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A STUDY OF WASTES FROM THE CENTRALIA WATER TREATMENT PLANT AND THEIR IMPACT ON CROOKED CREEK

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ABSTRACT

The objectives of this study were to determine the quantity and quality of wastes generated at the Centralia water treatment plant and to assess their impact on Crooked Creek. The Centralia water plant processes an average of 3.78 MGD.

The major sources of discharge from the water treatment plant are the clarifiers and filters. These sources generate approximately 460 pounds of solids per day. The volume of wastes generated is 134,000 gpd with an average volume of settleable solids of 3730 gpd.

The influence of this discharge on Crooked Creek was determined by evaluating water quality and sediment samples taken at eight creek sampling stations. After receiving the plant discharge, the sampling station immediately downstream had water quality parameter concentrations that were statistically the same or lower than those measured at the upstream location. There were also no significant differences in the water quality parameters measured at the other six downstream locations. Therefore, it was concluded that the water plant discharge has no adverse impact on Crooked Creek water quality.

Evaluation of stream sediments indicated that the effect of the water plant discharge was detectable in the bottom sediments at the monitoring station immediately downstream of the discharge, but not at the other downstream locations. The station immediately downstream showed an increase in chemical concentrations, a change in particle size distribution, and a shift in the diversity and abundance of macroinvertebrates. However, the macroinvertebrate biotic index (MBI), which is used by the Illinois Environmental Protection Agency to indicate water quality on the basis of the type of benthic life, showed that there was no difference in the MBI at the sample stations immediately upstream and downstream of the water plant's discharge.

INTRODUCTION

Background

In order to protect public health, all surface water and most ground water used for public water supplies requires treatment. The type and degree of treatment are set by state and federal standards and also by local preferences for certain water characteristics. The treatment processes may include coagulation, sedimentation, softening, iron and manganese removal, aeration, and disinfection (with or without other treatments). With the exception of disinfection (for which chlorination is commonly used), each treatment process generates wastes, either solids, liquids, semi-solids, or brines. The waste residues consist mainly of impurities in the form of suspended, colloidal, and dissolved materials contained in the raw water. Small quantities of waste residues also are produced by chemical additions and the resulting chemical reactions.

The type, quantity, and characteristics of the waste stream from a water treatment plant vary considerably depending on treatment process chemistry, raw water quality, plant operating conditions, pH, seasons of the year, and other parameters. They are also quite different from plant to plant. The major components of waste streams from water treatment plants are alum sludge retained in flocculatorg and sedimentation basins, washwaters generated from filter-backwash operations, precipitates from lime softening, and brines from ion exchange softening.

Alum is the most widely used primary coagulant in the United States. Activated silica, clay, or a variety of polymers are used as coagulant aids. Alum coagulation process residues may contain aluminum hydroxide, clay, sand, colloidal material, inorganic debris, organic material, and microorganisms including algae, plankton, and other organisms. Residues of alum coagulation have feathering and gelatinous characteristics with a moisture content of approximately 98.5~99.0 percent. They vary in color from a light yellow brown to a solid black (if powdered activated carbon is added). Alum sludge settles readily but does not dewater easily.

A waste stream from lime-softening units consists mainly of calcium carbonate and hydroxides of magnesium, aluminum, and iron. Softening plant residues from surface water supplies may have characteristics similar to those from alum coagulation plants.

Filter backwashes normally contain fine flocs which do not settle in sedimentation basins. The composition of filter washwater may be similar to that of coagulant residue. The backwash may also contain a small portion of filter media and activated carbon. The duration of the filter backwash operation and the release pattern of solids vary widely. In general, the volume of filter washwater may be from 3 to 5 percent of the water filtered.

Spent brine comes mainly from the rinse water used for regeneration of ion-exchange softening units. The quantity of brine generated is about 2 to 10 percent of the water treated (AWWA Research Foundation, 1969a, 1969b; Bishop, 1978). The brine contains extremely high concentrations of chlorides of calcium, magnesium, and sodium, with small amounts of various compounds of irons and manganese. It is high in dissolved solids and low in suspended solids. The high chloride content in the brine causes disposal problems. Chloride removal requires costly treatment methods. These wastes can generally be discharged only to deep underground strata or to oceans.

The disposal of waste from water treatment plants is a necessary part of their operations. Historically, water plant wastes have been discharged to the nearest drainage courses or receiving water. It has been the viewpoint of some water utility personnel that the largest portion of settled sludge and filter washwater originates from the raw water source and therefore should be allowed to return to its source. However, federal and state regulations currently classify water treatment plant waste with other industrial wastes and prohibit its direct discharge, except in certain cases.

The disposal of water plant wastes has been troublesome and costly for the water industry. Frequently the standards applied to the effluent of sewage treatment plants are similarly applied to the waste stream from water plants. Residue disposal causes each plant different and unique problems.

For nearly two decades a number of alternative waste treatment methods have been applied (Proudfit, 1968; AWWA Research Foundation, 1969a, 1969b, 1970; Bishop, 1978; Reh, 1980). These include disposal to a sanitary sewer or to other water courses; barging or pipeline transport to the ocean or to other sites; alum and lime reclamation; and treatment with lagooning, mechanical or gravity thickening, and dewatering (through polymer or pellet flocculation, sand bed or wedge wire drying, drying lagoons, centrifuging, vacuum or belt filters, filter presses, strainers, freezing, or heating). No matter which process is used, there still remains an end product which may contain 20 to 50 percent solids and which must be disposed of. The solids must ultimately be placed on land, underground, or in the ocean. The majority of water treatment plants do not have adequate facilities for waste disposal.

Little information is available on the effect of waste discharges from water plants on receiving waters. Evans and his associates (1979, 1982) were probably the first in Illinois to conduct such impact evaluations. They found no environmental degradation of receiving streams from the waste discharges of either the Pontiac (Illinois) or Alton (Illinois) water treatment plants. Similar conclusions were reported for the Ohio River by Gates et al. (1981) and Vicory and Weaver (1984), and for the Mississippi River by Lin et al. (1984).

Study Area

The Centralia water treatment plant, located at Centralia in Marion County, Illinois, serves the following entities: City of Centralia, Centralia Correctional Center, Murray Center, Hoyleton Rural Water Company, Raccoon Water Company, Kaskaskia College, Village of Hoffman, Village of Irvington, Village of Junction City, Village of Odin, Village of Richview, Village of Sandoval, and Village of Walnut Hill. The existing service area population is approximately 31,000. According to a reported study (Daily & Associates Engineers, 1983), the service area population is expected to be 37,163 in the year 2000, and 39,697 in the year 2020. At present, the peak-day demand is 4.5 million gallons per day (MGD) (17,000 m^3/d). Applying a 1.5 factor for daily peak to average demands, the plant must have a capacity of 6.39 MGD (24,200 m^3/d) in the year 2000 and 6.84 MGD (26,000 m^3/d) in the year 2020.

The treatment plant (figure 1) is located along Crooked Creek in the vicinity of the old Highway 51 bridge. The raw water is pumped from Raccoon Lake to the plant. The quality of raw water varies widely because of rainstorms, snowmelts, and other natural events. Waste generated from the treatment units is drained to Crooked Creek via a ditch. This ditch also carries part of the storm sewer flows from the cities of Centralia and Central City.

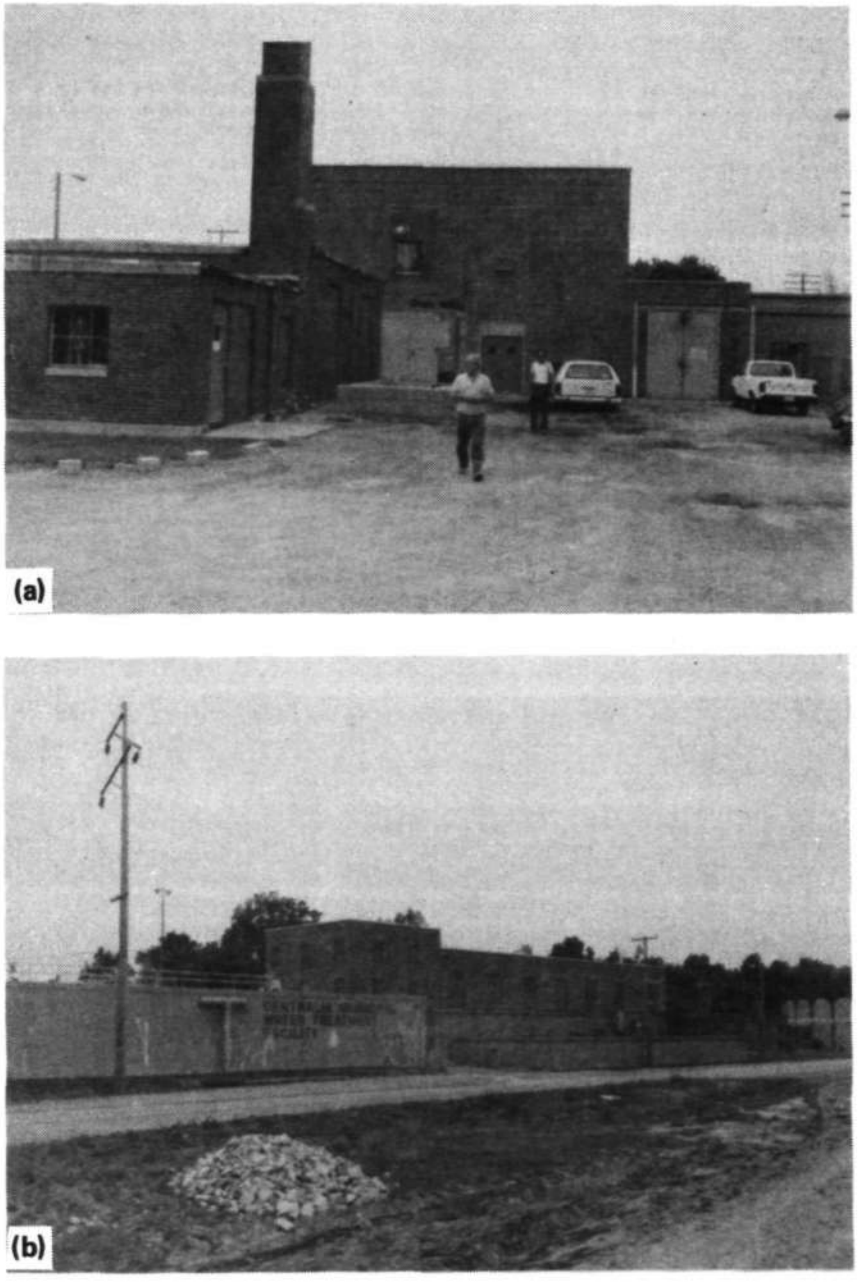

Figure 1. Centralia water treatment plant: a) main gates, b) side view

The headwaters of Crooked Creek are approximately 20 miles (32.2 km) northeast of Centralia in Marion County. The creek flows in a generally south-southwesterly direction through Marion and Clinton Counties to its confluence with the Kaskaskia River, a distance of around 60 river miles (96.5 km).

The drainage area of the Crooked Creek watershed above the water treatment plant is approximately 144.6 square miles (375 km^2). The average streamflow (1974-1985) for Crooked Creek near Hoffman is 225 ft^3/s. The maximum flow was 7060 ft^3/s on April 12, 1979 and the minimum was 2.1 ft^3/s on September 25 and 26, 1976. The streamflow of Crooked Creek near Odin is recorded only instantaneously. The terrain varies from gently rolling fertile farmland in the eastern part to farm and valley timberlands in the western part. A sewage treatment plant, oil storage tanks, pipelines, pumping stations, and many oil wells are located on the watershed.

Raccoon Lake (figure 2) is the water source for the Centralia water plant. It was built by the City of Centralia in 1942-1943 to replace Lake Centralia as the city's public water supply. The lake is located approximately one mile (1.6 km) northeast of Centralia in southwest Marion County and approximately 1.1 miles (1.77 km) upstream from the confluence of Raccoon Creek with Crooked Creek.

This 707-acre (286-ha) artificial reservoir is at maximum 3.0 miles (4.83 km) in length from the dam to the upper end where Raccoon Creek, the lake's major tributary, enters. The 16.4 miles (26.4 km) of shoreline is moderately developed with permanent homes. Much of the remaining shoreline area is in natural woodland or other vegetative cover. Emergent aquatic vegetation including smartweed (Polygonum) and cattails (Typha) border the lake's shoreline in many areas (Hite et al., 1979).

Morphologically, Raccoon Lake is a shallow lake basin with an average depth of 3.9 feet (1.2 m). Maximum recorded depth in the lake is about 14 feet (4.3 m) near the dam. Daily & Associates Engineers (1983) estimated that in early 1980 the lake volume was at a low of 3689 acre-feet (4.55×10^6 m^3), a loss of about 20 percent of the original reservoir storage capacity. The safe yield for a 20- to 25-year drought has been estimated at between 3.75 MGD (14,200 m^3/d) and 4.60 MGD (17,400 m^3/d). During high yield rainstorm periods the excess lake water is discharged to Crooked Creek.

Centralia has constructed pipelines and pumping facilities to supplement the Raccoon Lake water supply during low precipitation periods. Approximately 2.5 MGD (9500 m^3/d) can be pumped from Lake Centralia to the Raccoon Lake watershed. From 1980 to present, the Lake Centralia pump has run an average of 48 days per year. Water can also be pumped to the Raccoon Lake watershed from Lake Carlyle through a Texaco pipeline. The city's contract with Texaco permits up to 5.0 MGD (18,900 m^3/d) to be diverted to Raccoon Lake. This pump and pipeline was put into service in 1985 and, except for testing, has not been used.

The Raccoon Creek floodplain is primarily wooded land containing the city's water plant pumping station, a 1-acre sewage lagoon for Central City, and a few residences. The water plant pumping station and sewage lagoon are protected from flooding.

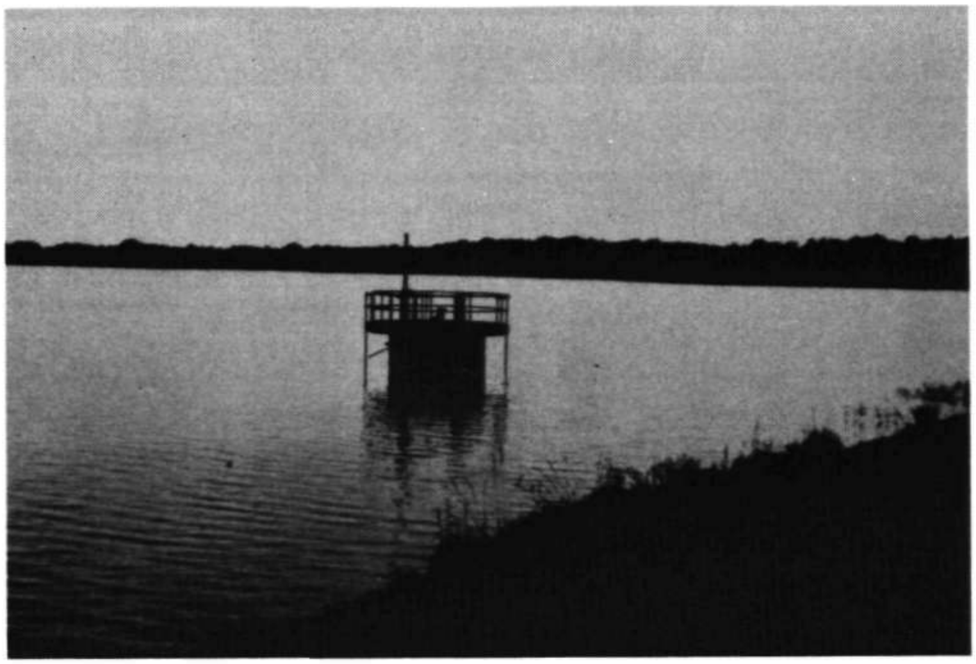

Figure 2. Water intake structure at Raccoon Lake

Purpose and Scope of Study

The principal purpose of the study was to determine the impact that wastes generated by the treatment facility have on the water quality and sediment quality of Crooked Creek. The basic tasks performed to attain the objectives were to:

- Determine quantities, characteristics, and release patterns of wastes generated within the treatment plant
- Document the pertinent physical and chemical characteristics of the water and sediments of Crooked Creek within and outside of the area of waste discharge influence
- Ascertain the type and abundance of benthic organisms in the creek's bottom sediments

The findings reported here pertain to three main areas: the wastes generated by the treatment facilities, streamwater quality, and stream sediment characteristics (biological, chemical, and physical). All pertinent data developed during the course of the study (May 1985 - May 1986) are included in the appendices.

Acknowledgments

This study was conducted under the general administrative direction of Richard Schicht, Acting Chief of the Illinois State Water Survey, and Raman Raman, Head of the Water Quality Section. The cooperation of Stan Browning and Phil Sutton (Centralia city engineers), Kenneth Oestreich (plant superintendent), and all the operation personnel is gratefully acknowledged. Treatment plant operational data were made available to the authors. This study was partially funded by the City of Centralia.

The authors are grateful to the other members of the Water Survey who participated. Dana Shackleford and David Hullinger performed chemical analyses. Dave Beuscher analyzed grain size distribution of sediments and prepared culture media. Personnel at the Centralia wastewater plant performed the BOD_5 analysis. Tom Hill identified the type and enumerated the number of benthos. Mahn Lu, Raman Raman, Dave Beuscher, and John McMenamy assisted in sample collections. Gail Taylor edited the report.

WASTES FROM THE CENTRALIA WATER TREATMENT FACILITIES

Treatment Units

The water treatment plant at Centralia is located near the bank of Crooked Creek at river mile 36.5. At present, raw water is pumped (3 pumps) from Raccoon Lake to the treatment plant through approximately 6800 feet (2070 m) of 24-inch (61-cm) cast-iron water main installed in 1941-194.2. During the study period the pumpage ranged from 3.09 to 4.60 MGD (11,700 to 17,400 m^3/d) with an average of 3.78 MGD (14,300 m^3/d). The waterworks treats surface water through coagulation, clarification, filtration, and chlorination. A schematic flow diagram of the treatment processes is shown in figure 3.

At the Raccoon Lake raw water pump station, potassium permanganate is added to the raw water line for oxidation of iron, manganese, and organic compounds (including those associated with objectionable taste and odor).

At the treatment plant, liquid alum, as a coagulant aid, is added at the water meter pit. During the study period the alum dosage rate varied from 534 to 2937 lb/d (233 to 1780 kg/d) with an average of 906 lb/d (403 kg/d).

Two slow mix basins, for flocculation purposes, are located ahead of the upflow clarifiers. The detention time in these flocculation basins is less than the theoretical value. Short circuiting occurs throughout the two basins. One 24-inch pipe connects each flocculator and clarifier. On the basis of 1.5 fps maximum allowable velocity of flow through the flocculators, the effluent flow rate from each flocculator should not exceed 3.0 MGD (total 6.0 MGD) including recirculated flow (Curry & Associates Engineers, Inc., 1983). Approximately 1.5 mg/L of cationic polymer (WTS 22 or Allied 308P) is added at the flocculators.

Two solids contact upflow clarifiers (figure 4) are provided for clarification. Each has a volume of 45,400 gal (17.2 m^3) and is 50-feet (16-m) square. The aggregate flocs are removed from the water as they pass through the sludge blanket with 30 minutes' detention time. Each clarifier is equipped with a sludge collector. Residue is drawn to a central discharge point for blow-down to Crooked Creek and for recirculation. A small amount of chlorine is dosed to the effluent of the clarifiers (filter influent).

Mixing in the upflow clarifier flocculation zone is accomplished by pumping clarifier basin solids from the blow-down pit back to the mixing basin ahead of the clarifier. Two blow-down timers are employed to control the discharge of excess solids. These timers are turned off periodically to improve the solids blanket in the clarifiers.

Filtration is accomplished by six rapid sand filters (figure 5). Each filter is equipped with granular activated carbon (18 inches, 46 cm) to remove organic precursors, sand and gravel (18 inches, 46 cm), a surface wash device, a rate-of-flow controller, a loss-of-head gage, a recording nephelometer, and a Wheeler bottom. Each unit has a surface area of 304 sq ft (28.2 m^2). The total filter capacity is 5.25 MGD (19,900 m^3/d) with a 2 gpm/sq ft (1.358 $L/m^2 \times s$) filtration rate. These filters are backwashed after approximately 30 to 50 hours of operation depending on filter performance.

Chlorine, hydrofluosilicic acid, and liquid caustic soda are added to all filter discharges for post-chlorination, fluoridation, and pH adjustment. Flow from all the filters proceeds to the two clear wells.

The principal waste-producing units at the plant are the upflow sedimentation clarifiers and filters. Wastes generated by these treatment units are discharged to Crooked Creek (figure 6) through a pipeline to a tributary ditch (figure 7).

