COMPREHENSIVE PERFORMANCE EVALUATION OF THE BOZEMAN, MONTANA, WASTEWATER TREATMENT PLANT

EPA Contract No. 68-01-7108

ERM-Southeast, inc.

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From

ERM-Southeast, Inc.
2629 Sandy Plains Road
Suite 201
Marietta, Georgia 30066
404/971-4671

To

Ms. Marie Perez
U.S. EPA-OMPC (WH-547)
401 M Street, SW
Washington, D.C. 20460
(202) 382-7286

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EXECUTIVE SUMMARY

On September 15 to 17, 1987, a comprehensive performance evaluation (CPE) of the Bozeman, Montana, wastewater treatment plant was conducted to assist state and federal personnel in evaluating a 100% M/R grant request. During the CPE, administrative and operating records were reviewed, interviews with treatment plant personnel were conducted, and an inspection of the treatment plant was performed. Using the information collected during these procedures, an analysis of the major unit processes and the performance limiting factors was conducted.

Deficiencies were not found in the administrative, maintenance, or laboratory procedures used by the treatment plant personnel. A major unit process evaluation, however, indicated that the rapid infiltration system is not able to provide consistent fecal coliform removal. Other rapid infiltration (RI) systems have reported difficulty in removing fecal coliforms; thus, RI alone should not be counted on for fecal coliform removal. The rapid infiltration system does appear to have adequate ammonia removal and hydraulic capacity.

The inability of the rapid infiltration system to consistently provide fecal coliform removal was ranked as the factor most limiting the treatment plant's ability to meet its NPDES permit discharge limits. Operator Application of Concepts and Infiltration/Inflow were rated as factors having a major effect on performance on a periodic basis. Operator Application of Concepts was identified as a performance limiting factor primarily because the inspection team felt improvement could be made in the aggressiveness with which plant personnel attempted to solve the fecal coliform removal problem. Infiltration/Inflow increases the flow to the plant and could potentially cause hydraulic overloading of the plant.

SECTION 1

BACKGROUND

1.1 Introduction

The city of Bozeman, Montana, is located in south central Montana, approximately 50 miles north of the Montana-Wyoming border. Bozeman has a population of approximately 21,700. Including the outlying areas, the Bozeman treatment plant serves an estimated population of 23,000. The treatment plant consists of complete mix activated sludge with fine bubble aeration, followed by rapid infiltration. Sludge is handled by anaerobic digestion, followed by land application. Design flow for the treatment plant is 5.78 mgd. The current flow is 4.57 mgd.

The rapid infiltration system was designed to be used on a seasonal basis (June through September) primarily to remove ammonia (via nitrification) and fecal coliforms. From June to September, flow in the receiving stream is very low. Ammonia removal is thus needed to prevent ammonia toxicity to the fish in the receiving stream. The Bozeman wastewater treatment plant is also subject to effluent fecal coliform and chlorine residual limits. When the rapid infiltration system is not in use, a chlorination/dechlorination system is used to disinfect the wastewater and remove any residual chlorine. When the rapid infiltration system is in operation, however, effluent chlorination/dechlorination is not conducted. Nitrification in the rapid infiltration system is a biological process and high chlorine concentrations could potentially inhibit nitrification. Dechlorination facilities are also not available after the rapid infiltration system.

Fecal coliform concentrations in the effluent from the rapid infiltration system periodically exceed discharge permit limits. The city thus notified the Montana Department of Health and Environmental Sciences (MDHES) and the U. S. Environmental Protection Agency (EPA) that the rapid infiltration system has failed to provide the desired treatment. The city was, therefore, seeking 100% modification/replacement (M/R) grant funding to conduct the changes needed to bring the plant into compliance.

1.2 100% M/R Funding

The Clean Water Act as amended in 1977 (P.L. 95-217) provides incentives to municipalities for accepting the inherent risk of choosing innovative and/or alternative (I/A) technologies

for treating their wastewater. To offset this risk, Section 202(a)(3) of the Act allows the EPA to pay for 100% of the costs of modification or replacement of any of the innovative or alternative processes which fail to meet their design performance specifications. Before funding these 100% M/R grants, the Agency must (1) verify that the innovative or alternative portion of the project has caused the failures, or (2) has significantly increased the capital or operating and maintenance expenditures of the facility, and (3) the failure is not attributable to negligence on the part of any person. In addition to the above three factors, the Agency must also determine that the facility failed within a two-year period following the final inspection, longer than two years, is not hydraulically or organically overloaded, or does not lack an adequate O&M program.

1.3 Composite Correction Program

The Office of Research and Development of EPA developed the Composite Correction Program (CCP) approach for determining if existing POTWs can achieve compliance without major construction. This approach is described in EPA's Handbook No. EPA-625/6-84-008 entitled "Improving POTW Performance Using the Composite Correction Program (CCP) Approach" (EPA, 1984). The CCP approach has two parts: the comprehensive performance evalution (CPE) and the CCP. A CPE determines if the major unit processes are capable of treating the existing flows and loads; what design, operation, maintenance, and administrative factors are limiting the performance of the facility; and if a CCP can improve performance without major capital expenditures. A CCP, if applicable, would implement a program for correcting the factors identified as limiting performance. The CPE/CCP approach is recommended by EPA as one of the first steps in evaluating an M/R request.

1.4 Purpose of Study

At the request of the MDHES and the U. S. EPA, ERM-Southeast, Inc. (ERM-SE) performed a CPE of the Bozeman system from September 15-17, 1987. The results of this CPE are contained herein. The individuals participating in various portions of the CPE are presented in Table 1-1. Section 2 presents a description of the Bozeman system, while the results of the CPE are presented in Section 3. Appendix A discusses fecal coliform removal in rapid infiltration systems.

TABLE 1-1. Participants in the Bozeman, Montana, CPE

Name/Affiliation		Telephone Number
City of Bozeman		
Mr. Jim Wysocki	City Manager	
Mr. Richard Holmes	Public Works Director	406/586-3321
Mr. Don Noyes	Plant Superintendent	406/586-9159
Mr. Don Keil	Plant Chemist	406/587-3248
Bozeman Consultants		
Mr. Glenn Wood	Thomas, Dean, and Hoskins	406/487-0277
Mr. Gary Hendrix	Thomas, Dean, and Hoskins	406/761-3010
Montana Dept. Health and Environ. Science		
Mr. Craig Brawner	Project Officer for Bozeman POTW	406/444-2406
U. S. Environmental Protection Agency		
Ms. Marie Perez	National I/A Coordinator	202/382-7286
Mr. Stan Smith	Region VIII I/A Coordinator	303/293-1547
CPE Team		
Dr. John Zirschky, P.E.	ERM-Southeast, Inc.	404/971-4671
Mr. Bob A. Hegg, P.E.	Process Applications, Inc.	303/223-5787
CPE Technical Support		
Mr. Sherwood Reed	Cold Regions Res. and Engr. Lab.	603/646-4443
Mr. Glenn Taylor	ERM-Southeast, Inc.	404/971-4671
Mr. Don Deemer	ERM-Southeast, Inc.	404/971-4671

SECTION 2

FACILITY DESCRIPTION

2.1 Background

The basic system at Bozeman is a secondary treatment system employing the activated sludge process, including chlorination/dechlorination facilities. Design capacity for the system is 5.78, with current operations at 4.57. The rapid infiltration basins were specifically designed to provide ammonia removal via nitrification and final effluent polishing prior to discharge to an adjacent stream. The basins are only generally used during the warm months of June, July, August, and September. During this period, the natural flow in the stream is very low and the fish population would be sensitive to the normal ammonia concentrations in secondary effluent discharges. During the remainder of the year, the fish are less affected by the wastewater ammonia because the dilution by natural background flow is greater, so the RI basins are bypassed and the disinfected effluent is discharged directly to the stream (Table 2-1, Figures 2-1 and 2-2).

