review. The data collected initially will be used to establish QC control charts. The results of each laboratory as to precision, accuracy, and performance on check samples will be reviewed by the QA coordinator to ensure that interlaboratory data is comparable.

The QC control charts will then be returned to the individual laboratories along with instructions for their use. Each laboratory will be required to report out-of-control events to the QA coordinator within 48 hours of discovery.

The QA coordinator will write a monthly QA/QC report on the basis of all laboratory activity for that period. The report will include a discussion of out-of-control events reported and their remedial measures. The report will go to the project manager for review.

11.0 BIBLIOGRAPHY

1. "Standard Methods for the Examination of Water and Wastewater," APHA-AWWA-WPCF, 15th Edition, 1980.

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3. "Handbook for Analytical Quality Control in Water and Wastewater Laboratories," EPA-600/4-79-019, United States Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio, 1979.