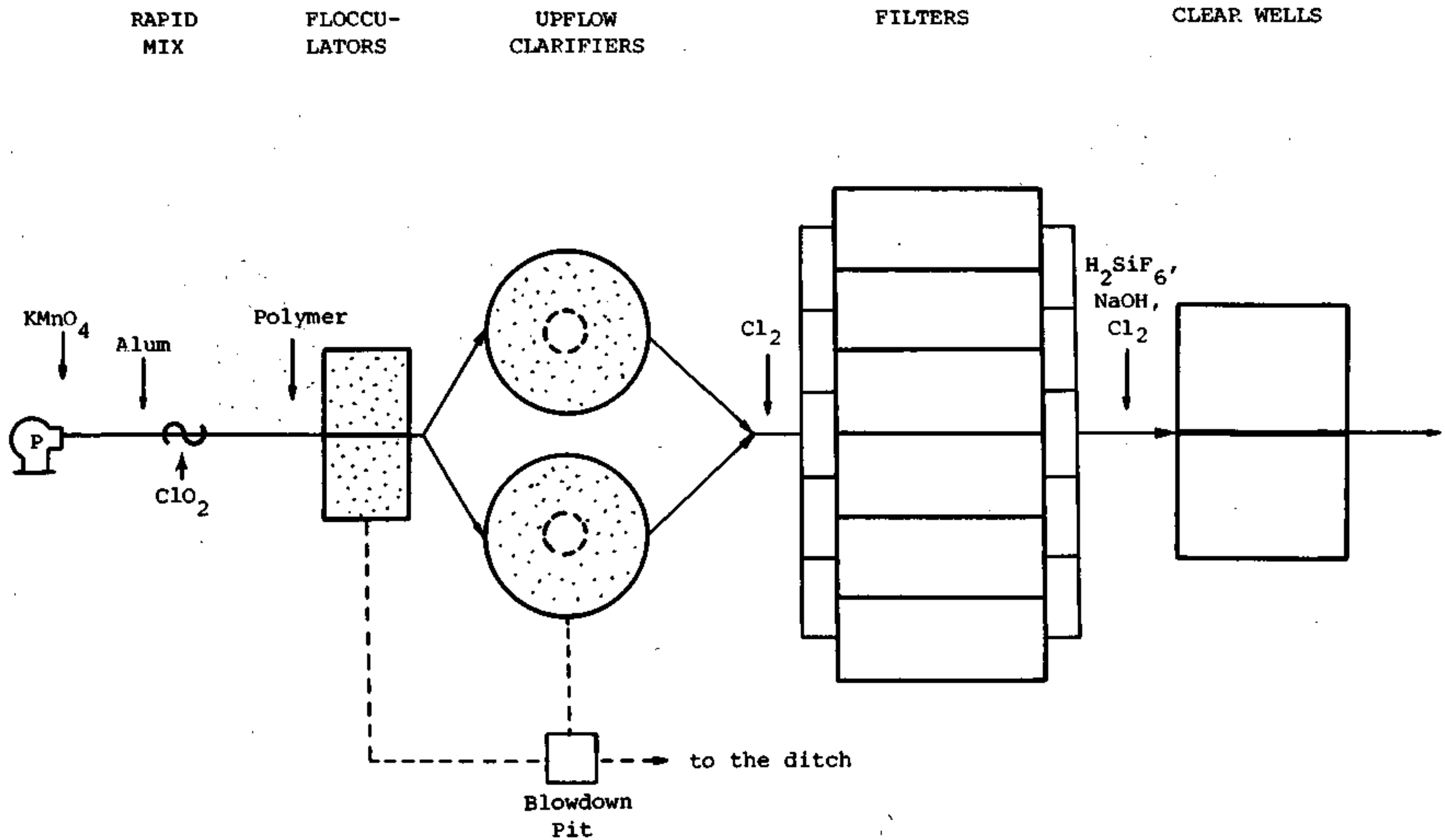

Figure 3. Schematic flow diagram of Centralia water treatment plant

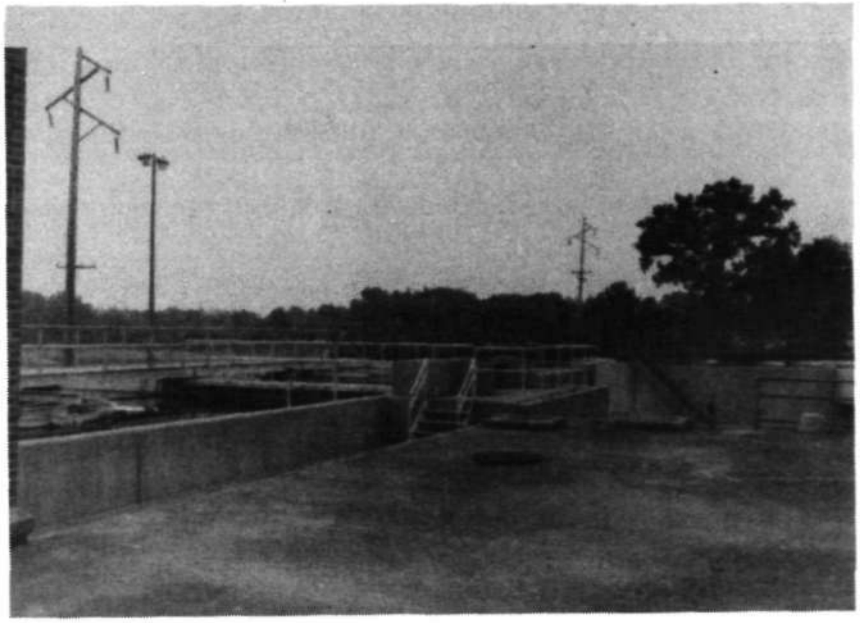

Figure 4. Upflow clarifiers

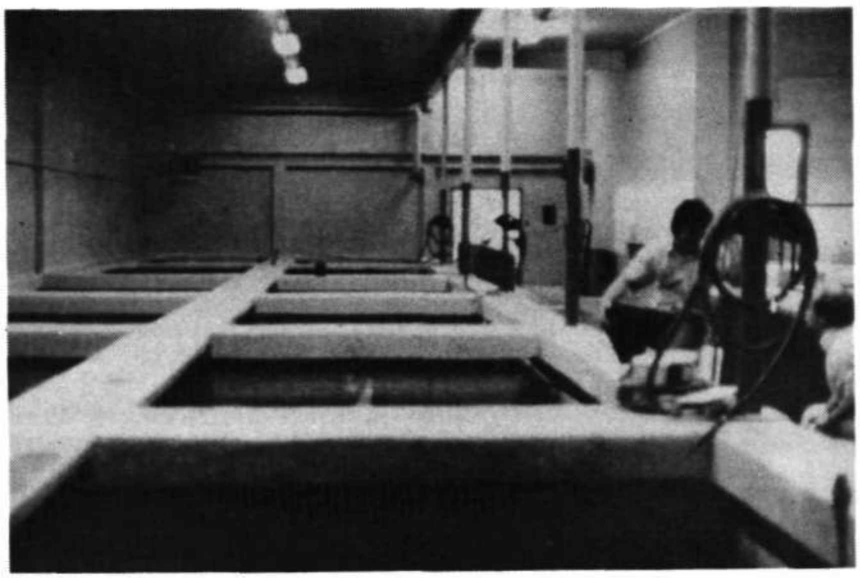

Figure 5. Part of rapid sand filters

Figure 6. Discharge point of water plant wastes

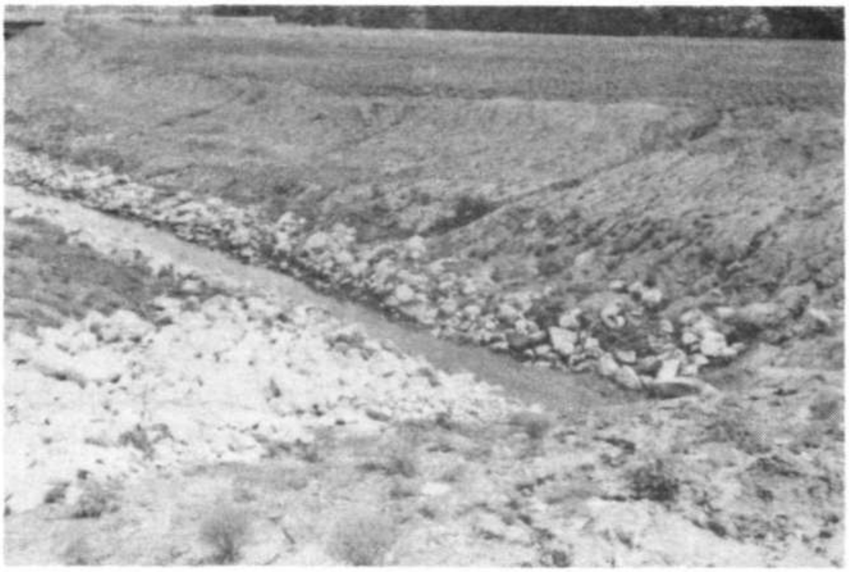

Figure 7. Ditch that receives wastes from waterworks

Sampling Procedures

The major sources of wastes generated at the Centralia waterworks are the clarifiers and filters. To determine the quantity of waste produced, it is necessary to: 1) measure the total suspended solids (TSS) of the raw water, 2) collect samples from the clarifiers and analyze them for solids concentrations, 3) perform sequential sampling of representative filter backwashes, and 4) review the operational reports for the frequency of backwashing, water pumpage, and chemical dosages.

Turbidity and TSS of the raw water were determined daily by the City of Centralia. Samples were collected from the treatment facilities and from Crooked Creek twice a month (from May 1985 to May 1986) by the Illinois State Water Survey. During each visit, samples were collected from the two clarifiers, from two filters, and from eight stations on Crooked Creek.

As stated previously, the timers for clarifier blow-down were turned on and off occasionally depending on the solids blanket condition. The duration of blow-down ranged from 30 seconds to 2 minutes for each 30- or 60-minute interval. During blow-down, waste was collected manually and continuously at the drain outlet above the pit (figure 8) with a wide-mouth bottle (1900 mL) in a sampling bottle carrier affixed to an extended aluminum rod. Approximately five gallons (19 L) of sample was composited from each clarifier blow-down. Settled (30 minutes) samples were used for dissolved oxygen (DO) determination.

The activated carbon mixed media filters were backwashed at a rate of about 4100 gpm (15.5 m^3/min) per unit once every 30 to 50 hours. The duration of backwash ranged from 7 to 10 minutes (appendices A1-A6). Generally there were three filter backwashes per day during the study period. The areal backwash rates ranged from 13 to 17 gpm/sq ft (8.8 to 11.5 $L/m^2 \times s$).

Filter backwash samples were collected sequentially near the end of the wash trough in a half-gallon (1900-mL) wide-mouth plastic bottle with the same sampler used for clarifier waste (figure 9). Sequential samples were generally obtained at 15-second intervals during the first 30 seconds, at 10-second intervals during the next minute, and at increased time intervals thereafter until backwash was completed. This time frame was selected so that an accurate estimation of waste production could be made. The sampling procedure required 16 sample collections per filter wash.

Each sequential sample obtained during backwash operations was analyzed for total and volatile suspended solids, and for settleable solids. Data for each filter wash sample are listed in appendices A1 through A6. A composite sample of backwash wastewater was obtained by a continuous pumping (ISCO sampler) device in a drain trough during each wash period. This sample was considered representative of filter washwater discharging to the receiving stream.

Physical, chemical, and biological analyses were made on filter washwaters and clarifier blow-down wastes. Water temperature, DO, pH, and alkalinity determinations were performed at the site immediately after sample collection. Analyses were also performed for turbidity, sulfate, solids, percent of water, specific gravity, total iron, total aluminum,

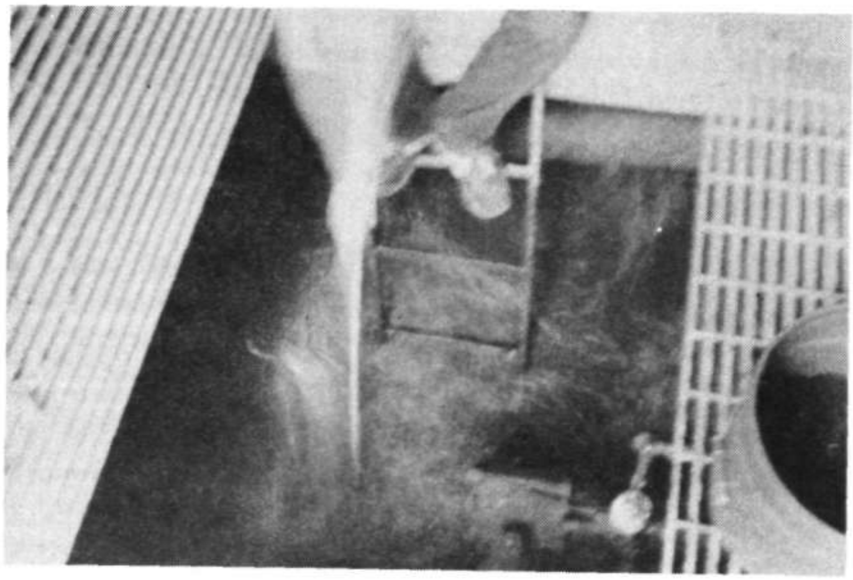

Figure 8. Collection of clarifier blow-down wastewater

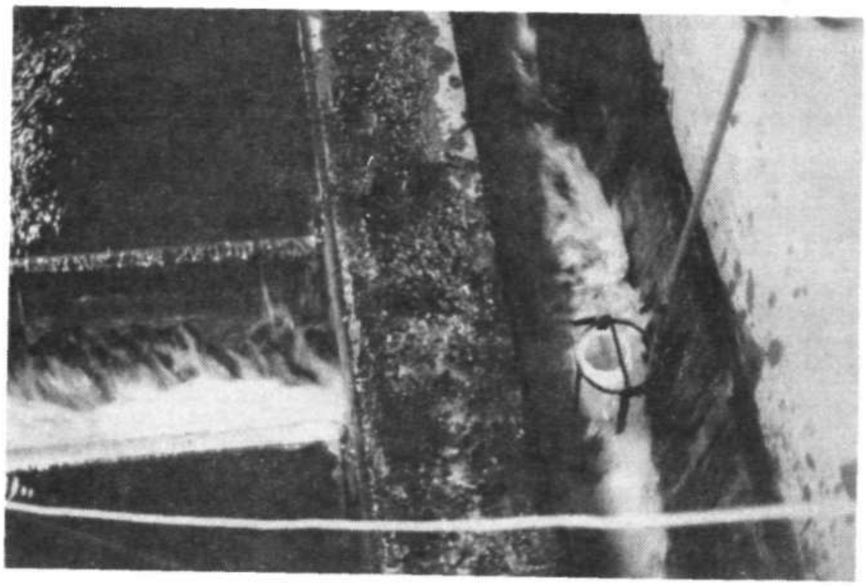

Figure 9. Collection of filter backwash wastewater

5-day biochemical oxygen demand (BOD_5), and fecal coliform (FC). Commencing in September 1985, BOD_5 determinations were carried out by the personnel of the Centralia wastewater plant. With the exception of BOD_5, raw water turbidity, and TSS (determined by the City of Centralia), all analyses were carried out by the Water Quality Section of the Illinois State Water Survey. FC enumerations were made from mid-October 1985 to mid-May 1986. Analyses were performed on each sample in accordance with Standard Methods (1985).

Waste Quantities and Characteristics

The wastes (solids) produced from water treatment plants vary widely in quantities and characteristics due to variations in raw water quality, treatment chemicals, the resulting chemical reactions, mixing, and the method of removal from the sedimentation units. The solids wastes generated within the Centralia waterworks are essentially the same as the TSS contents of the raw water with minor additions generated by the coagulant (alum).

Loads from Raw Water

The water treatment plant personnel do not routinely perform TSS analyses on the raw water. However, turbidity measurements are made routinely at least three times a day and the average value is recorded. As a part of this study Centralia city personnel performed TSS analyses on Raccoon Lake raw water in conjunction with turbidity measurements. After this study began, it was found that the raw water turbidity values recorded in the operational report were for the raw water with added alum coagulant, and not for the waters tested for TSS. Starting on August 7, 1985, both raw water turbidity and TSS were determined in waters collected from a raw water pump daily at around 8:30 a.m.

The results of these measurements are shown in table 1. Other characteristics of the raw water (with alum added) measured by the plant personnel are summarized in tables 2 and 3.

Turbidity vs. TSS

Inspection of table 1 shows that the data can be divided into two groups: data collected from November 18, 1985 through April 27, 1986 as group 1 (cold period), and data obtained on other dates as group 2 (warm period). For each group and all data, the relationships between turbidity and TSS were subjected to regression analyses by the least squares curve fit technique by using the following three mathematical expressions:

$Y = a + bX$ linear

$Y = a \exp(bX)$ semi-log

$Y = aX^b$ log-log

where Y = dependent variable, TSS in mg/L
X = independent variable, turbidity in NTU
a, b = constants

Table 1. Observed Turbidity (NTU) and Total Suspended Solids (mg/L) in Raw (Raccoon Lake) Water

1985

Day	May Turbidity	May TSS	June Turbidity	June TSS	July Turbidity	July TSS	August Turbidity	August TSS
1				8		8		7
2				7		18		7
3				8		14		10
4				6		11		8
5				6		12		7
6				12		11		7
7				13		10	5.0	6
8				8		9	4.6	6
9				9		13	4.9	7
10				6		13	5.1	6
11				9		8	4.7	6
12				9		9	5.3	6
13				10		8	5.3	5
14				10		10	4.7	5
15				20		8	4.3	4
16		5		8		8	4.6	4
17		5		9		7	10.0	8
18		7		8		8	7.9	6
19		11		6		8	7.6	6
20		9		5		8	7.8	10
21		9		6		8	10.4	8
22		10		7		9	10.7	8
23		5		5		7	9.4	7
24		12		7		9	9.8	8
25		16		6		9	7.4	6
26		16		8		7	6.0	4
27		10		6		6	7.4	5
28		16		5		6	9.7	6
29		12		8		5.2	7.5	6
30		8		7		7	6.0	5
31		15				8	4.5	8

Table 1. Continued

Day	September Turbidity	September TSS	October Turbidity	October TSS	November Turbidity	November TSS	December Turbidity	December TSS
	1985							
1	6.1	5		26	15	8	52	25
2	5.0	5	25	24	12	7	6.3	26
3	4.5	3	7.8	6	10	6	59	34
4	4.2	4	6.7	6	10	6	67	28
5	4.5	4		6	8	6	65	30
6	3.4	4	5.5	6	9	6	65	31
7	3.4	4	5.4	6	9	7	64	27
8	3.1	3	6.0	6	19	14	63	20
9	2.4	3	6.9	7	17	13	63	21
10	2.4	3	24.0	20	11	9	60	32
11	17	15	21	16	10	7	59	27
12	28	31	14	9	9	4	55	38
13	8.1	7	10	7	10	6	55	18
14	10.4	8	10	8	9	5	74	23
15	7.3	7	8.1	7	6	5	64	22
16	28.0	27	8.8	6	7	5	73	18
17	14	9	11	10	6	4	72	56
18	12	8	23	23	9.1	3	86	30
19	25	25	12	8	40	16	88	31
20	25	26	9.0	7	38	15	77	19
21	11.4	12	8.1	6	40	15	72	14
22	19.3	18	6.8	5	37	17	64	8
23	25	29	5.5	5	67	23	70	28
24	27	20	6.0	6	75	26	72	23
25		26	5.0	6	73	25	66	15
26		7	4.0	5	63	20	62	11
27	35	39	5.0	6	51	17	65	16
28		10	7	6	38	12	67	29
29	9.3	7	7	6	67	21	68	15
30	12.2	8	8	10	68	21	67	25
31			10	6			69	17

Table 1. Concluded

	1986									
	January		February		March		April		May	
Day	Turb.	TSS	Turb.	TSS	Turb.	TSS	Turb.	TSS	Turb.	TSS
1	63	15	24	12	66	17	74	30	18	12
2	59	18	23	11	61	15	77	25	13	12
3	65	19	27	12	61	22	87	24	14	7
4	62	16	25	10	54	13	81	23	9	8
5	59	14	35	10	62	29	62	19	9	7
6	57	16	61	12	60	24	61	16	12	11
7	55	13	57	17	56	17	65	13	14	13
8	50	16	64	17	52	14	55	27	12.3	8
9	47	13	74	19	56	14	62	25	12	9
10	46	22	73	14	50	12	58	16	13	6
11	46	35	75	18	51	14	59	29	6.9	8
12	42	12	70	22	43	9	58	29	4.0	9
13	41	13	79	16	47	16	48	28		
14	41	29	74	18	48	15	48	23		
15	36	19	73	17	34	10	47	24		
16	35	24	62	14	48	15	47	31		
17	52	17	67	14	41	11	41	21		
18	51	13	68	14	43	15	37	16		
19	41	10	68	14	36	14	36	14		
20	41	10.	67	10	70	27	40	15		
21	38	12	66	9	103	32	33	16		
22	37	12	65	10	106	29	32	14		
23	37	12	62	8	153	33	33	16		
24	37	12	53	10	97	24	28	18		
25	33	12	59	12	95	40	31	21		
26	31	9	56	12	83	22	32	17		
27	26	7	60	13	88	26	24	14		
28	27	12	58	13	86	27	17	13		
29	27	12			85	27	13	12		
30	31	15			62	34	20	14		
31	33	19			81	22				

Table 2. Six-Year (1980-1985) Average Daily Pumpage and Pertinent Water Quality Parameters in Raw Waters

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Average
Pumpage, MGD	3.46	3.30	3.25	3.27	3,51	3.73	4.00	3.94	3.69	3.44	3.29	3.38	3.52
Turbidity, NTU*	80	75	59	80	38	32	26	20	25	28	56	85	50
pH (median)	7.3	7.2	7.3	7.3	7.2	7.1	7.3	7.3	7.3	7.2	7.3	7.4	7.3
Alkalinity, mg/L as $CaCO_3$	69	65	55	60	67	78	81	84	82	83	66	69	72
Total Hardness, mg/L as $CaCO_3$	118	115	123	118	126	127	127	123	124	118	94	107	118

* Measured in the plant after $KMnO_4$ and alum were added

Table 3. Average Pumpage, Turbidity, TSS Concentrations and Loading Rates

Year & month	Flow, MGD	Turbidity, NTU	TSS, mg/L	TSS loading rate, lb/d Average	Range
1985					
May	3.85	—	10	329	147 - 540
Jun	3.72	—	8	249	150 - 589
Jul	4.20	—	9	317	199 - 612
Aug	3.99	6.8	7	217	131 - 343
Sep	4.00	13.1	13	419	101 - 1207
Oct	3.75	9.9	9	287	150 - 915
Nov	3.57	28	12	347	90 - 763
Dec	3.82	67	24	778	228 - 1810
1986					
Jan	3.68	43	15	474	213 - 1120
Feb	3.66	59	14	408	229 - 701
Mar	3.52	67	21	598	285 - 1190
Apr	3.58	47	20	601	383 - 980
May	3.88	11	9	291	197 - 389
Average	3.78	38	13	418	

The coefficients of correlation for each regression analysis are as follows:

	Number of observations	Linear	Semi-log	Log-log
Group 1	161	0.504	0.529	0.563
Group 2	113	0.929	0.921	0.882
All data	274	0.720	0.771	0.849

Generally log-log relationships gave better correlation coefficients, but not for group 2. The expressions giving the highest coefficients of correlation were chosen to define the relationships. They are:

$Y = 0.388\ X^{0.621}$ for group 1

$Y = 0.914\ X - 0.598$ for group 2

$Y = 0.817\ X^{0.525}$ for all data

The above relationships are presented for information purposes only. The daily TSS data were used for estimation of solids loading from the raw waters to the treatment plant.