There are 19 RI basins in the system, most rectangular in shape (about 250 x 450 ft), with an infiltration area of about 2.6 acres (Figure 2-1). Only 14 of the basins are in routine service for a total infiltration area of 41 acres. The discharge valves to two basins (Basins 6 and 11) are broken and thus these basins are not used. Basins 17 through 19 infiltrate very slowly and are not used. The underdrain system may be responsible for the poor infiltration rate of these basins. Crushed pipes during construction, air locks in the underdrains and/or plugging of the underdrains due to intrusion of soil after construction, or differences in soil characteristics could be responsible for the lower infiltration rates in basins 17-19. All of the basins are grass covered to help sustain adequate infiltration and to avoid sealing of the infiltration surfaces with fine silt if bare soil had been used.

The underdrain piping is on 40-foot centers under the basins. The minimum design depth of burial is about four feet. Some of the pipes may be slightly less than four feet and some may be deeper than eight feet. The depth of burial was limited by the equipment used during construction. The underdrains were installed using a trenching machine which cuts a narrow trench and directly installs the plastic drain pipe. A drainage sock was not placed around the drainage pipe. The underdrains connect to a common header which then connects to the discharge flume located on a drainage ditch to the

TABLE 2-1. Unit Process Design Data at the Bozeman, Montana, POTW.

Preliminary Treatment	1-42" Mechanical Bar Screen, 1.25 clear space. 1-42" Manual Bar Screen, 1.25" clear space (backup). 3-Comminutor 1-18 ft by 18 ft by ? deep mechanically scraped grit basin.
Primary Clarifier	
Number	2-65 diameter by 8 ft deep
Weir Overland Rate	14/67 gpd/ft
Surface Overflow Rate	871 gpdsf
Hydraulic Detention Time	2.38 hrs @ 5.78 mgd.
Aeration Basins	
Number	4-55 ft by 55 ft by 20.25 ft deep.
Volume	458,200 gallons, each
Hydraulic Detention Time	7.6 hours
BOD Loading	25.8 lb/d/1000 cu. ft.
Aeration	3-200 HP five bubble diffusion @ 19' deep (each basin) 38.5% clean water efficiency.
Secondary Clarifiers	
Number	3-65 ft diameter by 12 ft deep.
Weir Overland Rate	9444 gpd/ft
Surface Overflow Rate	580 gpdsf
Hydraulic Detention Time	3.71 hours @ 5.78 mdg
Volume (total)	894,750 gallons
Disinfection	
Number	2-112 ft by 54 ft by 8 ft deep basins
Detention Time	69 minutes
Volume (total)	277,100 gallons
Surge Basin	
Number	1-50 ft diameter by 19 ft deep w/aeration
Volume	279,435 gallons

TABLE 2-1. Unit Process Design Data at the Bozeman, Montana, POTW (cont'd).

Anaerobic Digestion	
Primary	
Number	1-50 ft diameter by 28.5 ft. deep
Volume	374,517 gallons
Detention Time	22.2 days
Secondary	
Number	1-35 ft diameter by 28.5 ft
Volume	165,522 gallons
Sludge Dewatering	2-Dissolved Air Flotation Units
Sludge Storage	2 ponds with total of 404,800 cu. ft. capacity

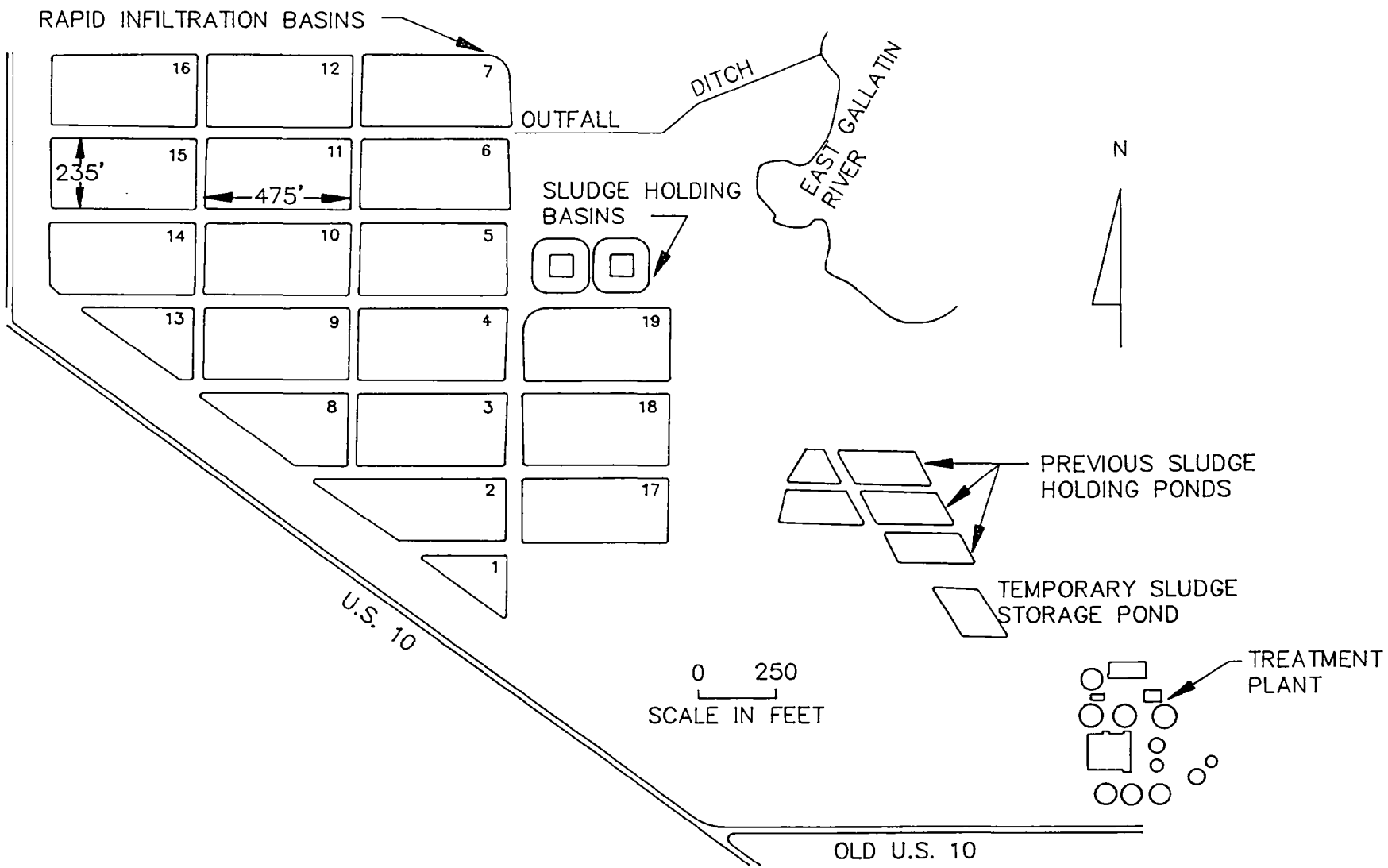


FIGURE 2–1. PLAN VIEW OF THE BOZEMAN, MT POTW.

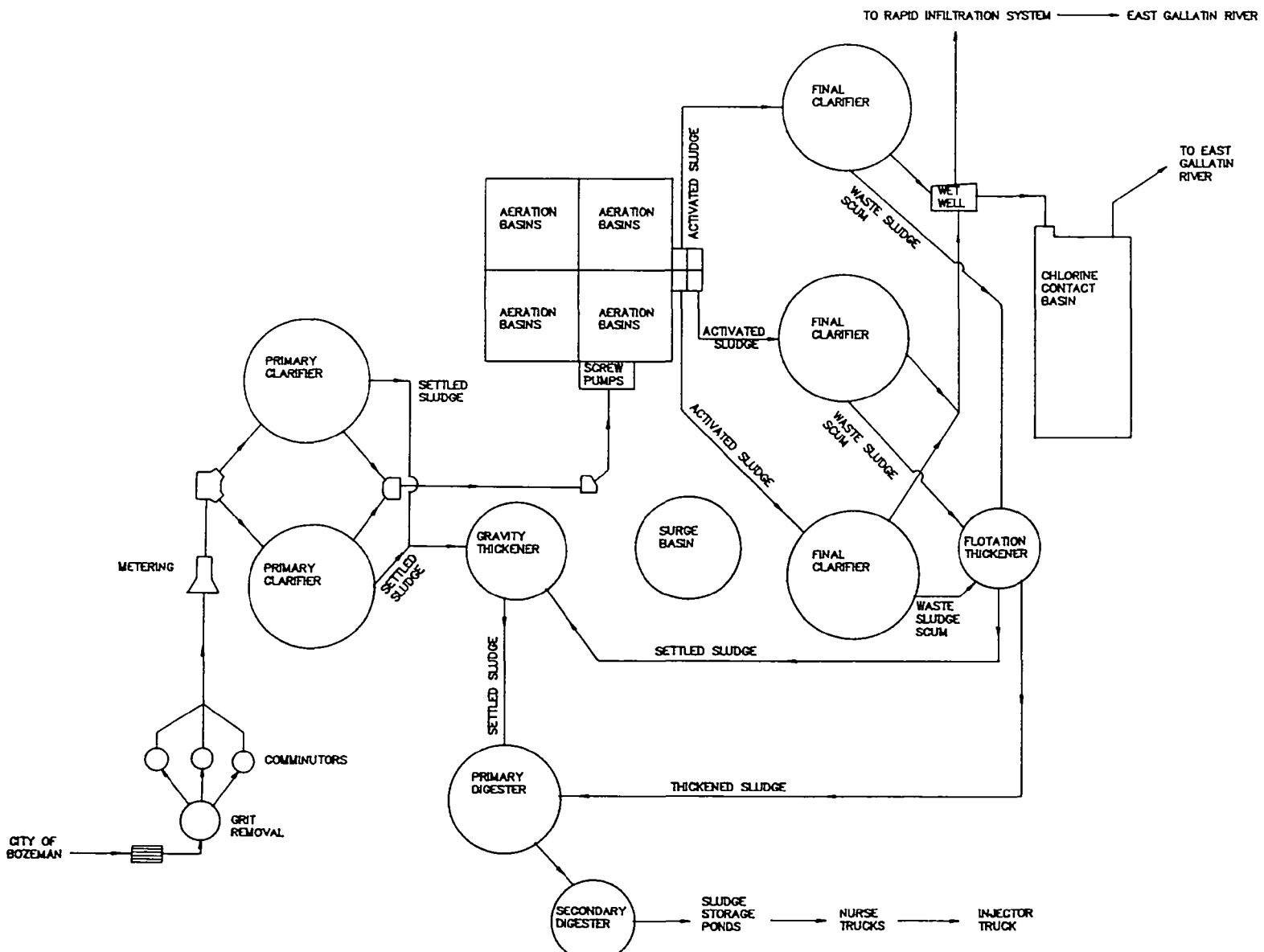


FIGURE 2–2. PROCESS FLOW DIAGRAM OF THE BOZEMAN, MT POTW.

receiving stream. There is no subsurface bedrock or other natural underground barrier to vertical flow. Thus, if the ground water table and/or percolate mound is not at a reasonably shallow depth the underdrains would only collect a portion of the applied effluent. The O&M manual for the treatment plant states that the underdrain system was designed to collect only a portion of the applied wastewater.

The natural soil profile in the RI basin area is a wind blown loess (clayey, sandy silt) overlying a glacial till. The two soil types became somewhat mixed during construction of the basins. The steady-state hydraulic conductivity of the soils was estimated about 0.78 inches per hour. This infiltration rate represents a soil with moderate permeability and which is near the low end of the range for soil types normally considered for use in RI systems.

A four- to six-day cycle is normally used for basin operation in the Bozeman system. The basins are filled to a depth of about 30 inches in about 8 to 12 hours, with the remaining 3 to 5 days in the cycle allowed for percolation through and drying of the infiltration surface to occur. During the approximately 120-day operational period (June through September) each basin experience approximately for 18 to 20 loading cycles.

2.2 NPDES Permit Limits

The Bozeman plant effluent is required to meet secondary standards (i.e. monthly average BOD_5 and TSS concentrations of 30 mg/L). Ammonia in the effluent is limited based upon un-ionized ammonia concentration in the receiving stream and ranges from 92 lbs/day in August to 938 lbs/day in April. The plant has met discharge requirements for BOD_5 and TSS except for the first three months of 1985. Fecal coliform limits are 1,414 organisms per 100 mL, with weekly peaks of 2,828/100 mL allowed. The chlorine residual limit is 0.02 mg/L (Table 2-2).