Assuming TSS contents in raw water are completely removed in the sedimentation and filtration units, the dry weight of solids (W_1, pounds per million gallons of water treated or lb/d) generated from TSS in the raw water can be calculated as:

$$\text{Dry weight of solids (in lb/MG)} = \left(\frac{2.205 \times 10^{-6}\ \text{lb}}{\text{mg}}\right)\left(\frac{\text{L}}{0.2642 \times 10^{-6}\ \text{MG}}\right) \times \text{TSS (in mg/L)}$$

$$W_1 \text{ (in lb/MG)} = 8.34 \times \text{TSS (in mg/L)} \qquad (1a)$$

$$\text{or } W_1 \text{ (in lb/d)} = 8.34 \times \text{TSS (in mg/L)} \times \text{Flow (in MGD)} \qquad (1b)$$

On the basis of equation 1a, 8.34 pounds of solids per million gallons of raw water treated will be generated per mg/L of TSS.

The average daily concentrations of TSS measured for the raw (Raccoon Lake) waters, for the period from May 16, 1985 to May 12, 1986, varied from 3 to 56 mg/L with an overall average of 13 mg/L. The TSS contents in the lake water were generally very low (table 1). During the same period, the average daily pumpages ranged from 3.27 MGD on April 20, 1986 to 4.75 MGD on July 18, 1985. The average flow was calculated to be 3.78 MGD (table 3).

On the basis of the recorded raw water pumpages and the TSS concentrations, the daily average TSS loadings to the treatment plant were calculated by equation 1b. The calculated average daily TSS loading rates for each month, as well as flow rates, turbidity, and TSS contents, are included in table 3.

The observed TSS loading rate to the plant ranged widely: from 90 pounds (40.9 kg) per day (November 18, 1985) to 1810 pounds (822 kg) per day

(December 17, 1985). On these two dates the pumpages were near the annual average value. However, the TSS concentrations were 3 and 56 mg/L, respectively. On the basis of monthly averages, the TSS loading rates ranged from a low of 217 pounds (99 kg) per day in August 1985 to a high of 778 pounds (353 kg) per day in December 1985 (table 3). It seemed that the TSS load was higher in cold months and was lower during warmer months. The annual average was 418 pounds (190 kg) per day. This average TSS load corresponds to 110.6 pounds (50.2 kg) per million gallons of water processed.

Loads from Coagulants

Fundamental Concepts. Aluminum sulfate (alum) is the coagulant most widely used for water treatment. Its first reaction with water is one of solution; its second reaction is one of combination with the hydroxide (OH^-) ions made available by the alkalinity of the water. The stoichiometric relation between commercial alum and alkalinity can be written as:

$$Al_2(SO_4)_3 \cdot 14\ H_2O + 3\ Ca(HCO_3)_2 \longrightarrow 2Al(OH)_3 + 3\ CaSO_4 + 6\ CO_2 + 14\ H_2O \qquad (2)$$

On the basis of this chemical reaction (equation 2), approximately 0.262 (156/594) pounds of $A1(OH)_3$ precipitate will be produced per pound of dry alum dosed. In the case or commercial dry alum, Al_2O_3, content is only about 17 percent of the total. Therefore the solid waste produced by dry alum coagulation will be:

$$\text{Pounds of precipitate} = 0.262 \times 0.17 \quad \text{pounds of dry alum dose}$$
$$= 0.0445 \times \text{pounds of dry alum dose} \qquad (3)$$

or, in a calculation similar to that for TSS loading, the dry weight (W_2) of solids produced by dry alum dosage (D_1, in mg/L) can be estimated as:

$$W_2 \text{ (in lb/MG)} = 8.34 \times 0.0445 \times D_1 \text{ (in mg/L)} \qquad (4)$$

Combining equations 1 and 4, the total dry weight of the precipitate in lb/MG would be:

$$W = 8.34\ (TSS + 0.0445\ D_1) \qquad (5)$$

In 1973, Neilsen and his co-workers first proposed the following empirical formula to predict the precipitate production in water plants.

The total dry weight of the precipitate is given as:

$$W \text{ (in lb/MG)} = 8.34 \times \text{Turbidity (in JTU)} + 2.75\ D_d \text{ (in mg/L)} \qquad (6)$$

The averages of solids loading to filters were 26 and 60 pounds per million gallons of flow in summer and winter, respectively. Extensive tests at the East Bay Municipal Utility District, Oakland, California, indicated a greater weight formation of $A1(OH)_3$ floc, at the rate of 0.3 mg/L of floc per mg/L dry alum dosage (Neilsen et al., 1973). The formation of $A1(OH)_3 \cdot 1.2\ H_2O$ was postulated.

On the assumption that one turbidity unit (JTU) corresponds to one mg/L of TSS, total dry sludge (in lb/MG) resulting from dry alum coagulation can be determined as follows (Chapman, 1974):

$$W = 8.34\ (\text{Turbidity in JTU} + 0.3 \times D_d \text{ in mg/L}) \qquad (7)$$

The total dry weight of the solids is from the flocculators, sedimentation basins, and filter backwashes.

Cationic polymers are gaining wide acceptance as a partial or total replacement for metal-salt coagulants such as alum. When polymers are used, less sludge is produced since a lower metal-salt dosage is required. The use of polymers at Centralia over the last three years has not helped to reduce alum dosages (see table 5).

Alum Sludge Production. Monthly daily chemical dosages at the Centralia water treatment plant are summarized in tables 4 through 6. The data in table 4 suggest that the potassium permanganate dosage ranged from 16 to 89 lb/d with an annual average of 47 lb/d. The caustic soda dosage averaged 822 lb/d with a range of 319 to 2233 lb/d. Total chlorine applications were between 100 and 580 lb/d with an average of 170 lb/d.

Alum has been used as a coagulant at the Centralia plant. The long-term alum dosage is shown in table 5. In the last three years alum dosage increased significantly, especially from December 1982 through February 1985.

Although liquid alum is used at the Centralia plant, the alum dosage is reported on a "dry alum" basis. According to the plant operational report, the alum dosage was kept at a constant rate for a certain period, either short or long, without regard to the variations in TSS contents, turbidity, and flow. For example, the alum dosage rate was 1068 lb/d for the period from July 31, 1985 through October 8, 1985, and it was 801 lb/d from October 9, 1985 through November 18, 1985. These two alum dosage rates were the most commonly employed: 38.7 and 32.1 percent of the time, respectively. Only nine alum application rates were used during the study period. They were 534, 634, 801, 1068, 1335, 1602, 2136, 2403, and 2937 lb/d. The dosage rate of 534 lb/d was used frequently. Alum dosages of 2937 and 2136 lb/d were applied only one day each on February 3, 1986 and February 6, 1986, respectively, and the dosage of 2403 lb/d was used for only two days, on March 5 and 6, 1986.

The data in table 6 indicate that during the study period (May 14, 1985 through May 12, 1986) the monthly average alum dosages ranged from 667 lb/d in May 1985 to 1157 lb/d in May 1986 with the year's average being 935 lb/d. A comparison of tables 1 and 6 shows that the alum dosage was not related to the turbidity or TSS of the raw water.

On the basis of the plant operational data, pounds of alum dosed per million gallons of water treated was also calculated for each day during the study period. Those values ranged from a low of 112 lb/MG on July 5, 1985 to a high of 802 lb/MG on February 3, 1986, with an overall average of 249 lb/MG. There seems to be an overdose of coagulant despite the good quality of the raw water supply. In comparison, at the East St. Louis water

Table 4. Monthly Average Values and Ranges of Chemical Dosages (lb/d) during the Study Period (May 14, 1985 through May 12, 1986)

	1985								1986					
	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Avg
Potassium permanganate (95%)														
Average	22	44	64	66	62	50	48	37	32	42	43	47	51	47
Max.	28	54	70	73	65	60	89	56	35	43	48	51	51	
Min.	21	16	54	57	57	41	40	30	30	35	27	41	51	
Caustic soda, liquid (50%)														
Average	780	871	1019	1019	840	710	680	844	813	877	751	744	744	822
Max.	957	1276	2233	1914	1595	757	1595	1595	1276	1595	957	957	957	
Min.	638	638	638	638	638	319	319	319	319	319	638	319	319	
Chlorine gas														
Average	175	179	220	199	170	149	144	146	153	178	159	176	163	170
Max.	220	580	500	280	200	180	180	180	180	220	200	240	180	
Min.	140	100	120	120	140	120	120	100	120	110	120	140	140	

Table 5. Monthly Average of Pounds of Alum Dosages (Dry Equivalent) per Day

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg	Dosage (mg/L)
1980	1715	2000	1738	1901	825	568	458	452	472	387	605	424	962	33.7
1981	302	381	350	356	599	952	415	333	302	345	277	328	412	15.1
1982	1463	1740	1178	446	336	943	921	1257	941	599	557	2594	1081	38.3
1983	1729	1633	983	1760	1757	1367	1514	1430	1376	1690	1738	2110	1591	54.8
1984	2102	2020	1817	2403	1191	1651	1654	1946	1753	1389	2027	2196	1846	57.0
1985	2222	2107	714	748	629	756	706	1068	1068	870	792	956	1053	33.6
1986	999	1114	1057	979	1205	1353	1301	1292	1530	1352	1184	896	1189	37.3
Avg.	1505	1571	1120	1228	935	1084	996	1111	1063	947	1029	1359		

Note: 1 lb = 0.454 kg

Table 6. Monthly Average Values and Ranges of Alum Dosage and Alum Sludge Production during the Study Period (May 14, 1985 through May 12, 1986)

	1985 May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	1986 Jan	Feb	Mar	Apr	May	Avg
Alum dosage, lb/d														
Average	667*	756	706	1068	1068	870	792	956	999	1114	1057	979	1157*	938
Max.	1335	1335	1602	1068	1068	1068	1068	1068	1602	2937	2403	1602	1602	
Min.	534	534	534	1068	1068	801	534	534	534	634	534	534	534	
Alum dosage, lb/MG														
Average	173	204	170	268	268	232	222	251	272	307	301	274	298	248
Max.	348	352	396	296	320	289	296	323	424	802	703	462	404	
Min.	116	134	112	248	244	204	153	136	143	162	155	127	136	
Sludge production, lb/d														
Average	29.7	33.7	31.4	47.5	47.5	38.7	35.2	42.5	44.7	49.6	47.0	43.6	51.5	41.7
Max.	59.4	59.4	71.3	47.5	47.5	47.5	47.5	47.5	71.3	130.7	106.9	71.3	71.3	
Min.	23.8	23.8	23.8	47.5	47.5	35.6	23.8	23.8	23.8	28.2	23.8	23.8	23.8	
Sludge production, lb/MG														
Average	7.9	9.1	7.6	11.9	11.9	10.3	9.9	11.2	12.1	13.8	13.4	12.2	13.3	11.0
Max.	15.8	15.7	17.6	13.2	14.2	12.9	13.2	14.4	18.9	35.7	31.3	20.6	18.0	
Min.	5.3	6.0	5.0	11.0	10.9	9.1	6.8	6.1	6.4	7.2	6.9	5.7	6.1	

*Not a full month's average

treatment plant the mean alum dosage was 306 lb/MG for the turbid Mississippi raw water (Lin et al., 1984). The monthly average values presented in table 6 range from 170 lb/MG in July 1985 to 307 lb/MG in February 1986.

On the basis of "dry alum" dosages, residues generated by alum coagulation were calculated daily by equation 3. The monthly average and ranges of daily alum sludge production are shown in table 6. The daily alum sludge production ranged from 23.8 to 130.7 pounds (10.8 to 59.3 kg) with a yearly average of 41.7 pounds per day (18.9 kg). The average quantity represents about 10 percent of the TSS loading contributed solely by the raw water, since the annual average TSS loads in the raw water were estimated at 418 lb/d. Thus the total solids loads to the Centralia plant would be approximately 460 lb/d (209 kg/d). The annual total solids load was estimated at 83.95 tons or 167,900 pounds (76,200 kg). Table 6 also shows the alum sludge production per million gallons of water processed. The values ranged from 5.0 to 35.7 pounds (2.3 to 16.2 kg) per million gallons with an average of 11.0 lb/MG (5.0 kg/MG). As previously mentioned, the TSS loads from the raw water were estimated at 110.6 lb/MG. Thus the total solids load to the Centralia plant was 121.6 lb/MG (55.2 kg/MG).

Wastes from Filter Backwashes

The pertinent data from the observations of filter backwash operation by sequential sampling are shown in appendices A1 through A6. The sampling schedule for the filter backwashes is summarized in table 7. The average values and ranges of backwashes, associated information, and information on sludge production from the operational data and from calculations are summarized in table 8. The water quality characteristics of the filter wash wastewaters are presented in appendix B and appendices G1 through C14.

A total of 50 filter backwash sequential samplings were made from May 14, 1985 through May 12, 1986. Between 6 and 11 data collections were made per filter. However, the data collected on March 18, 1986 for filter 3 were excluded from the data analysis because the sequential samples were taken less than a day after 18 inches of activated carbon filter media was replaced.

The filter backwash cycle was set at between 30 and 60 hours depending on filter requirements. Generally, the duration was shorter during cold-weather periods. The average number of hours of operation of the six filters ranged from 44.1 (filter 6) to 55.1 (filter 5) with an overall average of 47.2. This converts to 3.05 filter washes per day or approximately one wash per filter every two days. The six observations on filter 5 were mostly in the summer. With few exceptions, the backwash durations were within the range of 7.5 to 9.3 minutes (appendix A). The overall average was 8.34 minutes. The average observed backwash rates for each filter ranged from approximately 4700 to 5100 gpm (0.30 to 0.32 m^3/s) and from 15.4 to 16.9 gpm/sq ft (10.5 to 11.5 $L/m^2 \cdot s$). The range of the filtration rate in gpm/sq ft for each filter unit is shown in table 8. With some exceptions, most backwash rates were between approximately 15 and 17 gpm/sq ft (10.2 to 11.5 $L/m^2 \cdot s$). The average of 49 observed wash rates was 16.2 gpm/sq ft (11.0 $L/m^2 \cdot s$) or 4900 gpm (0.31 m^3/s).

Table 7. Schedule for Sample Collection from Filter Backwashes

Date	Filters	Date	Filters	Date	Filters
1985		1985		1986	
5/14	1 & 2	9/4	3 & 5	1/7	1 & 3
5/28	5	9/17	3 & 5	1/21	4 & 6
5/29	6	10/2	4 & 6	2/4	4 & 6
6/11	4	10/15	4	2/18	2
6/12	3	10/16	5	2/19	3
6/25	1 & 5	11/5	1 & 4	3/5	1 & 2
7/11	2 & 3	11/19	2 & 6	3/18	1 & 3
7/23	6	12/3	3 & 4	4/1	2 & 4
7/24	4	12/18	1 & 6	4/15	3
8/6	2 6 5			4/16	2
8/20	2 & 3			5/12	3 & 6

Table 8. Average Values for Each Filter Backwash and Solids Production

		Filter 1	Filter 2	Filter 3	Filter 4	Filter 5	Filter 6	Overall Average
No. of backwashes		7	9	10	9	6	8	8.3
Hours of operation/cycle		44.8	46.5	47.3	47.0	55.1	44.1	47.2
Water filtered, MG/cycle		1.125	1.204	1.259	1.241	1.550	1.209	1.254
Backwash duration, minutes		8.65	8.50	8.23	8.40	8.76	8.11	8.34
Backwash rate, gpm		4765	4808	5125	4966	4664	5034	4915
gpm/sq ft,	Average	15.7	15.8	16.9	16.3	15.4	16.6	16.2
	Max.	16.6	16.3	19.3	17.6	17.9	17.4	
	Min.	14.6	13.0	14.5	13.5	13.3	15.2	
Waste volume,								
gal	Average	41,100	40,900	42,000	41,600	40,300	40,800	41,200
	Max.	44,000	50,000	46,000	43,000	44,000	43,000	
	Min.	38,000	32,000	39,000	40,000	37,000	38,000	
Total suspended solids,								
lb/d,	Average	14.9	15.8	16.6	8.9	6.0	7.9	12.1
	Max.	34.3	27.8	27.8	17.5	7.7	11.0	
	Min.	8.6	8.9	10.6	4.3	4.3	3.8	
lb/MG,	Average	24.1	25.3	26.8	13.7	8.9	11.9	19.1
	Max.	52.0	46.2	46.9	26.5	11.1	15.9	
	Min.	15.4	14.8	16.3	7.1	6.6	6.0	
Volatile suspended solids,								
lb/d,	Average	5.2	5.8	6.2	3.6	2.6	3.6	4.6
	Max.	10.8	10.3	9.1	7.7	3.6	6.7	
	Min.	2.6	2.9	2.2	1.2	2.2	1.2	
lb/MG,	Average	8.4	9.0	10.1	5.5	3.9	5.4	7.3
	Max.	16.3	17.3	18.3	11.6	5.1	9.6	
	Min.	4.3	5.7	3.5	2.2	2.8	2.0	
Settleable solids,								
gal/d,	Average	105.0	164.2	200.6	63.4	32.4	41.5	108.5
	Max.	217.0	373.2	380.4	175.2	68.6	115.0	
	Min.	13.0	29.0	69.1	10.8	11.3	0.7	
gal/MG,	Average	172.1	254.5	321.3	95.8	47.7	62.8	170.6
	Max.	361.8	520.6	533.7	264.2	100.1	183.8	
	Min.	21.1	96.7	107.0	18.1	18.1	5.7	

Note: 1 gal = 3.785 L; 1 gpm = 6.308×10^{-5} m^3/s; 1 gpm/sq ft = 0.679 $L/m^2 \times s$

The quantity of water treated by each filter between wash cycles was estimated from the pumpage and hours of operation. The average volume of water filtered ranged from a low of 1.125 MG (4260 m^3) for filter 1 to a high of 1.550 MG (5870 nr) for filter 5. The value for each of the other four filter units was approximately 1.2 MG (4600 m^3). The annual average for all filters was 1.254 MG (4750 m^3) per filter cycle.

Total Volume. The quantity of filter backwash water used per cycle was obtained from records maintained at the plant site. As can be seen from table 8, the range of waste volume was between 32,000 and 50,000 gallons (121 and 189 m^3). These extreme values occurred at filter 2. The average daily wash volumes for each unit were fairly constant: 40,300 to 42,000 gallons (153 to 159 m^3) with an overall average of 41,200 gallons (156 nr) per filter wash. This represents about 3.3 percent (41,200/1,254,000) of the water treated.

As previously mentioned, there were an average of 3.05 washes per day at the plant. Therefore, total wastewater volume released by filter backwashes at the plant would be 125,700 gallons (476 m^3) per day. With the year's average flow at 3.78 MGD, the average wastewater volume from the filters was 30,600 gallons per million gallons of water processed.