2.3 Description of the Claimed I/A Failure

The rapid infiltration system has not been able to consistently remove fecal coliforms from the effluent sufficiently to fully meet the effluent limits for the plant. The city maintains that the inability of the rapid infiltration system to remove fecal coliforms effectively has resulted in the continual inability of the treatment plant to meet its effluent discharge limits. The rapid infiltration

Table 2-2. NPDES Permit Limits for Bozeman, MT, POTW (mg/L, except as noted).

Parameter	Max. Month Average	Max. Weekly Average	Monitoring Frequency	Sample Type
Flow			Continuous	recorder
BOD_5	30	45	1/week	composite
TSS	30	45	1/week	composite
Cl residual	0.02	0.02	daily	grab
Fecal Coliforms org/100 ml	1414*	2828	2/week	grab
pH, std. units	6-9	6-9	daily	grab
Oil and Grease	10	10	daily	visual

Ammonia	Month	Mass Discharge Limit (lb/day)	Equivalent Conc. at Design Flow (mg/L)
	Jan	750	15.6
	Feb	613	12.7
	Mar	499	10.4
	Apr	938	19.5
	May	838	17.4
	Jun	410	8.50
	Jul	123	2.55
	Aug	92	1.91
	Sep	250	5.19
	Oct	306	6.35
	Nov	438	9.09
	Dec	836	17.3

* geometric mean

system was funded was an alternative construction grants project. Thus, the city is seeking 100% M/R funding to finance whatever measures are needed to achieve compliance.

2.4 System Performance

2.4.1 Influent Wastewater Quality

For the period from September 1986 through August 1987, the wastewater treatment plant treated an average of 4.57 mgd (Table 2-3). The average influent BOD concentration was 151 mg/L (range 144 to 190 mg/L), while the average influent TSS concentration was 123 mg/L (range 104 to 139 mg/L). The influent flow rate and BOD and TSS concentrations correspond to an average loading rate of 5,760 lb/day BOD and 4,683 lb/day TSS. Influent ammonia and fecal coliform concentration are not routinely measured.

2.4.2 Effluent Wastewater Quality

Average secondary treatment plant effluent BOD and TSS concentrations for the period September 1986 through August 1987, were 8.48 and 11.7 mg/L, respectively. Effluent BOD and TSS concentration for the RI basins were 2.03 and 1.0 mg/L, respectively, while the average effluent flow rate from the RI basins was 2.23 mgd (Table 2-3). Average effluent concentrations for the plant for the preceding year was 4.2 mg/L. Effluent ammonia concentrations from the RI basins averaged 0.93 mg/L. The average effluent mass discharge during the use of the RI basins was thus 17.3 lb/day of ammonia, well below the most stringent limits.

A comparison of the average effluent concentration (Table 2-3) versus the NPDES discharge limits for the Bozeman system (Table 2-2) indicates only fecal coliform counts consistently exceeds the discharge limits, and these violations only occur during operation of the rapid infiltration system. The BOD, TSS, and ammonia limits are consistently met throughout the year.

2.4.3 Performance of RI System Prior to 1987

During a CPE, generally only the data for the preceeding year is reviewed, since data collected in previous years oftentimes does not accurately reflect the current operating procedures. For the last year, however, the effluent applied to the RI basins has not contained concentrations of ammonia in excess of the permit limits. Therefore, achieving nitrification in the RI basins has not been critical.

TABLE 2-3. Average Influent and Effluent Quality
June 1986 through August 1987.

Month	Influent Flow (MGD)	BOD (mg/L) Inf.	BOD (mg/L) POTW Eff.	BOD (mg/L) RI Eff.	TSS (mg/L) Inf.	TSS (mg/L) POTW Eff.	TSS (mg/L) RI Eff.
1986							
Sep	4.83	144	7.03	1.56	112	6.36	0.33
Oct	4.77	177	20.7	1.47	127	24.6	0.30
Nov	4.54	170	20.4	2.95	128	27.6	1.13
Dec	4.43	175	21.6	2.8	120	32.6	0.7
1987							
Jan	4.40	176	7.39	-	131	7.23	-
Feb	4.52	168	4.43	-	137	6.36	-
Mar	4.36	190	2.66	-	139	9.90	-
Apr	4.30	175	5.07	-	136	8.14	-
May	4.80	153	2.52	-	117	3.37	-
Jun	4.82	180	2.56	3.27	115	4.42	3.03
Jul	4.60	153	2.39	1.02	113	3.19	0.47
Aug	4.45	149	4.97	1.13	104	6.74	1.05
Average	4.57	151	8.48	2.03	123	11.7	1.0
Percent removal (vs POTW influent)		-	94.3	98.5	-	90.5	99.2
Mass Load, lb/day		5756	327	37.8*	4689	44.6	18.6*

*Based upon an effluent flow rate from the RI basins of 2.23 mgd. Effluent flow is less than influent flow due to evaporation/infiltration.

TABLE 2-3. Average Influent and Effluent Quality
June 1986 through August 1987 (cont'd).

Month	RI Effluent Flow	NH_3 (mg/L) Inf.	NH_3 (mg/L) POTW Eff.	NH_3 (mg/L) RI Eff.	F. Coliform (org/100ml)	TSS (mg/L) POTW Eff. (avg.)	TSS (mg/L) POTW Eff. Max.
1986							
Sep	2.89	-	6.49	0.51	-	1159	3199
Oct	-	-	9.40	1.86	-	1556	123000
Nov	1.60	-	13.3	2.15	-	-	-
Dec	1.88	-	10.3	1.92	-	-	-
1987							
Jan	-	-	1.36	-	-	-	-
Feb	-	-	1.21	-	-	-	-
Mar	-	-	1.89	-	-	-	-
Apr	-	-	4.95	-	-	31	115
May	-	-	1.06	-	-	24	87
Jun	-	-	0.106	0.024	-	98	138
Jul	2.22	-	0.056	0.027	-	1939	7658
Aug	2.56	-	0.109	0.044	-	1641	3936
Average	2.23	-	4.18	0.933	-	921	19733
Percent removal (vs POTW effluent)		-	-	77.7	-	-	-
Mass Load, lb/day			678	17.4	-	-	-

*Based upon an effluent flow rate from the RI basins of 2.23 mgd. Effluent flow is less than influent flow due to evaporation/infiltration losses in RI system.

In order to determine the nitrification potential of the system, operational data from 1985 and 1986 was examined (Table 2-4). These data indicate that the system is capable of removing ammonia as an approximately 90 percent reduction in ammonia occurred through the RI basin.

2.5 Summary

This data review indicated that there was a fecal coliform problem at the Bozeman system. The plant effluent did consistently contain fecal coliform counts in excess of permit limits during operation of the RI basins. The CPE portion of the inspection was then conducted to determine the reasons why the treatment system was not in compliance. The CPE results are discussed in Section 3.

Table 2-4. Performance of the RI System Prior to CPE Review Period.

Month	Flow Inf.	Flow Eff.	BOD Inf.*	BOD Eff.	TSS Inf.	TSS Eff.	NH_3-N Inf.	NH_3-N Eff.
1985								
Jun	4.97	2.43	10.6	1.64	7.31	1.4	2.32	0.3
Jul	4.64	2.63	11.25	0.98	11.38	0.6	4.81	0.45
Aug	4.58	3.05	9.75	1.58	11.06	1.18	0.87	0.17
Sep	4.61	2.73	5.73	1.15	5.77	0.35	0.27	0.10
Oct	1.69	0.85	14.25	1.65	15.16	0.56	9.71	1.10
1986								
Jun	5.65	3.75	7.25	2.11	7.62	1.67	2.38	0.33
Jul	5.21	3.48	6.6	1.40	5.42	0.38	7.51	0.75
Aug	4.71	2.72	6.0	1.74	6.42	1.0	6.52	0.61
Sep	4.83	2.89	7.0	1.60	6.36	0.33	6.49	0.51
Oct	4.77	0.84	20.7	1.47	24.6	0.30	9.40	1.86
Avg.	4.57	2.54	9.91	1.53	10.1	0.78	5.03	6.18
Percent Removal	-	44.5	-	84.6	-	92.3	-	87.7

*Influent to RI Basins

SECTION 3

COMPREHENSIVE PERFORMANCE EVALUATION

3.1 Introduction

The results of CPE allow an assessment of the ability of a particular treatment plant to meet its discharge limits to be made. Significant components of a CPE include : 1) an evaluation of the quality of the treatment plant data, 2) a major unit process evaluation, and 3) a performance limiting factors analysis. The results of the Bozeman CPE are summarized herein.

3.2 Assessment of the Quality of the Treatment Plant Data

During a CPE, several analyses are generally conducted as a means of verifying the quality of a treatment plant's data. Influent BOD concentrations and flow are used to calculate the BOD loading (lb/day) to the treatment plant. Population estimates and "rule of thumb" per capita BOD generation rates are then used to calculate an estimated BOD loading. If the measured and estimated BOD loadings are in approximate agreement, the BOD data are assumed correct. If the two BOD loadings are not in agreement and no reasonable explanation exists (e.g., the presence of a large industry in a small town), the BOD data may be suspect.

The population of Bozeman is approximately 23,000. Assuming a BOD generation rate of 0.18 lb BOD/capita/day yields an estimated BOD loading to the plant of 4140 pounds per day. Treatment plant records indicate that the influent wastewater contained 5760 lb/day. The difference between the estimated and measured BOD loading is 1,520 lb/day, or approximately thirty percent. A fifteen percent difference is generally considered an acceptable balance. The average wastewater generation rate is 200 gal/cap/day which indicates that either the plant has a significant infiltration/inflow (I/I) problems, or the influent flow measurement system needs to be recalibrated. Either problem, as well as analytical error, could be responsible for the discrepancy in the BOD loading.

A sludge accountability analysis can also be used to assess the accuracy of the plant effluent data. For example, the influent and effluent BOD concentrations can be used to calculate a mass BOD removal. Suspended solids (TSS) or sludge generation can then be estimated by converting mass BOD removed to mass TSS generated using process specified conversion factors presented in the CPE/CCP manual (EPA, 1983). A solids mass balance is then conducted. The

recorded mass of sludge wasted plus the mass of solids discharged should approximately equal the estimated mass of solids generated. If the agreement between solids generated and solids accounted for is good (15% tolerance), the TSS data are assumed to be accurate.

An attempt was made to conduct a sludge accountability analysis without success. Inconsistencies were found in the sludge wasting records. The mass of solids reportedly wasted to the thickener was significantly less than that removed from the thickener. Inaccurate flow metering may explain this discrepancy. Due to the uncertainties associated with the sludge wasting records, the results of a sludge accountability analysis could not be used to verify the treatment plant data. The inability to do a solids mass balance, however, does further suggest problems with the plant data quality.

The effluent ammonia data from the plant also appeared suspect. The secondary treatment plant is achieving ammonia removal efficiencies much better than would be expected for a conventional secondary system. The treatment system, however, has EPA perform an independent QA/QC check on their laboratory procedures each quarter. The results of the laboratory QA/QC indicate that the analytical data is accurate even though the influent BOD data sludge accountability analysis, and effluent ammonia concentrations suggested otherwise.

3.3 Major Unit Process Evaluation

3.3.1 Introduction

As part of a CPE, an evaluation of the treatment performance potential of each major unit process is conducted, and the flow rate at which the process would function effectively is determined. These results are then presented graphically in a performance potential graph (Figures 3-1 and 3-2). A discussion of factors considered in developing Figures 3-1 and 3-2 is presented below.

3.3.2 Primary Clarifiers

A surface overflow rate (SOR) of 800 gallons per day per square foot (gpdsf) was used to evaluate the primary clarifiers. At this SOR, the clarifiers were assigned a performance potential of 5.3 mgd.