Weight of Total Suspended Solids. The quantity and characteristics of filter backwash wastewater and the frequency of wash are functions of the filters, the efficiency of the units preceding the filters, and the quality of the raw water. The quantity of dry solids (TSS and VSS) released from each filter backwash was estimated with a personal computer from the data presented in appendices A1-A6. The formula used was:

$$S = \sum_{i=1}^{n} [1/2\ (t_{i+1} - t_i)(C_i + C_{i+1}) \times Y \times 3.785 \times 2.202 \times 10^{-6}]$$

$$S = 4.1673 \times 10^{-6}\ Y \sum_{i=1}^{n} (t_{i+1} - t_i)(C_i + C_{i+1}) \qquad (8)$$

where S = solids released per wash, lbs

n = number of sequential samples collected

$t_1, t_2, \ldots, t_n$ = time of collection, minutes

$C_1, C_2, \ldots, C_n$ = solids concentration, mg/L

Y = backwash rate, gallons per minute

1 gallon = 3.785 L

1 mg = 2.202×10^{-6} lb

The average quantity of total suspended solids released from the backwash for each filter is shown in table 8, expressed as both lb/d and lb/MG of water processed. There was wide variation in the amount of TSS released in the filter washes. Amounts ranged from a low of 3.8 lb/d (6.0 lb/MG) at filter 6 on January 21, 1986 to a high of 34.3 lb/d (52.0 lb/MG) at filter 1 on December 18, 1985. The average TSS released from each filter ranged from 6.0 lb/d (8.9 lb/MG) at filter 5 to 16.6 lb/d (26.8 lb/MG) at filter 3. Including all filters, the overall average TSS production was 12.1 lb/d (19.1 lb/MG). The TSS levels in composite backwash samples ranged from 23 to 238 mg/L (appendix C1).

To estimate the total weight of TSS released daily from filter backwashes in the treatment plant, the following assumptions are made: 1) all filters were in service all the time; 2) each filter unit generates the same quantity as the annual overall average (12.1 lb/d); and 3) each filter has the same backwash cycle, i.e., average value of 47.2 hours.

The estimated TSS generated from the filters was 72.6 pounds (33 kg) per day. This represents 15.7 percent (72.6 459.7) of the total solids load to the plant. Thus, the total estimated daily weight of TSS released from the filters would be about 26,500 pounds (13.3 tons) yearly.

Weight of Volatile Suspended Solids. Volatile suspended solids content in the filter wash wastewater was evaluated in a manner similar to that for TSS. VSS release patterns during filter backwash were found to be similar to those for TSS. The ranges and daily average VSS released from each filter unit are also shown in table 8. Observed daily VSS released from the filters was between 1.2 lb/d (2.0 lb/MG) and 10.8 lb/d (18.3 lb/MG). The average daily release for each filter ranged from 2.6 lb/d (3.9 lb/MG) for filter 5 to 6.2 lb/d (10.1 lb/MG) for filter 3.

The overall average of VSS released was 4.6 lb/d (7.3 lb/MG) for each unit. This overall volatile content of filter backwash solids was 38 percent. This was significantly higher than the 23 percent observed at Alton (Evans et al., 1982) and the 26 percent observed at East St. Louis (Lin et al., 1984). These differences might be due to different raw water sources and different operational modes.

The dry weight of VSS produced at the Centralia plant would be 27.6 lb/d or 10,100 lb/y or 5 tons per year. This amount of dry solids represents 6.0 percent of the plant's total solids load.

Volume of Settleable Solids. Settleable solids are determined by the volume of residues, in milliliters, which settle in a 1-liter Imhoff cone after a quiescent period of 60 minutes. Depending on the receiving stream conditions, a fraction of the settleable solids can create residue deposits.

The release pattern for settleable solids during filter backwash was similar to that for TSS as depicted in figure 10. Inspection of the data presented in appendices A1-A6 shows that 99 to 100 percent of settleable solids were released after 4 to 5 minutes. The quantity of solids residue during filter backwashes, as measured by settleable solids, was estimated from the data in appendices A1-A6 by the following formula:

$$V = \sum_{i=1}^{n} \frac{1}{2} (t_{i+1} - t_i)(v_i + v_{i+1})(10^{-3})\ Z$$

$$V = \frac{10^{-3}\ Z}{2} \sum_{i=1}^{n} (t_{i+1} - t_i)(v_i + v_{i+1}) \qquad (9)$$

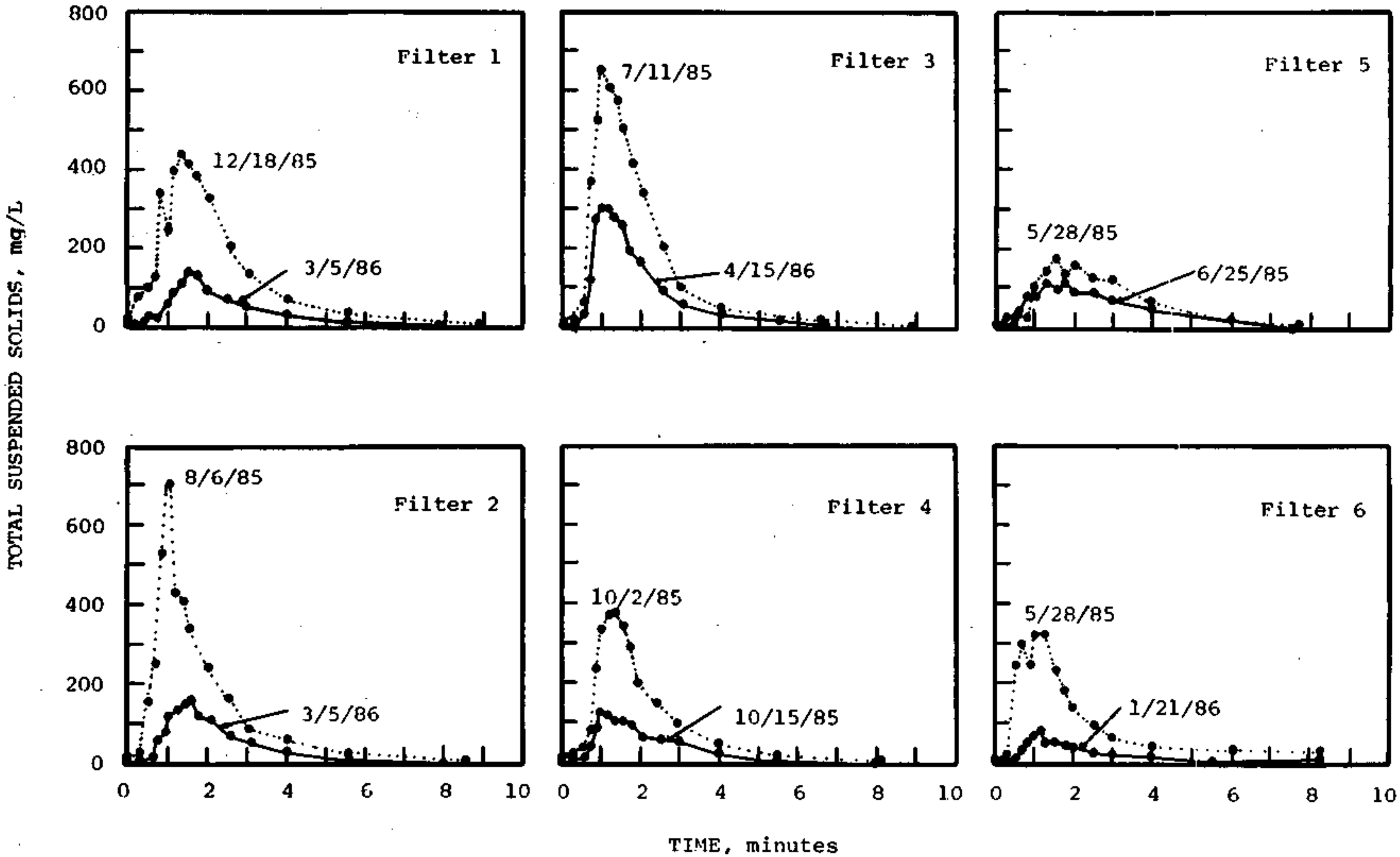

Figure 10. Total suspended solids release during filter backwashes

where V = volume of residue, gallons

$v_1, v_2, ..., v_n$ = volume of settleable solids, mL/L

Z = filter backwash rate, gpm

1 mg = 1 ml = 10^{-3} L (assumed)

The other symbols used above are the same as for TSS.

The estimated volumes of settleable solids for each filter backwash are set forth in table 8. The volumes per backwash for each filter unit were quite variable. Similar results have been reported previously (Evans et al., 1979; Lin et al., 1984). The variability may be due to the water quality of the clarifier effluent, hydraulic loading of each filter, and other operational variables.

The observed volume of settleable solids ranged from a low of 0.7 gal/d (5.7 gal/MG) at filter 6 on December 18, 1985 to a high of 380.4 gal/d (533.7 gal/MG) at filter 3 on July 11, 1985. The average volume of settleable solids released from the filters was also quite variable: from 32.4 gal/d (47.7 gal/MG) for filter 5 to 200.6 gal/d (321.3 gal/MG) for filter 3.

For the 49 observations, the overall average volume of settleable solids released was 108.5 gal/d for each unit and 170.6 gal/MG of water treated. Therefore, the total daily volume of settleable solids from the treatment plant was estimated as 651 gallons (2.46 m^3). This represents approximately 0.017 percent of the plant pumpage. At the East St. Louis water treatment plant, the settleable solids were found to be 0.039 percent of the plant's pumpage (Lin et al., 1984).

Other Characteristics of Filter Wash Wastewaters. Dissolved solids, moisture content, specific gravity, temperature, dissolved oxygen, pH, alkalinity, total iron and aluminum, BOD_5, and fecal coliforms of the filter wash wastewaters are summarized in appendices B and C4 through C14. In appendix C, for each sampling date Fa indicates the filter with the lower identification number and Fb indicates the filter with the higher identification number.(The filter backwash sampling dates in appendix C are for tabulating convenience only. The correct sampling dates for backwashes are shown in table 7, and appendices A and B.) SD stands for standard deviation. Some of these data will be included in the discussion in the following section, on the water quality of Crooked Creek.

Appendix B shows that the observed dissolved solids concentrations in the filter backwash wastewaters ranged from 146 to 306 mg/L. The average volume of dissolved solids among the filters was low, ranging from 218 to 245 mg/L. The moisture content for all filter backwash samples was between 99.95 and 99.98 percent with an overall average of 99.97 percent. The specific gravity was approximately 1.0, essentially the same as for water.

Because samples were collected from each filter at different times of the day and at different points in the season, the average value of temperature for each filter was meaningless. This is also the case for dissolved oxygen, which is temperature-dependent. The observed temperatures varied from 2.1 to 26.8°C (appendices B and C5).

Dissolved oxygen concentrations were between 7.5 and 13.7 mg/L (appendices B and C6). As expected, DO values were generally lower in the summer and higher in the winter.

Turbidity in the wastewater of the filter backwashes ranged from 21 to 118 NTU (appendices B and C7). The average turbidity for each of filters 1, 2, and 3 (61-76 NTU) was significantly greater than that for filters 4, 5, and 6 (29 to 42 NTU). The overall average was 55 NTU.

Appendices B and C8 show that the observed pH of the filter wash wastewater ranged from 6.6 to 7.6. During cold periods, with the exception of January 1986, pH values tended to be lower than 7.0. The median pH value was 7.3.

Total alkalinity values for the filter's wash wastewater were similar for each sampling date. These values ranged between 18 and 78 mg/L as $CaCO_3$ (appendix C9). The overall average alkalinity was 51 mg/L as $CaCO_3$. The buffering capacity of the filter backwash wastewater was low.

As shown in appendices B and C10, sulfate concentrations of the filter wash wastewater varied from 50 to 106 mg/L. The average sulfate concentration of each filter's wastewater ranged from 73 to 87 mg/L.

The total iron concentrations of the filter wash wastewater were very low, between 0.44 and 3.57 mg/L (appendices B and C11). Individual filter average iron concentration varied from a low of 0.78 mg/L for filter 5 to a high of 1.93 mg/L for filter 3. The overall average iron content for all filter wastewater was 1.46 mg/L.

As shown in appendices B and C12, the total aluminum concentration of the filter washwater varied widely, from 1.57 to 13.6 mg/L. The average value for each filter ranged from a low of 3.62 mg/L for filter 5 to a high of 7.65 mg/L for filter 3. These trends were similar to those for total iron concentrations. The overall aluminum concentration was 5.02 mg/L. This was significantly less than the concentration in the clarifier residue (appendix C12).

Appendix C13 indicates that the BOD_5 of the filter wastewater was low, between 1 and 8 mg/L. Most samples had a $B0D_5$ of 1 to 3 mg/L. The overall average of BOD_5 was 2 mg/L.

Inspection of appendix C14 shows that fecal coliform densities in the filter backwash wastewaters varied from non-detectable to 120 FC per 100 mL. Most samples showed no FC. Samples obtained in October and November 1985 contained moderate densities of fecal coliform. Aluminum coagulation showed effective removal of fecal coliform.

Wastes from Clarifiers

Total Volume. The records on clarifier blow-down during the period from May 14, 1985 to October 13. 1985 were not available. For the purpose of this report, the records for the period from October 14, 1985 through June 10, 1986 were used for estimating the total volume of clarifier blow-down to Crooked Creek.

The settled solids in the two upflow clarifiers were blown down once every half-hour or every hour. The duration of the blow-down was either 30, 45, 60, or 90 seconds. The 90-second duration was used for both clarifiers only on January 10 and 11, 1986. The timers which control the blow-down operations were turned off and on by the operators from time to time depending upon the solids settling characteristics.

Figure 11 shows the periods of sludge clarifier blow-down. The duration of blow-down operations varied from 2 to 24 hours per day. For the 238-day period from October 14, 1985 through June 10, 1986, excluding March 29 and 30 (missing data), the total turn-on times were 2198 and 1811 hours for C1 (north clarifier) and C2 (south clarifier), respectively. This means that 49.9 and 39.9 percent of the time, respectively, the C1 and C2 timers were turned on.

Waste volumes of each blow-down as a function of blow-down duration were provided by the Centralia city engineer. They are as follows:

Blow-down time, seconds	Volume of discharge, gallons
12	32
15	50
30	190
45	350
60	510
90	825

By means of the above information as well as records on blow-down, the wastewater volume of the blow-down for each "time-on period" can be estimated. The daily overall average was estimated from the summation of volumes of all periods divided by 238 days. The average daily blow-down volumes were calculated to be 4680 and 3620 gallons, respectively, for C1 and C2.

The average value for the plant discharge from the clarifiers was 8300 gpd, or 2200 gal/MG of water treated. The maximum daily volumes released were 13,700 gallons on October 17, 1985, and 23,200 gallons on October 19, 1985, respectively, for the north (C1) and south (C2) clarifiers. The volume of wastes released by the two clarifiers was 0.22 percent of pumpage.

Weight of Total Suspended. Solids. The total weight of solids generated by the clarifiers, on a dry weight basis, may be estimated from the discharge volumes and the TSS concentrations in the wastewater of the clarifiers (C1 and C2), which are shown in appendix C1.

On the basis of 25 observations during this study, the average TSS concentrations were 3040 and 3890 mg/L for the north (C1) and south (C2) clarifiers, respectively. The average discharge volumes were, respectively, 4680 and 3620 gpd. Therefore, the respective dry weight of solids would be 123 and 117 pounds (56 and 53 kg) per day. The total amount from both clarifiers was measured as 240 pounds (109 kg) per day.

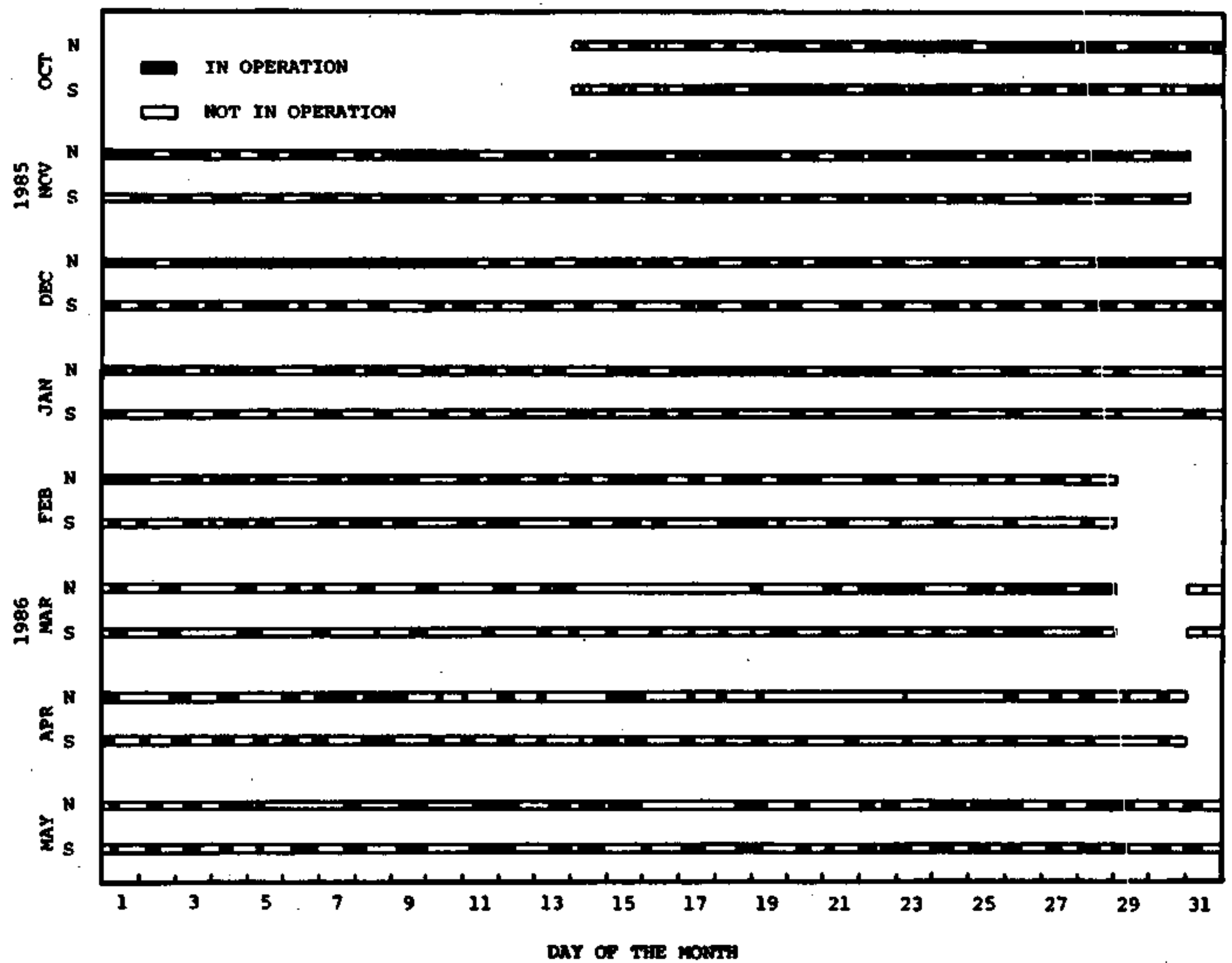

Figure 11. Periods of operation of the clarifier blow-downs

The weight of solids which accumulated in and were subsequently released from the clarifiers can also be calculated from the difference between the total plant input load and the TSS released from the six filters. This was found to be 387 lb/d (table 9).

As shown above, there is a difference between the amount of solids blown down from the clarifiers as measured (240 lb/d) and as calculated (387 lb/d). The difference could be due in part to the unmeasured amounts of solids that accumulate in the clarifier flocculator and discharge pit. These solids are cleaned out periodically for tank inspections. The difference may also be due to collecting grab versus continuous samples. Samples obtained by a continuous sampler might have given a more accurate figure. Therefore, the mass loading values used for solids may be 61 percent [(387- 240) ÷ 240] higher than the measured amount.

Weight of Volatile Suspended Solids. The observed VSS concentrations in the clarifier wastewater are shown in appendix C2. The ratio of VSS to TSS for each clarifier sample was calculated. For 25 observations the ratios ranged from 12 to 44 percent with an average of 26 percent for both clarifiers. The results indicated that the ratios were higher during warm weather periods and lower during cold periods.

The VSS concentrations in the wastewater of the clarifier blow-downs ranged from 28 to 1370 mg/L and from 30 to 1940 mg/L, respectively, for the north and south clarifiers. On the average, the values were 690 and 830 mg/L, respectively. On the basis of average concentrations and discharge volumes (4680 and 3620 gpd, respectively), the dry weights of VSS discharged were 26.9 and 25.0 lb/d, respectively. The total amount from the plant was 51.0 lb/d. This value represents 13.8 pounds per million gallons of water processed and corresponds to 11.3 percent of the total plant load. As noted for TSS, the mass loading values may be 61 percent higher than measured.

Volume of Settleable Solids. The measured volumes of settleable solids from the two clarifiers during blow-down are shown in appendix C3. The results suggest that the volume of settleable solids per blow-down for each clarifier was quite variable, ranging from 140 to 820 mL/L. High values can be expected after long periods of shut-off (without blow-down). The average volumes of settleable solids were 367 and 403 mL/L for C1 and C2, respectively.