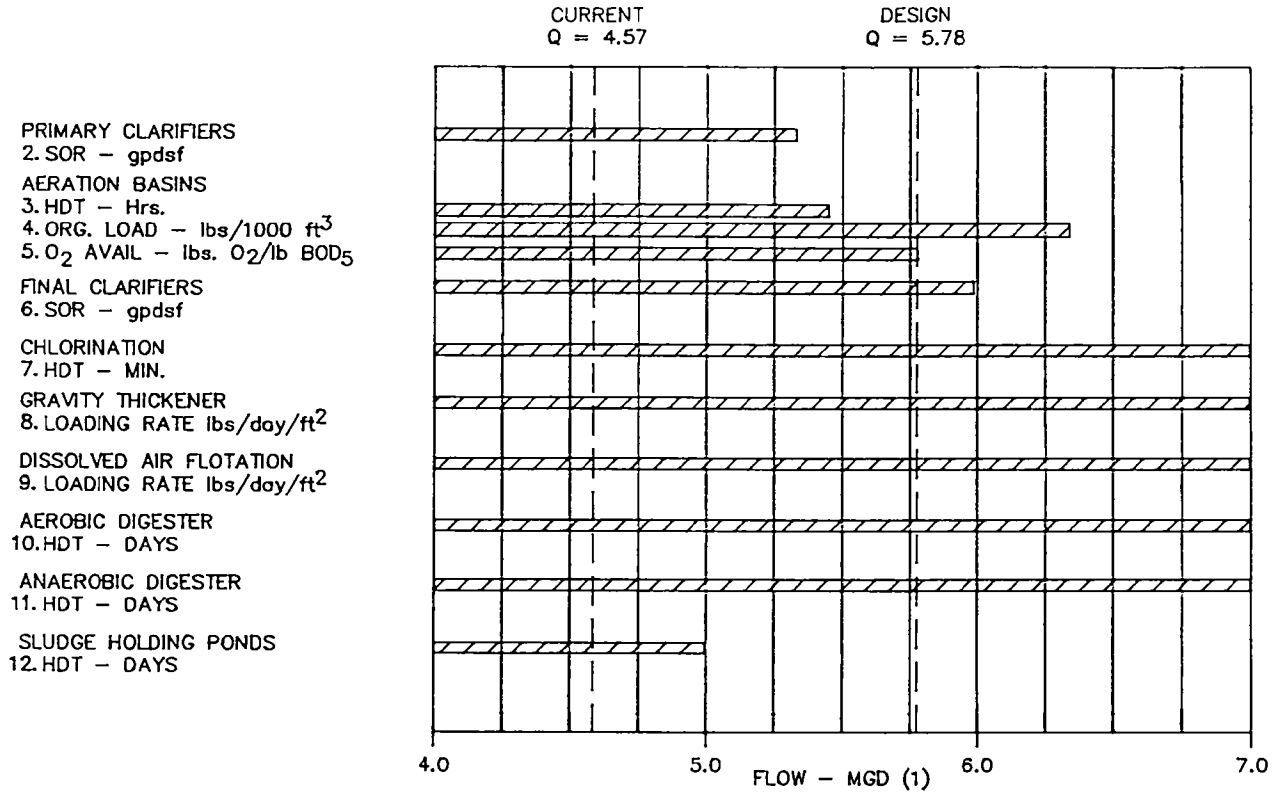
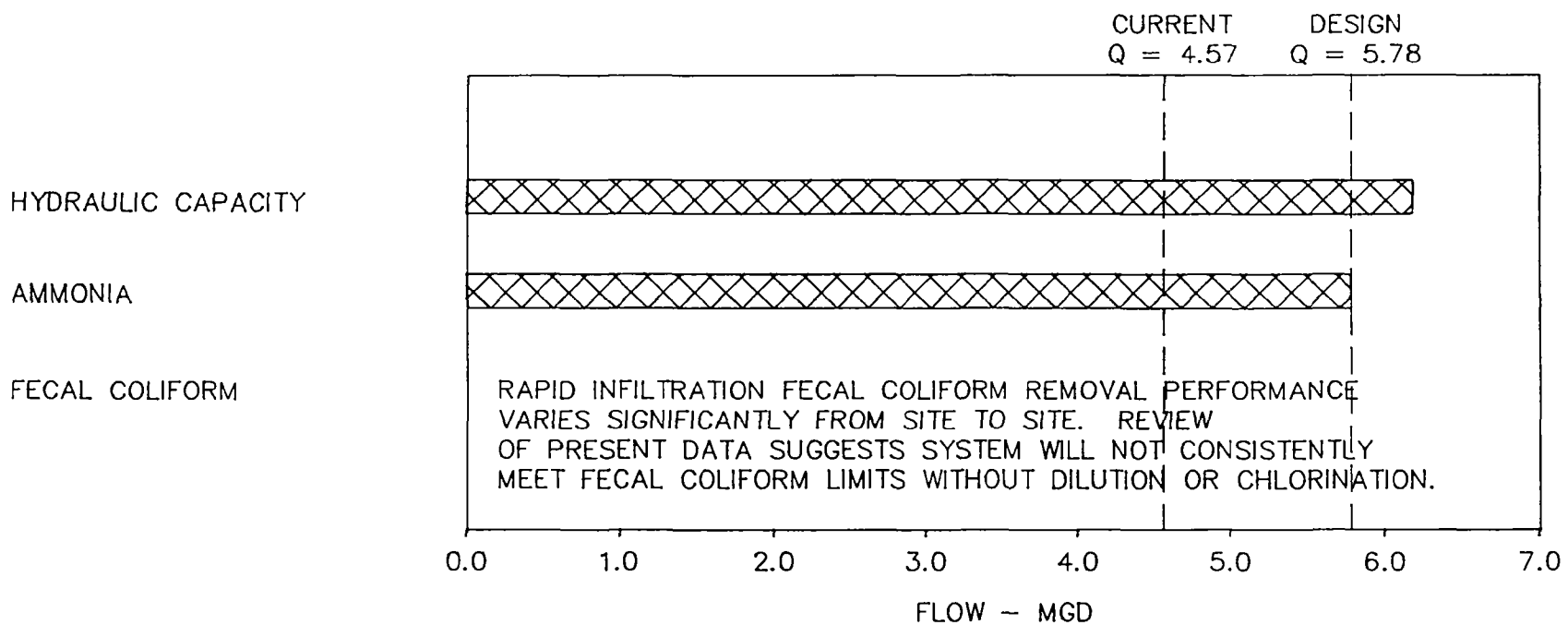


FIGURE 3–1. PERFORMANCE POTENTIAL GRAPH – BOZEMAN, MT, SECONDARY TREATMENT COMPONENTS.



ASSUMPTIONS:

1. SEASONAL OPERATION, APPLICATION OF ADVANCED SECONDARY QUALITY EFFLUENT, REPAIR NONFUNCTIONAL BASINS.
2. PAST SUCCESSFUL PERFORMANCE WITH WET/DRY RATIO OF APPROXIMATELY 0.3, INFLUENT AMMONIA CONCENTRATION OF 10 mg/L OR LESS.

FIGURE 3–2. PERFORMANCE POTENTIAL GRAPH – BOZEMAN, MT, RAPID INFILTRATION SYSTEM.

3.3.3 Activated Sludge System

Hydraulic detention time was determined to be the most limiting design factor. Using a hydraulic detention time of 8 hours yields a performance potential of 5.45 mgd. The secondary clarifiers were also rated based upon an SOR of 800 gpdsf of which yielded a performance potential of 6.0 mgd.

3.3.4 Disinfection Facilities

A 60-minute chlorine contact time was used to evaluate the disinfection system. The volume of the chlorine contact time is such that greater than 7.0 mgd can be effectively disinfected with the present system. Dechlorination facilities are also believed to be adequate.

3.3.5 Sludge Handling Facilities

The sludge holding ponds were determined to be the most limiting component of the sludge handling facilities. At a holding time of 180 days, the holding ponds were rated as having a performance potential of 5.0 mgd.

3.3.6 Rapid Infiltration System

3.3.6.1 Hydraulic Capacity

Based upon historical records of infiltration rate of 1986 and 1987 (one measurement each year), the rapid infiltration system appears to have adequate hydraulic capacity to treat the design flow of 5.78 mgd. The city however should correct the valve problems which have made two basins (Numbers 6 and 11) inoperable in order to reduce the hydraulic loading to the remaining basins.

Three basins (Nos. 17-19) reportedly have low infiltration rates. Possible factors for the low infiltration rate in these three basins include an air lock in the underdrains, blockage of the underdrains, and different soil characteristics in these basins. Installing an air vent in the underdrains to these basins would prevent an air lock and allow the city to easily determine if the underdrains are blocked.

3.3.6.2 Ammonia Removal

In 1985 and 1986, the RI system averaged approximately 90 percent ammonia removal (Table 2-4). The secondary treatment plant has shown the capability to produce an wastewater quality of 10 mg/L of ammonia-nitrogen. The critical month for effluent quality for ammonia is August, during which time

the treatment plant is permitted to discharge 98 pounds/day of ammonia. At the design flow of 5.78 mgd, this mass limit corresponds to an effluent concentration of approximately 1.9 mg/L. A significant water loss, however, occurs in the rapid infiltration system. When the RI basins are in use, effluent flow averages roughly 60 percent of the influent flow. The effluent ammonia concentration during the critical month could thus be (1.9/0.6) 3.2 mg/L. To produce an effluent quality of 3.2 mg/L, the RI basins need only operate at 67 percent efficiency, instead of at the 90 percent efficiency achieved in 1985 and 1986 (Table 2-4).

3.3.6.3 Fecal Coliform Removal

The RI system is not providing effective fecal coliform removal. Based upon the literature (see Appendix A) and the CPE team's previous experience at other RI systems, there does not appear to be an accurate means to predict fecal coliform removal performance. Several attempts were also made to relate the fecal coliform removal performance to the infiltration rate of each basin without success. Thus, there was no means to accurately assess the fecal coliform performance potential of the RI system.

3.4 Performance Limiting Factors

3.4.1 Overview

Seventy potential performance limiting factors were evaluated during the course of the CPE. The 70 factors covered four main areas: design, operation, maintenance, and administration. Interviews, reviews of existing records, performance data, and the results of the major unit process evaluation were used to detemine if any of the 70 factors were significantly affecting performance.

Once the performance limiting factors were identified, these factors were prioritized. "A", "B", and "C" factors were first identified, using the definitions presented below:

Rating Class	Adverse Effect of Factor on Plant Performance
A	Major effect on a long-term repetitive basis
B	Minimum effect on a routine basis or major effect on a periodic basis
C	Minor effect

The importance of each of these factors within their rating class was then assessed. The performance limiting factors in order of priority are presented below:

A Factors

1. Fecal Coliform Removal in the RI System

B Factor

1. Operator Application of Concepts

2. Infiltration/Inflow (Historical)

C Factors

1. Equipment - Malfunctions

2. Performance Monitoring

3. Process Flexibility

4. Process Accessibility for Sampling

5. Industrial Loading to Plant

A brief discussion of each of these factors is presented below.

3.4.2 "A" Factors - Fecal Coliform Removal in RIB's

Current design guidance for rapid infiltration systems (EPA, 1983) states that fecal coliform removal in RI systems is excellent. Poor fecal coliform removal efficiencies, however, have been experienced at several full-scale operational systems (e.g., Waycross, Georgia). Poor fecal coliform removal has been experienced under a variety of soil types and site conditions and in systems with and without underdrains. The data from the Bozeman system indicates that the Bozeman system does not provide consistent fecal coliform removal. Possible explanations for the poor fecal coliform removal performance include a short travel distance to the underdrains, the inability to dry the fine textured silt loam soil such that pathogen die-off occurs before the next loading cycle, and contamination of the underdrains from non-wastewater sources (e.g., rodents). Additional studies are recommended to further document the sources and removal of fecal coliforms in the rapid infiltration basins such that an effective solution can be developed.

3.4.3 "B" Factors

3.4.3.1 Operator Application of Concepts

A number of factors combined led to the ranking of "Operator Application of Concepts" as a performance limiting factor. It is important to note that the operators' appitude and abilities were felt to be very good. The CPE team, however, felt that there was some confusion between the plant staff as to why certain operating parameters were selected. For example, by not operating the RI basins and using the chlorination-dechlorination facilities, the treatment plant would have been in compliance with its NPDES permit during the summer of 1987. A clear explanation as to the reasons for continued operation of the RI basins instead of using the conventional disinfection system was not provided. Improvement in the aggressiveness with which plant personnel pursued special studies and operational changes to optimize performance of the system could also be made. Finally some common operational parameters for RI systems (e.g., infiltration rate) were not routinely measured and recorded.

3.4.3.2 Infiltration/Inflow (I/I)

I/I was ranked as a performance limiting factor based upon the CPE team's past experience with the plant and the high per capita wastewater generation rate (approx. 200 gal/person/day). As the wastewater flow approaches design capacity, I/I could become a more significant problem. Maximum performance and longevity of the RI basins is enhanced by decreasing the flow through the basins. Thus, decreasing I/I can improve system performance.

3.4.4 "C" Factors

3.4.4.1 Equipment Malfunctions

At the present time, equipment malfunctions or any of the other C factors are not significantly limiting the performance of the system. These factors, however, should be addressed. Two of the basins are currently out-of-service due to malfunctioning valves. These valves should be fixed as soon as practical. Three basins are not being used due to slow infiltration rates. Plant personnel believe that the soil types are fairly uniform across the site. The CPE team personnel generally agreed with this assessment of the soil characteristics. The soils in basins 17-19, however, may have had a higher clay content than soils from the other basins. The three poor infiltrating basins are all located on the same underdrain lines. Lack of venting for these underdrains could have caused an air lock in the drains. Installing vents should prevent an air lock as well as allow

the lines to be flushed with water to determine if any of the lines are blocked.

3.4.4.2 Performance Monitoring

Improvement could be made in the fecal coliform monitoring procedures. Special studies should be developed to monitor fecal coliform removal through the system to help in developing an effective corrective measure.

3.4.4.3 Process Flexibility

Plant personnel stated that they were unable to effectively split flow between the RI basins and the chlorine contact basin. The system was originally designed to provide this flexibility. Overly sensitive flow controllers could be responsible for this lack of flexibility. Plant personnel should more actively pursue a solution to this problem.

3.4.4.4 Process Accessibility for Sampling

At present, there is no easy means to monitor the performance of each basin. Operational experiences at other RI systems has shown that individual basins within a system can perform differently. By being able to easily sample each basin, plant personnel could develop an operating schedule which would provide the highest quality effluent. During any future modifications to the plant, the addition of sampling points should be considered.

3.4.4.5 Industrial Loading to Plant

One industry periodically batch discharges a high strength waste. The shock loading to the plant can adversely affect performance by, for example, killing the nitrifying microorganisms. The city should continue pursuing measures to prevent future shock loads.

3.5 Summary

The CPE indicated that the RI basins were not capable of achieving adequate fecal coliform removal. Before designing corrective measures, however, additional studies should be conducted by the city to determine more accurately, the pathogen removal efficiency of the present facilities. With the exception of fecal coliform removal in the RI basins, the treatment plant appears to be capable of meeting its performance objectives.