On the basis of the average daily blow-down volumes (4680 and 3620 gallons, respectively, for clarifiers C1 and C2), 1720 and 1460 gpd of settleable solids were released, respectively, from C1 and C2. I.e., 3180 gpd of the total volume was discharged by the clarifiers. This corresponds to 841 gallons of settleable solids generated from the clarifiers per million gallons of water treated. This value also represents 0.084 percent of the average plant pumpage. As noted for TSS, the mass loading values may be 61 percent higher than measured.

Other Characteristics of Clarifier Wastewater. The water quality parameters measured for both clarifiers are tabulated in appendices C1 through C14. It can be seen from appendix C4 that the dissolved solids concentrations in the clarifier blow-down wastewater were generally low. They ranged from 136 to 514 mg/L with an overall average of 215 mg/L. The

Table 9. Estimated Mass Balance of Solids to the Centralia Water Treatment Plant, and Pertinent Characteristics

		Average per day	Per MG water treated	Percent of total load or pumpage
Average pumpage, MGD	3.78			
Average TSS, mg/L	13			
Solids loads				
Raw water, lb		418.0	110.6	90.9
Coagulant, lb		41.7	11.0	9.1
Total, lb		459.7	121.6	
Solids weight				
Filter: TSS, lb		72.6	19.2	15.7
VSS, lb		27.6	7.3	6.0
Clarifier: TSS, lb		387.1	102.4	84.3
VSS, lb		51.9	13.8	11.3
Waste volume				
Filter, gal		125,700	30,600	3.59
Clarifier, gal		8,300	2,200	0.22
Total, gal		134,000	32,800	
Settleable solids				
Filter, gal		651	171	0.017
Clarifier, gal		3,180	841	0.084
Total, gal		3,731	1,012	

average dissolved solids concentrations for both clarifiers were virtually equal.

During the study period, the observed temperature for wastewater from both clarifiers varied from 1.2 to 27.1°C (appendix C5). The wastewater temperatures for both clarifiers for each sampling date were also essentially the same. They had the same average value of 15.6°C.

Appendix C6 shows that DO in the clarifier wastewater was between 5.7 and 12.0 mg/L. As expected, DO in wastes from the two clarifiers collected at the same time were not exactly the same because of different operational modes. The average DO values for the wastes from the two clarifiers were approximately 9.0 and 8.7 mg/L. During blow-down DO may be added by aeration due to high turbulence.

Appendix C7 indicates that the turbidity of the clarifier wastewater varied widely from about 120 to 19,000 NTU. The average turbidity values were approximately 2900 and 3800 NTU, respectively, for clarifiers C1 and C2. However, the turbidity data were geometrically distributed. The geometric means were, respectively, 1880 and 2130 NTU. The observed results also showed that turbidity was generally lower during summer and higher during winter.

The pH values of the clarifier wastewater were found to be low because of alum addition to the raw water. The pH for both clarifiers' wastewater was in the range of 4.8 to 7.1 with the same median of 6.6 (appendix C8). Only four out of 50 samples had a pH over 7.0.

As shown in appendix C9, total alkalinity in the wastewater of the clarifiers ranged from 17 to 156 mg/L as $CaCO_3$ with an overall average of 95 mg/L as $CaCO_3$. This average value for the clarifier wastewater was almost twice that of the filter backwash wastewater.

An examination of appendix C10 indicates that sulfate concentrations in the clarifier wastewater were practically equal to those for filter wash residues. The sulfate content was between 55 and 110 mg/L with an overall average of 77 mg/L. For each sampling date, sulfate concentrations in waste from both clarifiers were found to be virtually equal.

The data in appendix C11 suggest that wide ranges of total iron concentrations were observed in wastes from each of the clarifiers. Iron concentrations varied from 7.3 to 190 mg/L for clarifier C1, and from 2.6 to 459 mg/L for clarifier C2. Geometric mean concentrations multiplied by (x) geometric standard deviations for C1 and G2 were 57 mg/L × 2.39 and 60 mg/L × 3.03, respectively. According to plant operators, it is more difficult to maintain a steady sludge concentration in C2 than in C1.

Total aluminum concentrations (appendix C12) in the wastewater of the clarifiers had the same pattern as total iron concentrations. The aluminum concentrations varied from date to date and clarifier to clarifier. They were between 123 and 394 mg/L for clarifier C1 and between 109 and 1044 mg/L for C2. The geometric mean aluminum concentrations multiplied by (x) geometric standard deviations for C1 and C2 were, respectively, 228 × 1.41 mg/L and 255 × 1.71 mg/L. Inspection of figure 11 and appendices C11 and C12 indicates that high iron and aluminum concentrations were observed on

February 4, 1986, and on March 18 through April 15, 1986. These might have occurred because there was no blow-down during the preceding dates.

The 5-day biochemical oxygen demand of the clarifier wastewater ranged from 6 to 68 mg/L (appendix C13). These values were significantly higher than those for filter wash wastes. In general, the observed BOD_5 values were high during warm weather periods and lower during cold periods, except on January 21, 1986.

The data in appendix C_{14} indicate that of the samples collected from the clarifier wastewaters, most contained no fecal coliform, and a few contained low fecal coliform densities. Efforts were made to recover any fecal coliform from floc residues by diluting and breaking up the flocs. There was no additional fecal coliform recovered with the break-up.

Summary

Bi-weekly sample collections were carried out from May 14, 1985 through May 12, 1986 to determine quantities, characteristics, and release patterns of wastes discharged from the Centralia water treatment plant. Samples were taken from raw water, the two filters' backwash wastewater, and the two clarifiers' blow-down wastewater. Fourteen water quality parameters were examined.

The amounts of solids generated by the water treatment processes were estimated from obtained data and plant operational records. Table 9 summarizes the mean values of solids loads to and from the treatment units at Centralia, Illinois. General summaries are as follows:

- The annual average pumpage was 3.78 MGD. The average TSS in the raw water was 13 mg/L.

- The solids loads entering the plant averaged about 460 pounds (118 kg) per day. Approximately 9.1 percent of the plant load was derived from alum coagulation precipitation; the remainder (418 lb/d) was from the TSS in the raw water source. The total plant solids load was equivalent to 122 pounds (55 kg) per million gallons of water treated.

- The major sources of wastes at the Centralia treatment plant are the clarifiers and filters. The average quantity of solids released daily from the filters and clarifiers was estimated at about 73 and 387 pounds (33 and 176 kg), respectively, or 19 and 102 lb/MG of water treated at the plant.

- Estimating solids production by the volume of wastewater and TSS concentrations of the clarifier blow-down gave much lower figures than estimating solids production by subtracting the filters' portion from the total loads.

- Volatile contents in the wastes from the filters and clarifiers averaged 38.6 and 13.4 percent, respectively.

- The average volume of wastes released from the filter backwashes was 125,700 gpd or 30,600 gal/MG of water processed and represents 3.3 percent of the pumpage.

- The average wastewater volume released from the blow-downs of the two clarifiers was estimated at 8300 gpd or 220 gal/MG of water treated, and represents 0.22 percent of the total pumpage.

- The settleable solids generated during filter backwashes averaged 109 gpd or 171 gal/MG of water treated, and represent 0.017 and 0.52 percent of the plant pumpage and the backwash volume, respectively.

- The average volume of settleable solids released from the clarifier blow-downs was approximately five times that from the filter backwashes.

- In comparison with Crooked Creek water, wastewater from the filter backwashes exhibited low TSS, DS, turbidity, pH, alkalinity, sulfate, bacteria, iron, and BOD_5, and high VSS, settleable solids, DO, and aluminum. The quality of the clarifier blow-down wastewater was generally similar to that of the filter wash wastewater, except for extremely high concentrations of TSS, turbidity, iron, and BOD_5 (appendices C1 through C14).

WATER QUALITY OF CROOKED CREEK

The Centralia water treatment plant takes raw water from Raccoon Lake and discharges the residues to Crooked Creek. The previous section characterized the quantity and quality of these discharges. This study also included an investigation of any impacts these discharges might have on the water quality and bottom sediments of the receiving stream. This section and the following section evaluate water quality data, chemical and physical analyses, and macroinvertebrate data for creek bottom sediments from samples taken upstream and downstream of the water treatment plant's discharge.

Streamflow

General descriptions of Crooked Creek and Raccoon Lake were given in the "Study Area" section. There are two streamgaging stations on Crooked Creek: stations G and 8 (figure 12). Station G is at a county road bridge near Odin, 5.3 miles (8.5 km) upstream from Raccoon Lake at river mile 45.7. Station 8 is at the Hoyleton Road Bridge, 2.2 miles (3.5 km) southwest of Hoffman at river mile 20.9. The drainage areas for these two gaging stations are 89.2 and 254.0 square miles (231 and 658 km^2), respectively (USGS, 1985).

The drainage area of the Crooked Creek watershed above the water treatment plant is approximately 144.6 square miles (272 km^2). Unfortunately, the value for average streamflow near the plant is not available. The quantity released from Raccoon Lake is normally zero, but was not recorded.

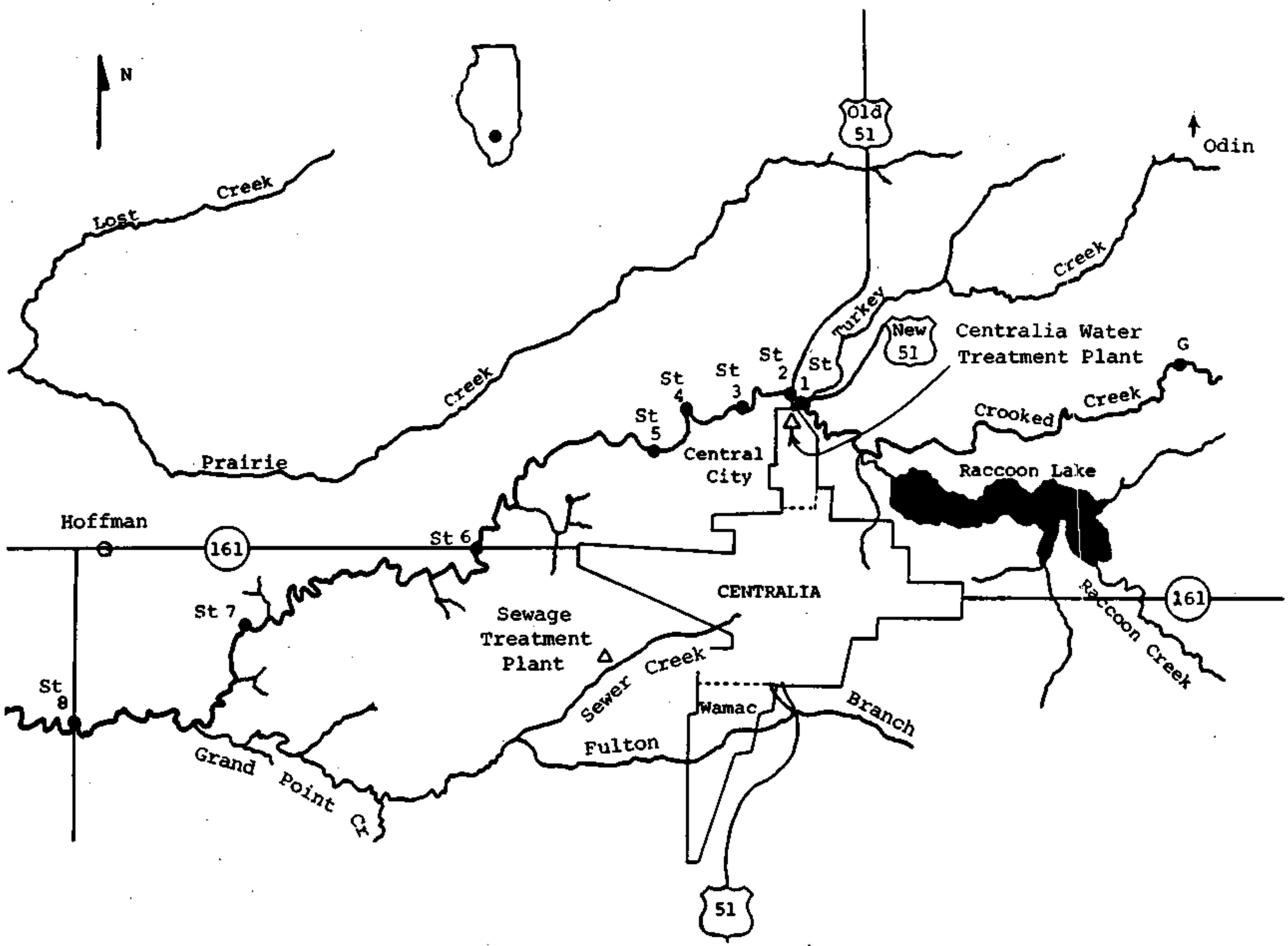

Figure 12. Map of sampling stations and study area

For the Odin station (G), only instantaneous flow records have been kept for Water Year 1978 to the present. The flow at G ranged from 1.3 to 1220 cfs. Daily flow was recorded at St 8. However, during this study (on November 19, 1985) the recorder at St 8 was destroyed and lost as a result of a 4-inch rainstorm. The average discharge for the last 11 years was 225 cfs (6.37 m^3/s. The extremes for the period of record were a minimum of 2.1 cfs (0.06 m^3/s) on September 25 and 26, 1976, and a maximum of 7060 cfs (200 m^3/s) on April 12, 1979 (USGS, 1985).

Sampling Procedures

Eight stream sampling stations, identified as St 1 through St 8 in figure 12, were selected for routine collection of streamwater and bottom sediment samples. Photographs of the sampling locations are shown in figures 13 through 20. Descriptions of the sampling locations are given in table 10. St 1, selected as a reference station, is 135 feet (41 m) upstream of the discharge point of residues from the Centralia water plant. The total stream length covered for the study was about 18 miles (29 km). In addition to samples from the eight creek stations, samples of the blow-down from each clarifier and of backwash wastewater from two filters were also obtained during each visit.

All the sampling stations except St 3 and St 7 were located at bridges. At St 3 there was a dead tree lying across the stream, and most of the time samples could be collected by walking on the dead tree trunk. At St 7 there was a concrete slab with three drainage pipes built on the creek bottom. During low-flow periods, the streamwater flowed mainly through the three aluminum pipes (12- to 18-inches in diameter) under the concrete slab.

Water samples at the eight creek stations were collected by submerging a bucket a few inches below the water surface. Three samples were taken at each station and composited. These samples were collected from the center and each one-third point of the stream cross section. Dissolved oxygen (DO) samples were taken with a DO sampler.

In addition to the routine filter backwash samples, samples from two filter backwashes were also taken during each sampling visit. These additional samples were collected continuously from the backwash by using an ISCO sampler. Additional clarifier blow-down samples were also taken during each sampling visit.

Water temperature, dissolved oxygen, total alkalinity, and pH measurements were performed in the field or in the water plant laboratory. Samples were kept cool en route to the Water Survey laboratory, where analyses were conducted for turbidity, solids (total dissolved, total suspended, volatile suspended, and settleable), sulfate (SO_4), total aluminum (T. Al), total iron (T. Fe), 5-day biochemical oxygen demand (BOD_5), and fecal coliform (FC). BOD_5 was determined by the personnel of the Centralia sewage treatment plant. All analyses were performed in accordance with Standard Methods (1985).

Figure 13. Sampling station 1, bridge on new U.S. Highway 51

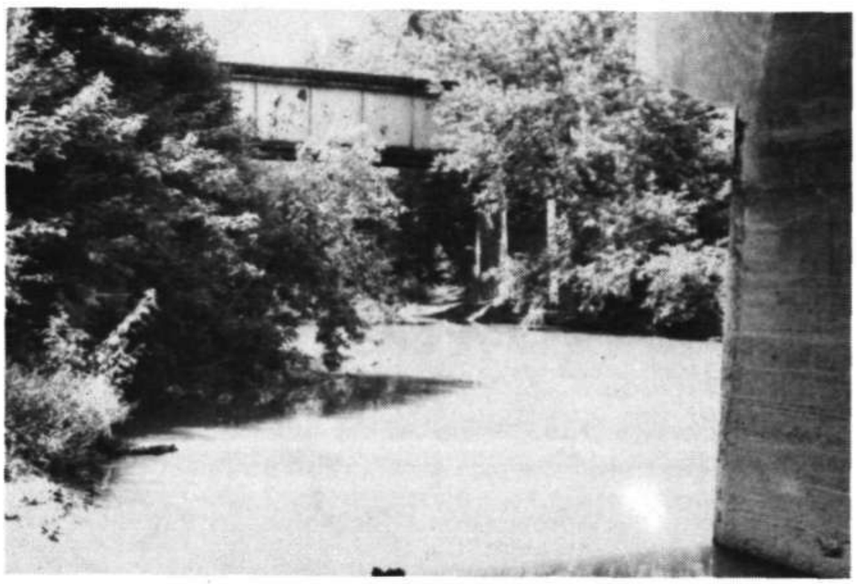

Figure 14. Sampling station 2, near the pier

Figure 15. Sampling station 3

Figure 16. Sampling station 4

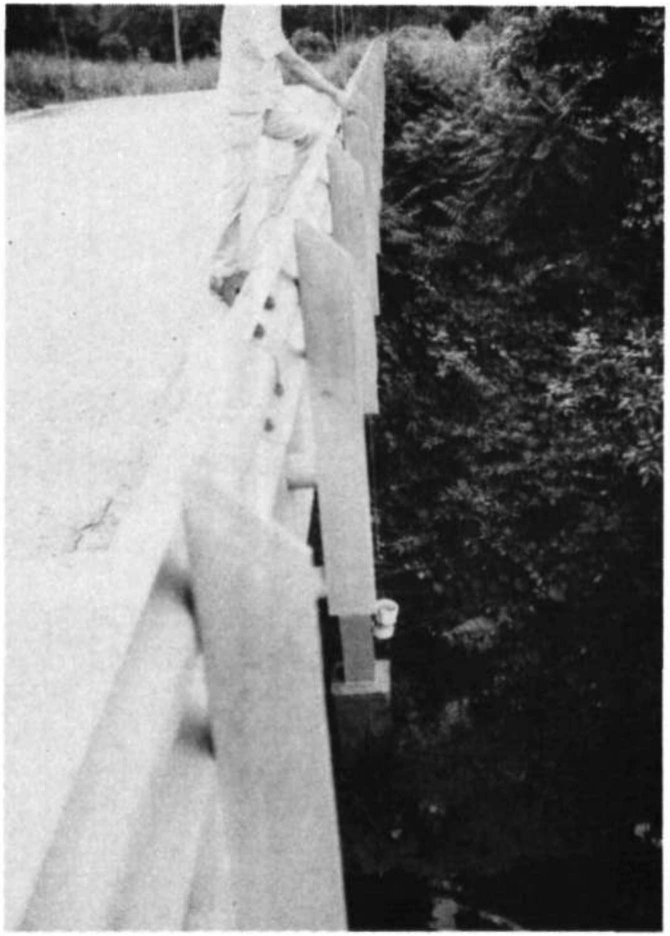

Figure 17. Sampling station 5

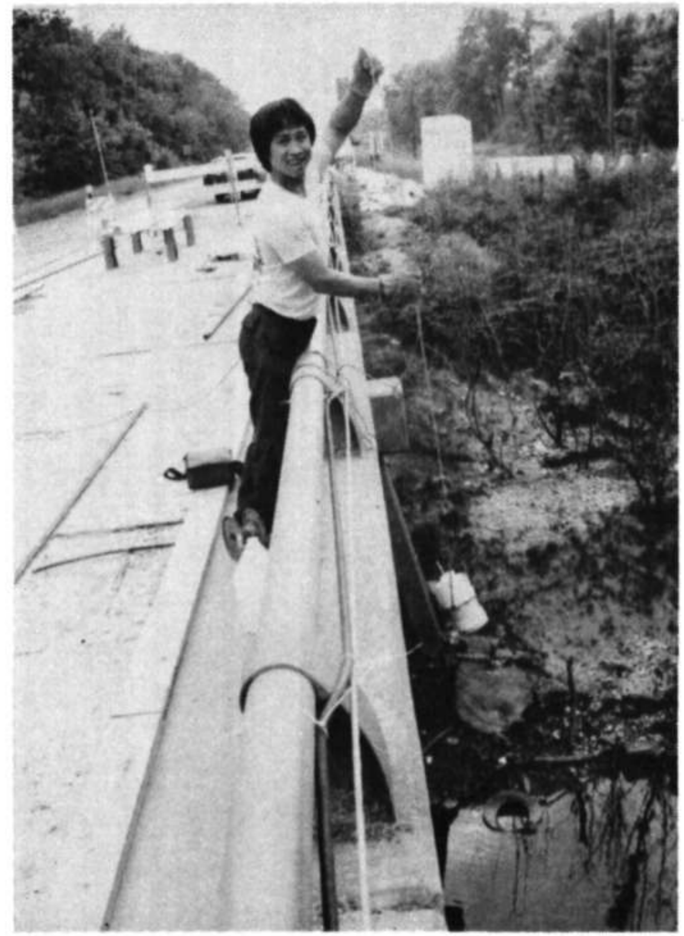

Figure 18. Sampling station 6, bridge on Highway 161

Figure 19. Sampling station 7

Figure 20. Sampling station 8, USGS gaging station

Table 10. Sampling Locations on Crooked Creek

Station	River mile	Location
1	39.04	West bridge on new U.S. Highway 51, 135 feet above the mouth of the plant wastewater ditch
	39.02	Water plant's wastewater discharge point
2	38.83	Bridge on old U.S. Highway 51, 980 feet below the plant wastewater discharge point
3	38.01	5330 feet below discharge point, near the city cemetery
4	36.97	Railroad bridge, 10,800 feet below plant discharge point
5	35.93	Bridge near Joliff School on 29.30 E, 1 mile north of Illinois Rt. 161
6	32.01	Bridge on Illinois Rt. 161
7	25.99	No bridge, end of 25.00 E, 1 mile south of Illinois Rt. 161
8	20.90	Bridge on 23.00 E, 2 miles south of Illinois Rt. 161, USGS gaging station

Results and Discussion

Appendices C1-C14 present results of the analysis of water quality-parameters made on the basis of 25 observations of Crooked Creek water and wastewater from the clarifiers and filters. St 1 was designated as an upstream control station. Wastewater from the clarifiers and filters is instantaneously discharged to the creek. The effect of these discharges on the creek water will be discussed for each parameter. The ranges and averages (or geometric means) for 12 of the 14 water quality parameters for the eight creek stations are depicted in figures 21 through 23. Because temperature and pH for the creek stations were almost identical for each sampling date, they have been omitted.