APPENDIX A

PATHOGEN REMOVAL IN RI SYSTEMS

APPENDIX A

PATHOGEN REMOVAL IN RAPID INFILTRATION SYSTEMS

Case studies and Removal Mechanisms

Pathogen removal in rapid infiltration systems, including bacteria, virus, parasitic protozoa and helminths is accomplished by filtration, adsorption, desiccation, radiation, predation, and exposure to other adverse conditions. Any protozoa and helminths are removed at the soil surface because of their larger size. Bacteria are also removed at the surface and in the profile by filtration, but soil adsorption may also be important. Viruses are removed almost entirely by adsorption. In slow rate land treatment with application rates of a few inches per week, fecal coliforms are typically removed by percolation through 5 feet of soil. In contrast, the EPA Process Design Manual (1) suggests an average fecal coliform percolate concentration of between 10/100 mL and <200/100 mL might be expected after 15 feet of travel through unsaturated soil. These removal mechanisms are approximately the same when either primary or secondary effluent is applied.

The data in Table A-1 suggests that, in general, rapid infiltration systems have the capability to remove fecal coliforms to levels well below 1000/100 mL with adequate travel distance in the soil. In addition to the geographical and soil differences, the systems listed in Table A-1 have quite different unit hydraulic loading rates and operational cycles. These data suggested that fecal coliform removal is dependent upon the following major factors:

- Soil Type and Texture: bacterial removal is inversely proportional to the particle size of the soil.(12) The finer the texture the better the removal as long as there are not fissures or channels in the soil allowing deep penetration.

- Soil Depth: the increased distance increases the residence time to the soil and provides greater opportunities for filtration, sedimentation, and adsorption.

- Hydraulic Loading Rates: the unit loading rate controls the flow rate in the soil (up to the <u>in situ</u> permeability). The rate and duration of application influence whether unsaturated flow or temporary saturated conditions prevail in the upper soil layers.

Table A-1. Fecal Coliform Removal at Selected RI Systems.

Location	Soil	Fecal Coliforms #/100mL Wastewater	Fecal Coliforms #/100mL Percolate	Travel Distance(ft)
Hemet, CA (3)[a]	sand	$6x10^4$	11	7
Hollister, CA (3)	sandy loam	$12.4x10^6$	$17.1x10^4$	23
Lake George, NY (4)	sand	$3.6x10^5$	72	7
Landis, NJ (5)	sand/gravel	TNTC[b]	16	7
Milton, WI (6)	gravel/sand	TNTC	0	40
Phoenix, AZ (7)	sand	$2.4x10^5$	104	100
Vineland, NJ (8)	sand/gravel	TNTC	0	23
Ft. Devens, MA (9)	sand/gravel	$4.2x10^4$	0	300
Medford, NY (10)	sand	2500	250	25
Corvallis, MT (11)	sand	1600	3	60

[a] Reference Number

[b] TNTC = too numerous to count

- Loading Cycle: if the drying portion of the cycle is too short, there may not be time for die-off of the bacteria to occur. The next application cycle might then desorb and flush some of the organisms out of the soil.

- Organic and nutrient content of wastewater and soil: there can be re-growth of fecal coliforms in the soil in the presence of adequate moisture and organic content. Re-growth is not likely if the organic status of the soil is poor. Temperature, pH, and other environmental factors can also be significant.

A change in the ionic composition of the water moving through the soil accompanied by a increased rate of flow has been shown to desorb both coliforms and bacteria from a variety of soil types (13, 14). In these cases, movement has been observed after sudden and intense rainfall. In a controlled laboratory study, Lance was able to desorb viruses by applying de-ionized water, but they were readsorbed within the eight-foot soil column (15). Allowing the soil to dry for five days prevented desorption with de-ionized water. It has also been noted in other studies that removal efficiency for bacteria increases as the soil mosture decreases (16).

Gerba has summarized movement of bacteria through soils at ten different sources with results very similar to those presented in Table A-1 (12). The maximum observed travel distances ranged from 3 to 1,500 feet in soils ranging from fine loamy sands to coarse gravels. Evidence of subsurface regrowth has been observed in Israel where chlorinated effluent with about 2 total coliforms/100 ml has been pumped into injection wells. Water is pumped out of the same wells during the irrigation season, and the total coliform count ranged from 10^5 to 10^6. Further investigation showed that coliform re-growth was occurring in the organic mat surrounding the well packing. Gerba also shows that virus removal on coarse sand is related to the hydraulic loading rate. At 0.02 gpm/ft^2, a 90 percent removal was observed; at >1 gpm/ft^2 more than 90 percent of the virus flushed through the system.

Bouwer described the performance of a full-scale rapid infiltration basin system in Phoenix, Arizona (17). When unchlorinated secondary effluent was applied to the coarse sand basins, fecal coliform peaks (>1000/100 ml) were observed in a well 60 feet below the basins. Chlorination was commenced and the effluent applied to the basins averaged 3500 fecal coliforms/100 mL. The concentrations in all of the observation wells then dropped essentially to zero. The chlorination did not seem to affect the nitrification. The

applied effluent contained 18 mg/L (mostly ammonia) while the recovered percolate (at 60 feet) contained less than 6 mg/L (mostly nitrate).

Rice (18) examined pilot RI basins and soil columns receiving primary effluent. The soil was a loamy sand and was flooded continuously for one week followed by one to three weeks of drying. The applied primary effluent contained $8x10^6$ fecal coliforms and the percolate averaged about 50/100 mL after 8 feet of travel in the soil column.

The Medford, NY, study listed in Table A-1 was conducted with disinfected tertiary effluent.(10) The soil involved was a coarse sand and since ground water recharge was the purpose of the study, very high hydraulic loadings were tested (about 15 feet) per day). The fecal coliforms in the applied effluent averaged 2500/100 mL (range:<3-$4.6x10^4$). Viruses at a concentration of <1 PFU/L were also found on six occasions at the same depth. The hydraulic rate used in this study was the highest found in the literature.

Application of Findings to Bozeman, MT, System

The literature discussed above indicate that even at very high hydraulic loading rates, significant bacterial removal is possible with sufficient travel distance in competent soils. It seems possible that a four-foot travel distance may be insufficient with the hydraulic loading rates in use at Bozeman, since saturated flow is likely to prevail on a temporary basis during at least part of the operational cycle.

Even with a high hydraulic loading, the performance at Bozeman is surprising given the soil characteristics. It is possible that the soil profile is not competent above the excavations made to install the underdrains. If this is the case, some portion of the applied effluent may flow almost directly to the drains. BOD and TSS data, however, do not suggest that the soil is not competent. The relaively low infiltration rates may also require that the basins be loaded before the soils are dry. Thus, pathogen die-off may not occur between loadings. Each loading may then wash out pathogens from the previous application.

It is also possible that only some basins are perform poorly with the other basins, in effect, providing dilution water. An investigation of the poor performing basins should be considered as a major focus during any further investigation to identify any soil or construction differences as compared to the other basins.

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