In order to define statistically significant differences, if any, between observations made at St 1 versus St 2, at St 1 versus St 3, and so on for St 1 versus each of the other stations, the student's "t" test was used. Paired observations for 14 water quality characteristics were examined. In cases of geometric distributions, logarithmic transformation was performed on the obtained data, and the "t" test was then applied. River sample data with geometric distributions were those for TSS, dissolved solids, turbidity, sulfate, total iron, total aluminum, and fecal coliform. A confidence level of 95 percent was selected. The results of the "t" tests for station 1 versus stations 2 and 3 are shown in table 11.

Total Suspended Solids

As shown in appendix C1, TSS concentrations at the control station (St 1) in Crooked Creek were highly variable, ranging from 12 to 414 mg/L with a geometric mean of 55 mg/L (average of 91 mg/L). During these sampling visits, TSS in clarifier blow-down ranged from 970 to 15,070 mg/L. In comparison, TSS in the filter wash wastewater exceeded that at the control station (St 1) exactly 50 percent (50/100) of the time. As shown in table 9» the average additional amount of solids resulting from the releases of clarifier and filter wastewater was estimated to be approximately 460 pounds per day. Unfortunately, a mass balance evaluation of solids in Crooked Creek cannot be made due to the lack of streamflow data.

Even after St 2 (which is 980 ft downstream of the discharge point) received wastes from the Centralia plant, the TSS content at that station was usually less than at station 1. In fact, the TSS concentrations at St 2 exceeded those at St 1 only 24 percent of the time (6 of 25 observations) (appendix C1). It is presumed that additional coagulation and sedimentation occurred in Crooked Creek water downstream of the discharge point.

Under normal streamflow conditions the wastewater plumes could be observed. Their dimensions ranged from one-half to a whole cross section (50 to 60 feet) of the creek in width, and they gradually disappeared at a downstream distance ranging from 40 to 100 feet (12 to 30 m). It was thought that waste residue deposits might have occurred in this area and might possibly have been scoured away during high streamflows. In the area from approximately 600 to 800 feet (180 to 240 m) downstream of the discharge point, which was shallow with a rocky bottom, no waste residue was ever found.

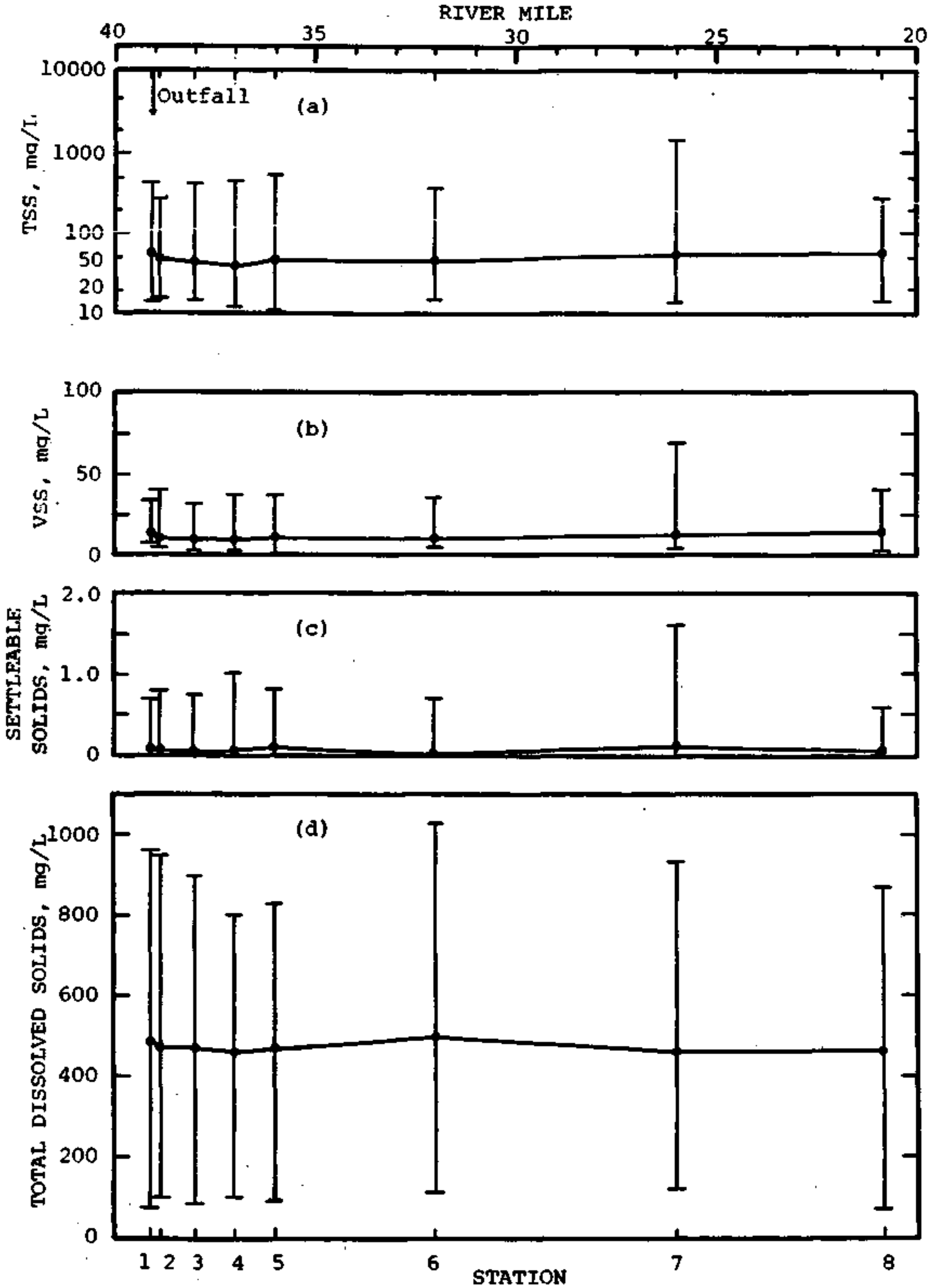

Figure 21. Profiles of solids (total suspended, volatile suspended, settleable, and total dissolved) in Crooked Creek water

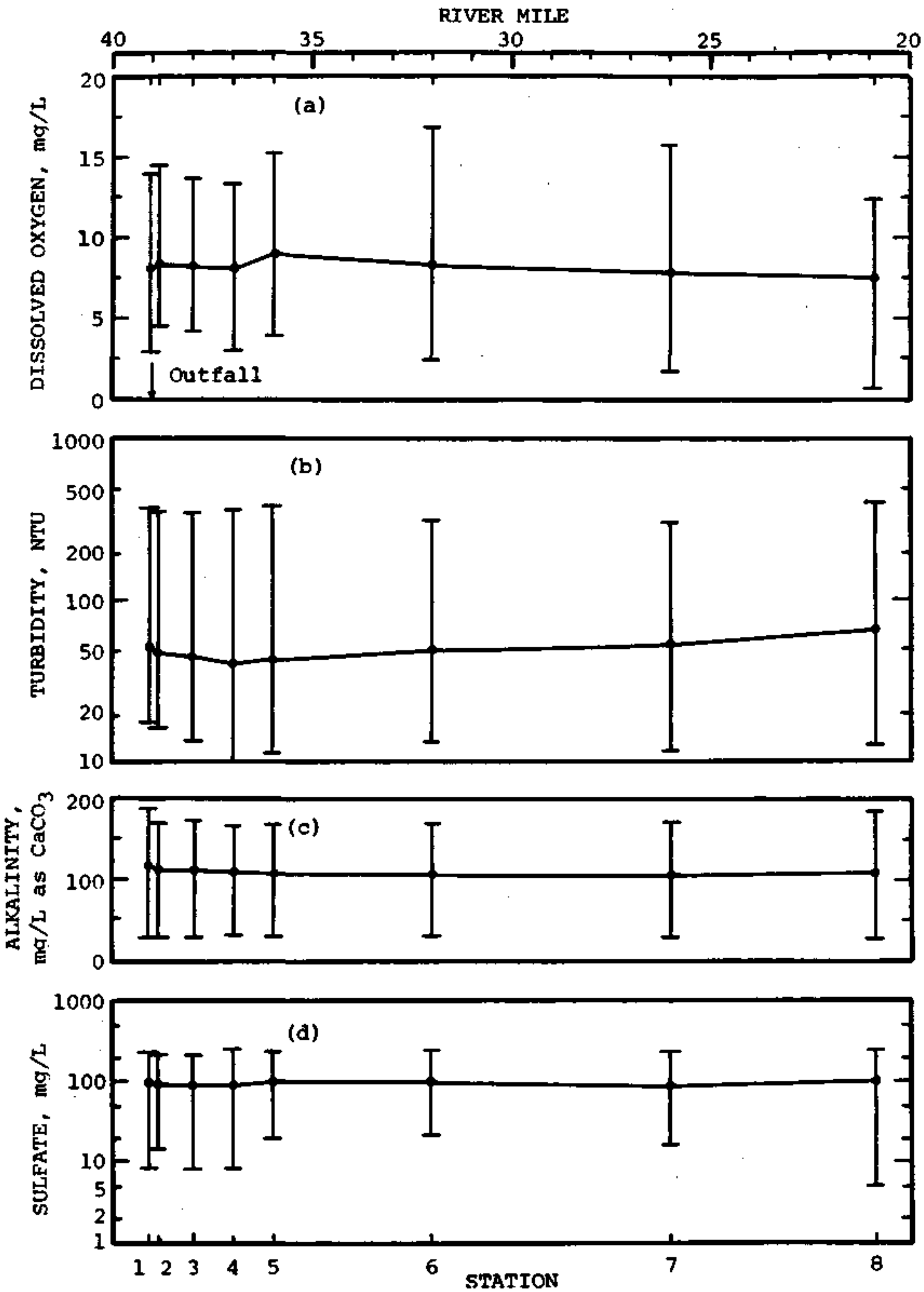

Figure 22. Profiles of observed dissolved oxygen, turbidity, total alkalinity, and sulfate in Crooked Creek water

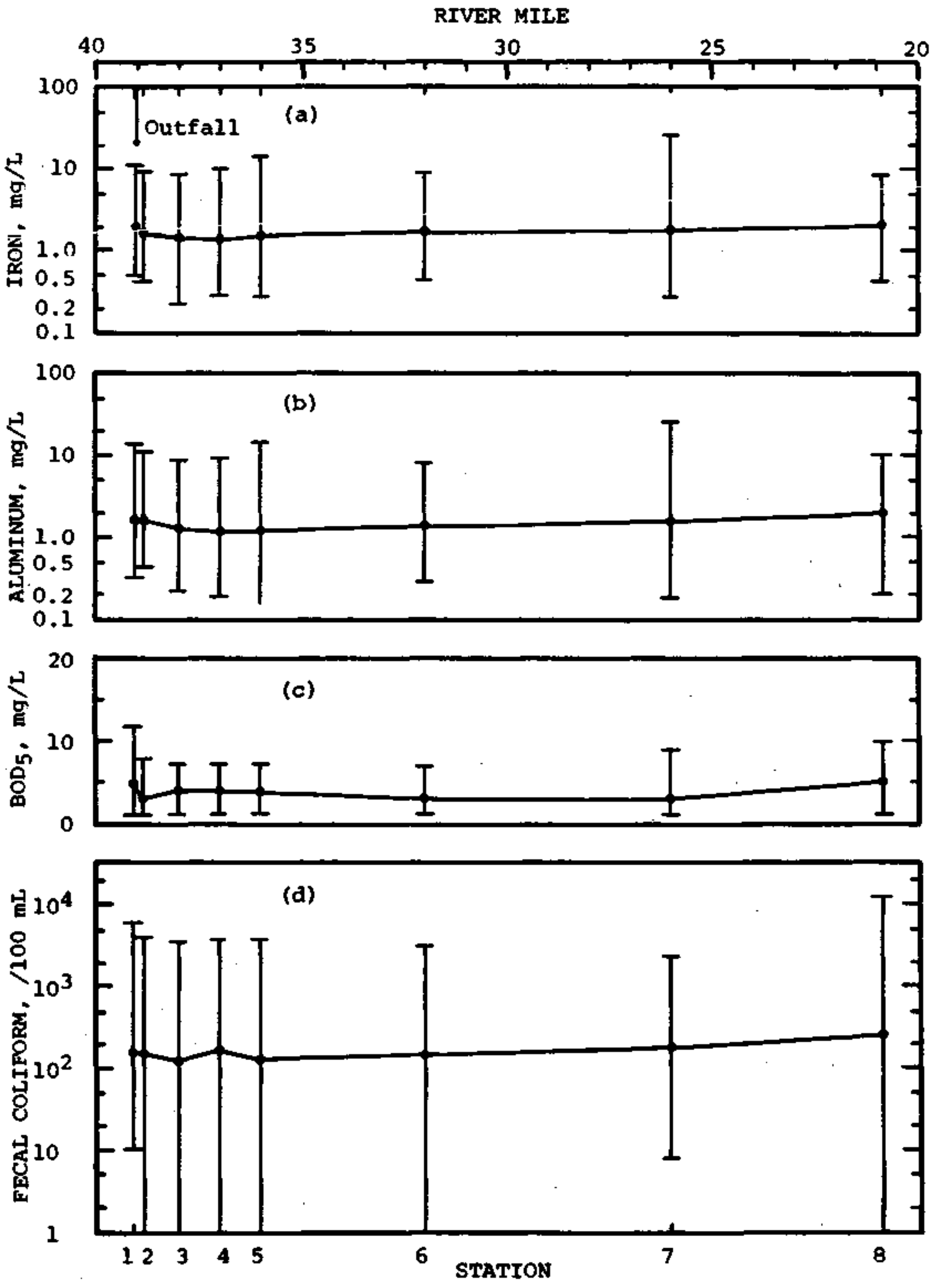

Figure 23. Profiles of iron, aluminum, BOD_5, and fecal coliform concentrations in Crooked Creek water

The Illinois Pollution Control Board (1986) stipulates that no single mixing zone shall exceed the area of a circle with a radius of 600 feet. This area is about 1,130,000 square feet. The width of Crooked Creek at the discharge point and throughout most of the creek is generally between 40 and 60 feet. Therefore, the allowable mixing zone would be 10 feet (25 percent of 40 feet) by 113,000 feet. It would extend 21.4 miles (34.4 km) downstream, to a point about 3 miles downstream of St 8 (river mile 20.90).

Inspection of appendix C1 and figure 21a shows that the ranges and mean concentrations of TSS for stations 2 through 6 were comparable. In fact, the average values for stations 2 through 6 were less than for the control station, St 1. The smallest range was found at St 2. The TSS concentrations at St 7 were generally comparable to those at the other stations. However, an extremely high TSS concentration occurred on March 18, 1986 due to local rain. On the same date, the water sample collected at St 5 was also turbid with 532 mg/L of TSS. In general, TSS at St 8 were only slightly higher than those for St 7 (appendix C1).

Statistical analyses (table 11) show that TSS for St 2 and St 3 were significantly less than those for St 1 with a 95 percent confidence level. Although not shown in table 11, "t" tests were also used for comparison of St 1 versus each of the stations 4 through 8. The test results indicated that TSS concentrations at stations 4 through 6 were also significantly less than those at St 1.

On the basis of the above analyses, one can conclude that there were decreases of TSS concentrations for the stream stretch from 980 feet to 7 miles downstream of the discharge point of the wastewater from the clarifiers and filters.

Volatile Suspended Solids

As shown in appendix C2, VSS concentrations for the control station (St 1) averaged 13 mg/L with a standard deviation of 7.4 mg/L. Average VSS concentrations in wastes from the clarifiers and filter washes were about 750 and 25 mg/L, respectively. The organic portions of suspended solids (VSS/TSS) for clarifier blow-down wastes and filter washwater averaged 44 and 39 percent, respectively; and those for the eight creek stations were lower, between 23 percent (St 7 and St 8) and 29 percent (St 4). The total weight of VSS and volume of these wastes were approximately 80 (27.6 + 51.9) pounds (36 kg) per day and 134,000 gallons (507 m^3) per day (table 9), respectively.

The sums of clarifier and filter wastewater average VSS concentrations for St 2 through St 8 were found to be less than or equal to those for the control station, St 1 (appendix C2 and figure 21b). Excluding St 7, the standard deviations of VSS contents for the creek stations ranged from 6.9 to 8.4 mg/L. The "t" tests (table 11) suggest that there were no differences in VSS between St 1 and St 2, or between St 1 and St 3. It can be concluded that the water plant wastes exert no impact on the VSS contents at St 2 (980 feet downstream of the outfall) and other downstream stations.

Table 11. Calculated "t" Values for Paired Samples and Tests of Difference

Parameter	Critical "t" value	St 1 versus St 2 "t" value	St 1 versus St 2 Significant difference, = .05	St 1 versus St 3 "t" value	St 1 versus St 3 Significant difference, = .05
Total suspended solids*	2.014	2.014	Yes	2.413	Yes
Volatile suspended solids	2.014	1.067		1.425	
Settleable solids	2.014	0.154		0.472	
Dissolved solids	2.014	1.921		1.434	
Temperature	2.014	0.988		1.270	
Dissolved oxygen	2.014	1.404		0.353	
Turbidity*	2.014	2.341	Yes	2.831	Yes
pH	2.014	0.327		0.377	
Alkalinity	2.014	2.536	Yes	1.421	
Sulfate*	2.014	0.504		1.058	
Total iron*	2.014	3.460	Yes	2.650	Yes
Total aluminum*	2.014	0.795		2.500	Yes
Biochemical oxygen demand	2.021	1.985		2.415	Yes
Fecal coliform*	2.056	0.852		1.662	

*Geometric distribution

Settleable Solids

It can be seen in appendix C3 that settleable solids for the control station, St 1, averaged 0.09 mL/L with a high of 0.70 mL/L. As expected, extremely high contents (145 to 820 mL/L with a mean of 380 mL/L) of settleable solids were observed in the blow-down wastes from the clarifiers. Settleable solids volume for filter backwashes varied widely from a trace to 16.4 mL/L, with an overall average of 2.25 mL/L. The average daily discharge volumes of settleable solids from clarifier blow-downs and filter washwater were, respectively, 3180 and 651 gallons (table 9).

In appendix C3, tr means trace, which is defined as settleable solids content of <0.01 mL/L, meaning that the settleable solids were slightly detectable but not measurable. This is the case for many samples collected from all eight creek stations. The maximums for all stations occurred either on August 8, 1985 or March 18, 1986. With the exclusion of data collected on these two dates, the settleable solids content for the eight stream stations was virtually the same for most of the sampling dates (appendix C3). The differences in settleable solids between St 1 and St 2 and between St 1 and St 3 were not detectable (table 11). The standard deviation of settleable solids concentrations ranged from 0.12 to 0.22 mL/L for all stations excluding St 7.

On the basis of the observed data and the statistical tests, it is concluded that even after the water plant wastes are received at St 2 and the other downstream stations, the settleable solids concentrations at these stations are unchanged from those at the control station, St 1 (figure 21c).

Dissolved Solids

As presented in appendix C4» dissolved solids concentrations at the control station, St 1, varied from 76 to 946 mg/L with a mean of 497 mg/L. Dissolved solids in the wastewater from the water treatment plant were found to be significantly lower than this in both concentration level and range. The average DS concentrations of the wastewater from the clarifiers and filters were, respectively, 215 and 231 mg/L.

Appendix C4 also suggests that the minimum DS content for each creek station occurred on either August 6, 1985 or November 19, 1985. There were heavy rains of 6 inches at Salem and 1-3/4 inches at Centralia on August 4» 1985. For the period from 6:00 a.m. on November 18, 1985 to noon on November 19, 1985, Centralia received 4 inches of rain, or 5-1/2 inches in a period of 40 hours. All four gates at the dam were opened on November 18 and 19, 1985, because of a high water level in Raccoon Lake. It seemed that the rainstorm caused low DS concentrations in Crooked Creek water.

From appendix C4 and figure 21d it appears that the average DS concentrations for all eight stations are comparable. In fact, the mean DS content at all the downstream stations except St 6 was lower than that at St 1 (control). However, the statistical tests (table 11) suggest no significant difference for DS in stations 1 through 3.

A close examination of data in appendix C4 indicates that data for the clarifiers and filters are normally distributed and data for stations 1 through 8 are geometrically distributed. The geometric means multiplied by (x) geometric standard deviations for stations 1 through 8 are respectively 417 × 1.97, 405 × 1.87, 407 × 1.92, 404 × 1.87, 405 × 1.87, 419 × 1.95, 410 × 1.74, and 411 × 1.78. The patterns of the geometric mean dissolved solids concentrations are similar to those of the average values.

Temperature

As appendix C5 indicates, water temperature for the control station, St 1, varied from 0.1 to 26.0°C. The creek water temperature exhibited distinct annual cyclical fluctuations. The wastewaters from the clarifiers and filters were slightly warmer than the streamwater (appendix C5). These wastewaters were found to have no effect on the downstream stations' temperatures (table 11).

Inspection of the data in appendix C5 indicates that the water temperatures for the eight stations for each sampling date were found to be similar. Small differences in temperature among the stations were presumably due to different times of collection.

Dissolved Oxygen

Appendix C6 indicates that DO content at the control station, St 1, averaged 8.2 mg/L with a range of 2.9 to 14.1 mg/L. With the exception of a few occasions during the winter, DO concentrations in the wastewater of the clarifiers and filters were significantly higher than those at St 1. The overall DO concentrations for the filter wash wastes averaged 9.9 mg/L and ranged from 7.5 to 13.7 mg/L. These wastewaters have a beneficial effect on the DO level of the creek water.

The mean DO concentrations for stations 2 through 6 were higher than those for St 1 (appendix C6 and figure 22a). However, the mean DO values for St 7 and St 8 were slightly less than those for St 1. Although the DO concentrations for St 2 and St 3 were generally greater than those for St 1 (appendix C6), the statistical tests (table 11) indicate that there was no significant difference.

The Illinois Pollution Control Board stipulates that DO shall not be less than 5.0 mg/L at any time (IPCB, 1986). Inspection of appendix C6 indicates that DO values for the control and most of the creek stations were less than the 5.0 mg/L limit on August 20, September 4, and October 15, 1985. On these three dates, the DO values at St 2 were, respectively, 5.77, 4.50, and 4.94 mg/L. It can be seen that the DO concentrations were higher than the level at the control station, St 1. It is concluded that the waste discharge from the water plant did not depress the DO content in Crooked Creek.

Turbidity

The turbidity of Crooked Creek water at St 1 ranged from 17 to 364 NTU (appendix C7). High turbidity in the creek water samples occurred on August 6 and November 19, 1985 during high streamflows. Appendix C7 indicates that turbidity values in the samples from the eight creek stations and the clarifiers were geometrically distributed. The geometric means for the creek stations were between 41 and 66 NTU.

The geometric means for turbidity in clarifiers C1 and C2 were approximately 1880 and 2130 NTU, respectively. Turbidity in the filter wastewater ranged from 21 to 118 NTU with an average of 55 NTU. However, on the basis of the daily observations, the turbidities in the filter wastewater were generally greater than those at St 1 except on days with high stream turbidity.

Even after additions of high-turbidity wastewater to Crooked Creek, the geometric means for St 2 through St 6 (41-49 NTU) were less than that for St 1 (51 NTU) (figure 22b and appendix C7). The results of the "t" tests suggest that turbidity at St 2 and St 3 was significantly less than that at St 1 (table 11). Although not shown in table 11, turbidity at St 4 and St 5 was also significantly less than that at St 1. It seemed that alum sludge discharged to the creek still had a coagulative effect in removing turbidity in the creek water.

pH

The pH of the control samples ranged from 7.05 to 8.22 with a median of 7.55 (appendix C8). Because the pH values are reciprocals of the logarithms of hydrogen ion concentrations in the water samples, the arithmetic average of the pH values was not meaningful and was not computed. Instead, the medians of pH for each station are presented in appendix C8.

Appendix C8 also shows that on the basis of either daily comparisons or median values, the pH for wastewater from the clarifiers and filters was generally lower than the pH for the creek stations. The median of pH for St 1 was the lowest among all eight stations. There were no statistical differences in pH between St 1 and St 2 and between St 1 and St 3 (table 11). It can be concluded that the discharge of low pH wastewater from the Centralia water plant did not affect the pH of Crooked Creek water.

Total Alkalinity

As shown in appendix C9, total alkalinity for St 1 ranged from 26 to 188 mg/L as $CaCO_3$ with a mean of 117 mg/L as $CaCO_3$. The mean alkalinity for filter wash water (52 mg/L as $CaCO_3$) was less than half that for St 1. The mean alkalinity concentration for clarifier wastewater was only 95 mg/L as $CaCO_3$.

The range of observed alkalinities for all eight stations was found to be similar (appendix C9 and figure 22c). According to the "t" test results, the total alkalinity for St 2 was statistically less than that for St 1 (table 11). This means that the alum sludge that was discharged had the effect of reducing the alkalinity. It was found that there were differences in alkalinity values between St 1 and St 5 through St 7. These are presumably not due to the water plant discharge.

Sulfate

Appendix C10 indicates that sulfate concentrations for the wastes from the clarifiers and filters were in the range of 50 to 110 mg/L with normal distributions. The average values were 76 and 79 mg/L for clarifier and filter wastes, respectively.

A wide range of sulfate concentrations (5-246 mg/L) for Crooked Creek stations was observed (appendix C10). The data for each creek station were geometrically distributed. As mentioned in the section on dissolved solids, floods occurred on August 6 and November 19, 1985. Two inches of rain was recorded on August 19» 1985. High flow in Crooked Creek reduced the sulfate content in the water significantly. With the exception of data collected on August 6 and 20 and November 19, 1985, the sulfate concentrations for all creek water samples ranged from 43 to 246 mg/L.

Nevertheless, the geometric means of sulfate for all stations were between 92 and 99 mg/L (appendix C10 and figure 22d). The standard deviations ranged from 1.87 to 2.33 (appendix C10). Table 11 shows that there was no significant difference in sulfate concentrations in the creek water at St 2 and St 3 compared with St 1. It can be extended that there was no detectable change in sulfate levels at any of the sampling stations.

A study at Pontiac by Evans et al. (1979) showed that there was a significant increase of sulfate concentrations in the Vermilion River water 650 feet downstream from the waste outfall of the Pontiac water treatment plant.

Total Iron

It can be seen from appendix C11 that the total iron concentrations for the control station, St 1, ranged from 0.49 to 11.62 mg/L with a geometric mean of 1.93 mg/L. The iron concentrations at each creek station and in each clarifier blow-down (but not in the filter backwashes) exhibited geometric distribution.

A very wide range (2.6 to 459 mg/L) and high geometric mean (59 mg/L) of iron concentrations were observed in clarifier blow-down. The average iron concentration in filter backwash wastewater was only 1.46 mg/L (geometric mean = 1.28 mg/L), which was significantly lower than that in the creek water at St 1.

The geometric means of iron content in Crooked Creek water downstream of the wastewater outfall (except at St 8) were less than that at St 1 (appendix C11 and figure 23a). The geometric standard deviations for all creek stations were in the range of 2.27 to 2.73. The statistical test results (table 11) show that the iron concentrations at St 2 and St 3 were significantly less than that at St 1. It was also observed, although not shown in table 11, that the iron concentrations at St 4 and St 5 were significantly less than that at St 1.

In their study of water plant waste discharges at Pontiac, Illinois, Evans et al. (1979) reported that there was no statistical difference between iron concentrations in the Vermilion River 650 ft below the waste outfall and those at the station upstream of the outfall.

Total Aluminum

As listed in appendix C12, the observed aluminum concentration of Crooked Creek at St 1 ranged from 0.30 to 14.00 mg/L with a geometric mean of 1.56 mg/L. The aluminum concentrations in the blow-down from each of the clarifiers and in the backwash from each of the filters were found to be in a normal distribution. The average aluminum values for clarifier and filter discharges were 270 and 6.02 mg/L, respectively.

Inspection of the observed aluminum data for the creek stations in appendix C12 indicates that they were geometrically distributed. The geometric means of aluminum concentrations of Crooked Creek water were slightly increased at St 2 and were decreased at St 3 through St 6 compared with that at St 1 (appendix C12 and figure 23b). Nevertheless, the "t" tests (table 11) suggest that there was no significant difference in aluminum between St 1 and St 2, i.e., the water plant waste discharges did not significantly increase the stream aluminum concentrations 980 feet downstream of the outfall. Table 11 also indicates that there was a significant decrease in aluminum levels at St 3 compared with that at St 1.

In the Pontiac water plant study, Evans et al. (1979) found that total aluminum was increased in the Vermilion River water 650 feet downstream of the outfall compared with the concentration at the upstream control station. The average aluminum concentrations were 0.07 and 0.13 mg/L respectively, for the control station and the station 650 feet downstream. The mean aluminum concentrations in Crooked Creek (1.56 mg/L for St 1 and 1.64. mg/L for St 2) were much greater than those in the Vermilion River.

Biochemical Oxygen Demand

From appendix C13, it can be seen that BOD_5 values for the control station, St 1, ranged from 1 to 12 mg/L with an average of 5 mg/L. BOD_5 concentrations for the wastewater from the clarifier blow-downs were higher than at any other sampling location. They averaged 29 mg/L and ranged from 6 to 68 mg/L. BOD_5 values for the filter wash wastewater were generally very low with an average of 2.5 mg/L. For the creek stations (St 2 through St 8) downstream of the waste outfall, BOD_5 concentrations ranged from 1 to 10 mg/L; the averages were between 3 and 5 mg/L for each of the stations (appendix C13 and figure 23c).

According to the results of the "t" tests (table 11), there was no statistical difference between the BOD_5 concentrations in the creek water at St 1 and St 2, but there was a significant difference between the BOD_5 concentrations at St 1 and St 3. It may be concluded that the water plant wastewater discharges did not increase the BOD_5 levels at downstream stations. In fact these levels were decreased.

Fecal Coliform

As expected, wide ranges of fecal coliform densities from non-detectable to 13,000 FC/100 mL were observed in Crooked Creek (appendix C14). Appendix C14 indicates that low or no fecal coliform occurred in the wastewater from the clarifiers and filters. Fecal coliform was not recovered from the majority of wastewater samples.

It was observed that the highest geometric mean (260 FC/100 mL) and the highest geometric standard deviation (8.18) occurred at St 8. The geometric means of fecal coliform for St 1, St 2, and St 3 were 160, 160, and 130 per 100 mL, respectively (appendix C14 and figure 23d). The geometric standard deviations for these three stations were, respectively, 6.70, 6.22, and 6.25.

Nevertheless, the data in table 11 suggest that there were no significant differences in fecal coliform densities between St 1 and St 2, or between St 1 and St 3. It is concluded that the waste discharges from the Centralia water plant had no impact on the fecal coliform densities of Crooked Creek.

Summary

- Eight creek stations were established for bi-weekly sampling for the purpose of evaluating the influence of water plant waste discharges.

- In addition, composite samples from wastewater from two filter backwashes and the two clarifier blow-downs were routinely collected for the purpose of comparison.

- The obtained data for 14 parameters (25 observations) are summarized in appendices C1-C14. Average values (or geometric means) and ranges for each of the parameters are shown in figures 21-23 and appendices C1-C14.

- Data were statistically evaluated with the student's "t" test. The results of the "t" test are shown in table 11.

- The concentrations of TSS, VSS, settleable solids, turbidity, iron, aluminum, and BOD_5 in the clarifier blow-down were substantially greater than those in Crooked Creek water. Water temperature and DO were slightly higher in the clarifier blow-down. On the other hand, dissolved solids, pH, alkalinity, sulfate, and fecal coliform were significantly less in the clarifier blow-down.

- VSS, settleable solids, DO, and aluminum were higher in the filter wash wastewater than in Crooked Creek water. Dissolved solids, turbidity, pH, alkalinity, sulfate, iron, BOD_5, and fecal coliform in filter wastes were extremely low.

- Comparison of the average (or geometric mean) concentrations of 14 parameters measured at St 1 (control) and St 2 (980 feet downstream of the wastewater outfall) revealed that concentrations of four of the parameters (settleable solids, temperature, pH, and fecal coliform) were virtually unchanged. For the other parameters except DO and total aluminum, a decrease in values was observed at St 2 in comparison with St 1.

- It is presumed that coagulation and sedimentation occurred in the vicinity of the wastewater outfall because of residual alum in the discharge.
- At the 95 percent confidence level there was a significant decrease in TSS, turbidity, alkalinity, and total iron in the creek water at St 2 as compared with St 1.
- The mean values of total aluminum and DO for St 2 were found to be slightly higher than those for St 1. However, the difference was not statistically significant.
- Water quality for St 3 through St 6 was generally similar to that at St 2. Water quality at St 7 and St 8 was slightly worse than at the upstream stations. This apparently was not due to the water treatment plant waste discharge.
- On the sole basis of water quality, it was concluded that waste discharges from the Centralia water plant did not have a negative impact on Crooked Creek water. In fact, some benefits were observed.

CROOKED CREEK BOTTOM SEDIMENTS

As described previously, solids residue and, to a lesser extent, settleable solids are major components of the waste from water treatment plants. Aluminum and iron are present in significant amounts in background concentrations in Crooked Creek. It is important to examine the bottom sediments of the receiving stream for concentrations of these elements, as well as any other sediment characteristics that will define the extent of the influence of the water plant waste on the bottom sediments.

There is also the need to assess the sediments in terms of their capability to provide a suitable habitat for benthic organisms. One aspect of a suitable macroinvertebrate habitat is the particle size distribution of the sediments. A predominantly sandy bottom with its inherent instability is not a productive benthic habitat, whereas silt in combination with organic (volatile) material can be very productive. Finally, it is desirable to identify the types and numbers of macroinvertebrates existing in the bottom sediments for comparative purposes.

The sampling program for bottom sediments was implemented to assess: 1) the extent and concentrations of aluminum, iron, volatile fraction, and moisture contents of the bottom sediments, 2) the particle size distribution of the bottom sediments, and 3) the types and densities of aquatic macroinvertebrates in the bottom sediments.

Sampling and Measurement Procedures

The same eight creek stations used for water quality sampling (figure 12) were selected for bottom sediment sampling. Fifty-six samples (seven monthly samples obtained at each location during the warm weather periods) were collected for physical, chemical, and biological analyses.

Bottom sediment samples were collected with a 6" × 6" ponar dredge. Because of rocky bottoms at stations 3, 4, and 5, samples were occasionally taken with a shovel. Each sample was composited by three ponar or shovel

For chemical and physical examinations, the dredged sediment was placed in a plastic bag and mixed thoroughly. The plastic bag was labeled and placed in a plastic quart container in an ice chest. Upon delivery to the laboratory the sediment samples were refrigerated until analyses were performed.

Sediments for macroinvertebrate examination were salt-floated, sieved, and preserved by the salt flotation technique. The composited sediment sample was placed in a bucket. Approximately the same amount of salt-saturated streamwater was also added to the bucket. The sample was stirred vigorously and decanted immediately through a U.S. Standard 30 mesh sieve bucket. This procedure was repeated at least three times for each sample. The material retained in the sieve bucket was then scraped out, rinsed with streamwater, and placed in a plastic jar. The sieved samples were preserved in 95 percent alcohol and labeled.

Benthic Macroinvertebrates

At the laboratory each preserved sample was washed with tap water again through a 30 mesh sieve, and the residue was picked for benthic organisms. The macroinvertebrates were identified, enumerated, and preserved in 70 percent ethanol. Identifications were made to family, genus, or species level depending on the organism.

Chemical and Physical Measurements

The sediment samples obtained for chemical and physical analyses were examined for concentrations of total aluminum and iron, percent moisture, and percent volatile content; they were also analyzed for percent, by weight, of gravel, sand, silt, and clay.

Aluminum and iron analyses were accomplished by digestion with nitric acid and subsequent atomic absorption spectrophotometry. Volatile solids analyses were conducted according to procedures set forth by Standard Methods (1985). The percent moisture was measured by decanting the supernatant from the sediment samples after the samples were left undisturbed for at least 24 hours, and then oven-drying the remaining material at 103° Celsius.

The procedure used in this study to determine the particle size distribution of sediments is known as the sieve-pipet method (Guy, 1977).

The sediment samples were refrigerated until analysis was performed. The samples were wet-sieved through a 2-mm sieve and the fines were washed from the samples with a stream of deionized water. A second sieve, 0.062 mm in size, was beneath the first sieve and all particles finer than 0.062 mm washed into a bucket. The material in the bucket was saved for the pipet portion of the analysis. Materials remaining on the 2-mm and 0.062-mm sieves were placed on aluminum pie-pans and then oven-dried (110°C) overnight. The dry weights for each were then recorded. For the purposes of this report, particles greater than 2 mm are called gravel, and particles between 0.062 and 2.0 mm in size are sand.

The concentration of fine material was then determined. A portion of the fine material was placed in a 1-L graduated cylinder, so as to create a 5- to 15-g/L concentration when the deionized water was added. The cylinder was then filled to a volume of 1 liter. A dispersing agent was added at a concentration of 2.5 mL/L.

The suspension of fine material was stirred thoroughly with a plastic disc plunger. Then, while the sample was being stirred, 25 mL was withdrawn, which represents the total concentration of silt and clay. The sample was obtained by using a 25-mL pipet attached to a point gage for accuracy of depth of withdrawal.

The remaining sample was then stirred again and a timer was started after stirring. Two more samples were taken at specific times and at specific depths to determine the silt and clay concentrations. The times for withdrawal of the samples were determined by a given relationship (Guy, 1977) based on particle size and temperature. The first sample (silt) was collected at a lower depth and represented particle sizes between 0.064 and 0.004 mm. The second sample (clay) was taken at a higher level and had particle sizes less than 0.004 mm.

These samples were then placed in a drying oven (110°C) and allowed to remain overnight. The samples were then weighed and calculations were performed to determine the amount of silt and clay present.

Results and Discussion

All data derived from the analyses for chemical and physical measurements and macroinvertebrates are listed in appendices D and E.

Particle Size Distribution

Appendix D shows the particle size distribution of Crooked Creek bottom sediments collected at eight stations. The average (7 observations) composition of the sediment particles in terms of gravel, sand, silt, and clay for the eight sampling stations is depicted in figure 24. Examination of appendix D and figure 24 indicates that the bed material composition at St 1 was 13 percent clay, 43.3 percent silt, 40.7 percent sand and 3.0 percent gravel. In comparison, for St 2 these values were, respectively, 16.6, 59.4, 16.4, and 7.6 percent. At stations 3 through 5, silt and clay reduced significantly to a total equal to or less than 11 percent. Significant amounts of gravel and sand (89-97 percent) existed at stations 3

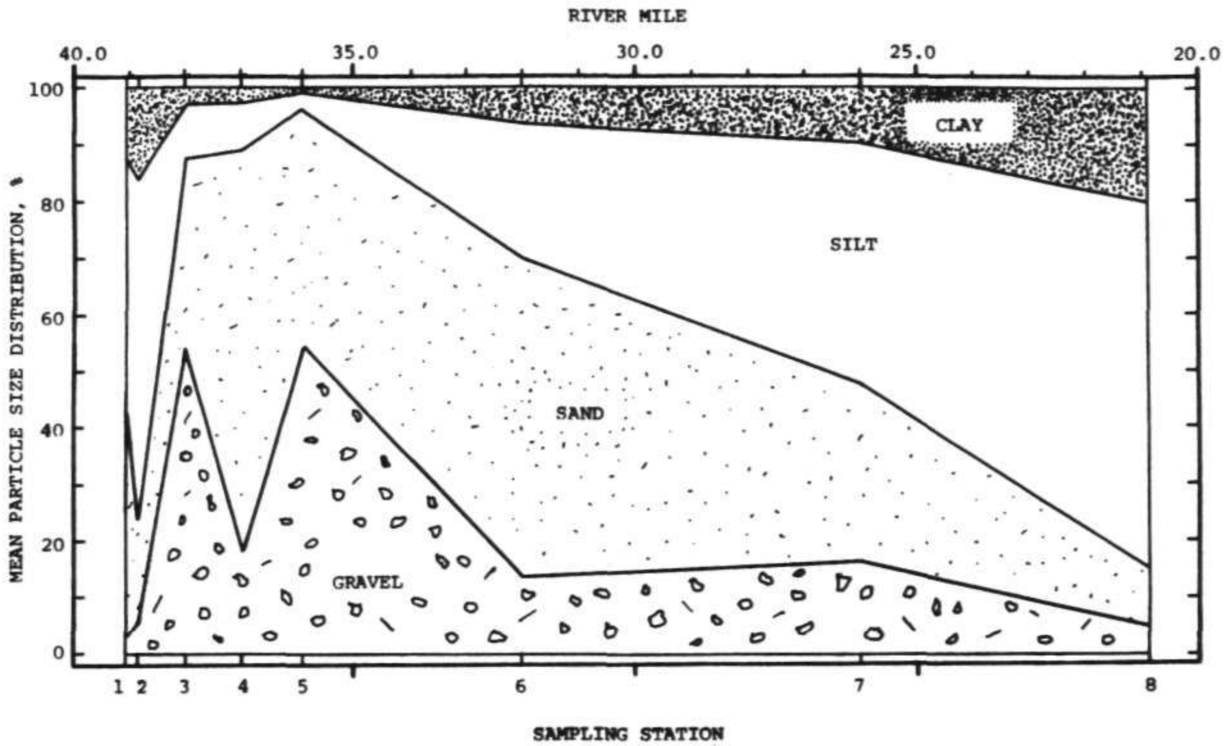

Figure 24. Particle size distribution of Crooked Creek bottom sediments

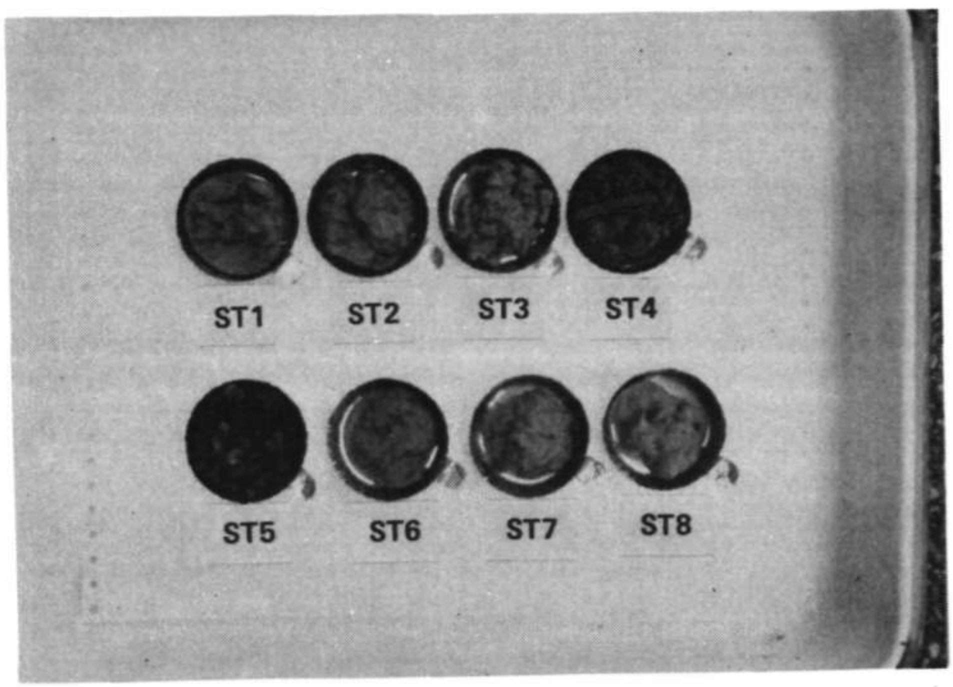

Figure 25. Dry sediments from Crooked Creek sampling stations

through 5 (figures 24 and 25). Figure 25 shows typical dry sediments from the eight stations. It is concluded that waste discharges and possibly stream morphology influenced the increase of silt at St 2. Sludge deposits were not found at stations 3 through 5.

For the downstream stations (6-8), silt and clay portions increased with stream distance (figures 24 and 25). Gravel and sand portions were only about 10 percent at St 8, presumably due to local stream morphology.

Total Aluminum and Iron

The data in appendix C11 indicate that concentrations of total iron present in the clarifier blow-down averaged 90.3 mg/L. Aluminum in the clarifier blow-down and filter backwashes averaged 270 mg/L and 6.1 mg/L, respectively. Previous studies (Evans et al., 1979, 1982; Lin et al., 1984) reported that substantial quantities of aluminum and iron were present in blow-down from clarifiers of water treatment plants. These are the constituents in clarification process wastes that are likely to be the most detectable in the receiving stream.

The observed concentrations of total aluminum and iron for Crooked Creek bottom sediments at each station are presented in appendix D. With the exception of St 2, the aluminum concentrations ranged from a low of 2640 mg/kg at St 5 to a high of 11,500 mg/kg at St 8, both on September 4, 1985. The average aluminum concentrations and standard deviations for stations 1 through 8 were, respectively, 6910 ± 840, 15880 ± 6370, 7830 ± 2300, 3440 ± 710, 3970 ± 780, 5880 ± 1240, 8760 ± 1280, and 9350 ± 1080 mg/kg. The aluminum concentrations were higher than in the Mississippi River. The background concentrations of aluminum and iron in the sediments of the Mississippi River and several other Illinois streams are as follows (Illinois State Water Survey data):

	Aluminum, mg/kg	Iron, mg/kg
Mississippi River at East St. Louis	760	2,590
Mississippi River at Alton	2,900	8,540
Clay Creek	-	11,000
Mill Creek	-	10,000
Poplar Camp Creek	-	15,000

The magnitude of the aluminum concentration at each station on Crooked Creek was compared with that at St 1 (control) for each visit. The results are plotted in figure 26a. In terms of the mean aluminum contents and ratio values, significant influence by waste loads was observed at St 2. Aluminum concentrations in the sediments at St 2 averaged 2.4 times those of St 1. On the basis of sediment aluminum contents, stations 4 through 6 have the best sediment quality.

On May 12, 1986, an extremely high iron (86,290 mg/kg) concentration was observed in the sediment at St 5. The reason for the high value was unknown. With the exception of this value the observed total iron concentrations in Crooked Creek sediments varied from a low of 7300 mg/kg at

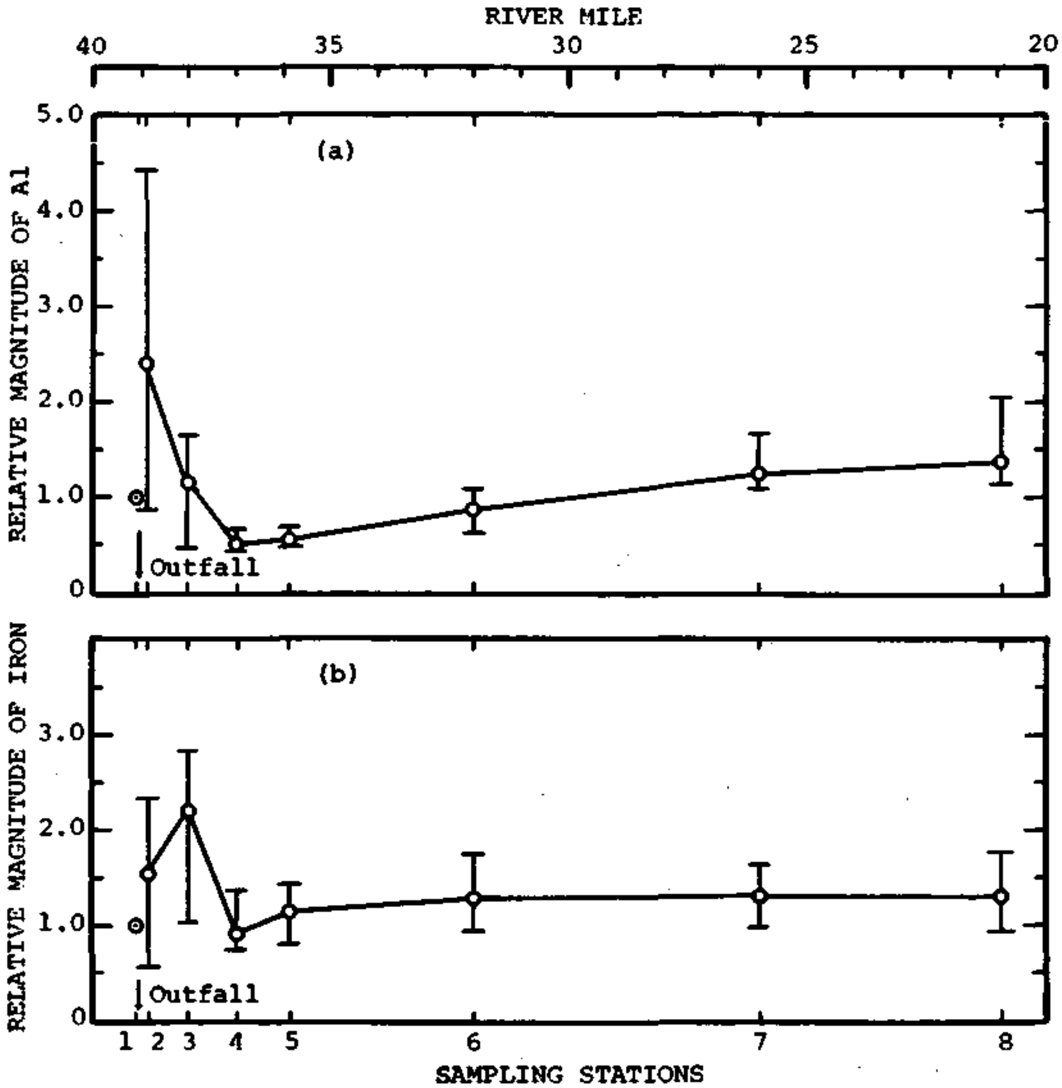

Figure 26. Ranges and mean relative magnitudes of aluminum and iron concentrations in Crooked Creek bottom sediments

St 4 on October 2, 1985 to a high of 38,630 mg/kg at St 3 on May 12, 1986. The averages and standard deviations of total iron in the sediments of creek stations 1 through 8 were respectively 11,300 ± 2110, 16,470 ± 4040, 25,140 ± 9760, 10,690 ± 4740, 12,360 ± 3150, 14,110 ± 2940, 14,440 ± 2140, and 14,260 ± 2060. The iron content was not considered to be higher than in other Illinois streams. In Illinois, if the iron concentration is less than 18,000 mg/kg, it is classified as NON-ELEVATED sediment (IEPA, 1984). On the basis of this classification, sediment iron concentration in Crooked Creek, except at St 3, can be designated as NON-ELEVATED.

As with total aluminum, the relative magnitudes of iron concentrations in sediment at the downstream stations were compared with those at St 1. The ranges and mean relative magnitudes are shown in figure 26b. In terms of iron concentrations, stations 2 and 3 were significantly influenced by waste loads. In terms of other parameters, St 3 was not impacted. The sediment iron content at St 2 averaged 1.54 times that at St 1.

Percent Moisture and Volatile Content

The moisture and volatile contents of the bottom sediments for six observations at each sampling site are shown in appendix D. The means and ranges of these two parameters are plotted in figure 27. The percent moisture in sediments at St 1 was in a small range, between 25 and 28 percent; while at St 2 it ranged from 46 to 68 percent. The average moisture content for St 2 (58 percent) was more than double that of St 1 (27 percent). The impact of waste discharges is detectable at St 2.

The percent moisture in the sediments was found to be similar to the silt content, i.e., the higher the silt composition, the higher the moisture content. The average percent moisture for stations 3 through 5 was low (19-29 percent). As with silt composition, the percent moisture of sediments at stations 6 through 8 was found to increase with distance (figure 27a).

As shown in figure 27b, the volatile content of sediments at St 2 was substantially greater than at St 1. The profile of volatile contents in the creek sediment showed no trend. The percent of volatile content decreased at stations 3, 5, and 8, and increased at stations 4 and 7. The increases at stations 4 and 7 might have been due to the local farmland runoff. It may be concluded that the waste loads under natural stream conditions impacted the volatile content of sediments at St 2 and not at St 3.

The selection of stream sampling stations was based primarily on accessibility to the creek. The study area of Crooked Creek was generally wooded with steep banks. Additional sampling locations between St 2 and St 3 would have been helpful in defining the impacts more thoroughly.

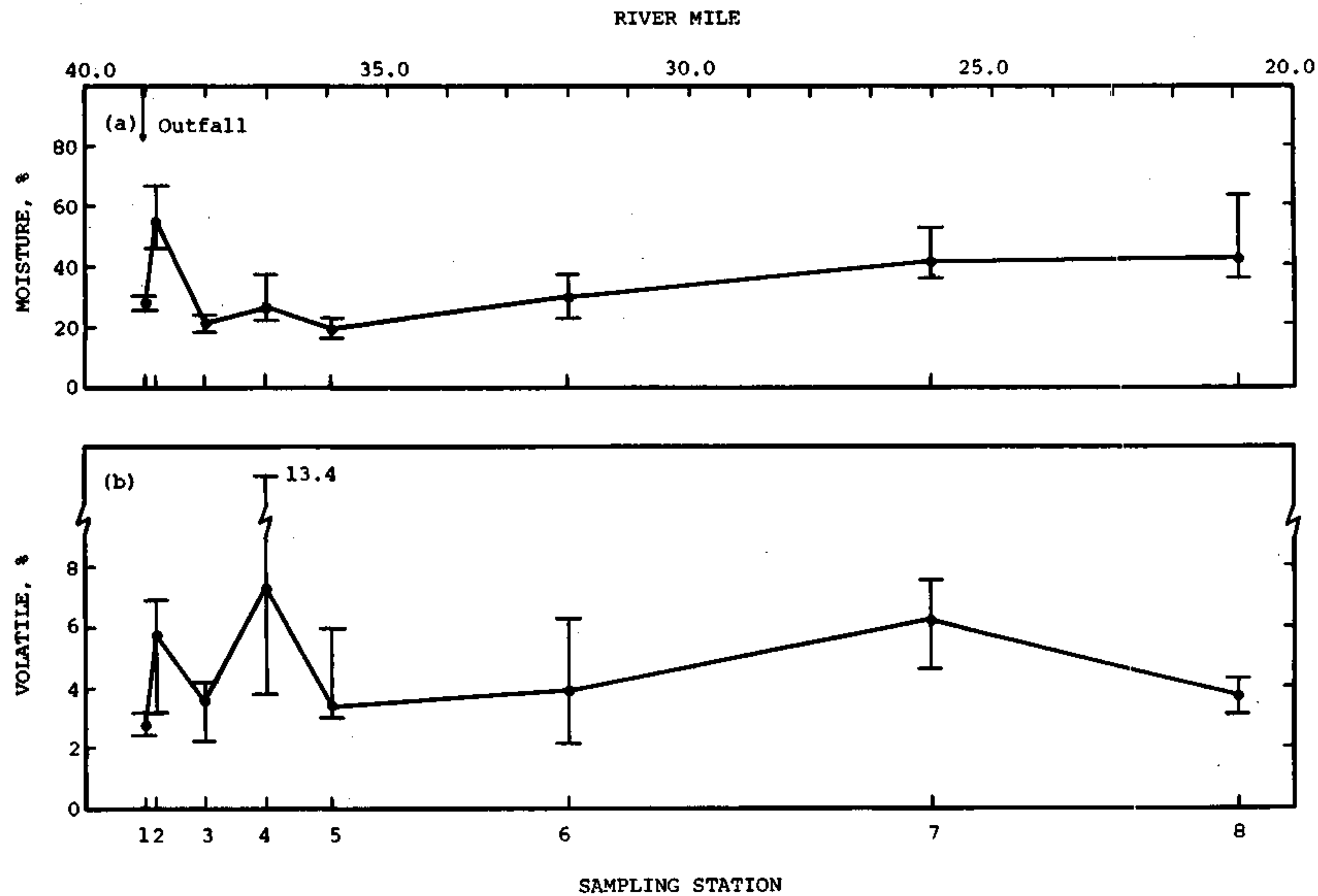

Figure 27. Ranges and means of moisture and volatile contents of Crooked Creek bottom sediments

Benthic Macroinvertebrates

Macroinvertebrate biotic index (MBI) values were calculated for each sediment sample. The MBI value is a weighted mean of tolerance rating and organism density of taxon calculated as follows (IEPA, 1984):

$$MBI = \sum_{i=1}^{n} \frac{(n_i \ t_i)}{N} \tag{10}$$

where n_i = number of organisms of taxon i

t_i = tolerance value of taxon i

N = total number of organisms in the sample

The tolerance value is the organism's tolerance to organic pollution, as developed by the Illinois Environmental Protection Agency (IEPA, 1984)• The lower the tolerance number, the better the water quality.

The MBI values may be between zero and 11, indicating best to worst water quality, respectively. The MBI value was calculated for each sediment sample collected.

The observed macroinvertebrate data for the sediments of Crooked Creek are summarized in appendix E. The appendix lists the number of individuals in each taxon found at each sampling station, tolerance rating of the taxon, total number of organisms, total number of taxa, MBI value for each sample, and the occurrence, in number of stations, for each taxon.

During the course of this study, 22 taxa of benthic macroinvertebrates were recovered from the 56 sediment samples of Crooked Creek. The scientific and common names of the 22 taxa, as well as their tolerance values, are presented in table 12. The tolerance values for the observed macroinvertebrates ranged from 2 to 10.

Composition. True midge fly larvae, Chironomidae, were predominant in density and frequency of occurrence at all stations (appendix E). For seven sampling dates, they occurred at all eight stations (except for St 7 on September 4, 1985). Chironomidae generally occurred in high concentrations at St 4. This organism remains in the bottom sediments until pupation and the emergence of the adult fly. It has a hemoglobin-like blood pigment and special gills to extract sufficient oxygen even from nearly oxygen-depleted waters.

Sludge worms (Tubificidae) were the second most frequently occurring macroinvertebrate in the creek sediments, with a high density at St 8. They are rated as having the highest tolerance value. The mayfly (*Caenis*) also occurred relatively frequently.

Density. Benthos density data expressed in terms of organisms per square meter were calculated for each sample. The observed total densities per sample ranged from a low of $58/m^2$ at St 5 on September 4, 1985 to a high of $2411/m^2$ at St 7 on July 11, 1985.

Table 12. Observed Benthic Macroinvertebrates

Taxa	Common name	Tolerance value
Centroptilum	Mayfly	2
Psychomyiid genus A	Caddis fly	2
Anodonta grandis	Floater clam	3
Corbicula	Asiatic clam	4
Perlesta placida	Stonefly	4
Sialis	Alderfly	4
Stenonema	Mayfly	4
Cambaridae	Crayfish	5
Dubiraphia	Riffle beetle	5
Hexagenia limbata	Burrowing mayfly	5
Hyalella	Sideswimmer	5
Sphaerium	Fingernail clam	5
Branchiura sowerbyi	Aquatic worm	6
Caenis	Mayfly	6
Cheumatopsyche	Caddis fly	6
Chironomidae	True midge	6
Ischnura	Damselfly	6
Asellus	Aquatic sow bug	7
Ceratopogonidae	Biting midge	7
Stenelmis	Riffle beetle	7
Chaoborus	Phantom midge	8
Tubificidae	Sludge worm	10

The benthos density ranges and geometric means for each sampling station are shown in figure 28a. These values decreased at St 2 and recovered at St 3. The geometric mean density at St 2 ($160/m^2$) was about one-half that at St 1 ($315/m^2$). The density range followed a similar pattern. Higher population densities were observed at downstream stations 4 through 8. Stations 4 and 8 had the highest geometric mean densities.

On the basis of macroinvertebrate density only, it can be concluded that waste discharge had a definite impact at St 2, which is 980 feet downstream of the outfall, but no impact at St 3 (1 mile below the outfall).

Taxa. The average number and range of macroinvertebrate taxa per sample and total number of taxa at each station are depicted in figure 28b. St 1 had the greatest range of 1 to 9 taxa/sample with a mean of 4.1 taxa/sample. In comparison with St 1, a lower range (2-3 taxa/sample) and mean value (2.6 taxa/sample) were found at St 2. The range and mean taxa per sample increased at St 3 and other downstream stations. The highest means were 6.0 and 5.0 at St 5 and St 7, respectively.

During the study period 11, 5, 10, 10, 13, 11, 15, and 10 taxa were recovered at stations 1 through 8, respectively (figure 28b). At St 2 only five taxa were identified, which was a significant decrease from 11 at St 1. These five taxa were *Centroptilum*, *Hexagenia limbata*, Chironomidae, *Chaoborus*, and Tubificidae. However, *Centroptilum* and *Chaoborus* were not found at St 1. More taxa were recovered at St 3 and the other downstream stations.

The *Chaoborus* (phantom midge) has air sacs which permit it to visit the surface water at night to feed and renew its oxygen supplies; during the day this organism burrows in the bottom sediments and may survive there in great numbers even under anaerobic conditions. *Chaoborus* occurred three times at St 2 and once each at St 6 and St 8. This organism is usually found only in lakes and ponds in deeper thermally stratified areas and not in water currents. It possibly came from Raccoon Lake raw water, was discharged with the plant wastes, and then was deposited in the bottom sediment at St 2.

An important factor in the production and diversity of benthic invertebrate macrofauna is the type and stability of the bottom sediments. Abundance is related to stability of the sediments and access to organic detritus. Sand is a relatively poor habitat for macroinvertebrates because of its instability, especially when its inherent instability is influenced by navigation traffic. On the other hand, the samples collected near the river bank, consisting of a mixture of sand, silt, and clay, provide a stable habitat which permits "burrowing" and "clinging" organisms to colonize.

The significant changes in physical and chemical characteristics of sediment at St 2 might cause changes in the type, diversity, and density of macroinvertebrates. At St 2 the diversity and types of macroinvertebrates decreased from those at St 1. It may be concluded that the waste discharges from the water plant impacted the diversity of taxa at St 2, 980 feet downstream of the waste outfall, and did not affect St 3 and other downstream stations.

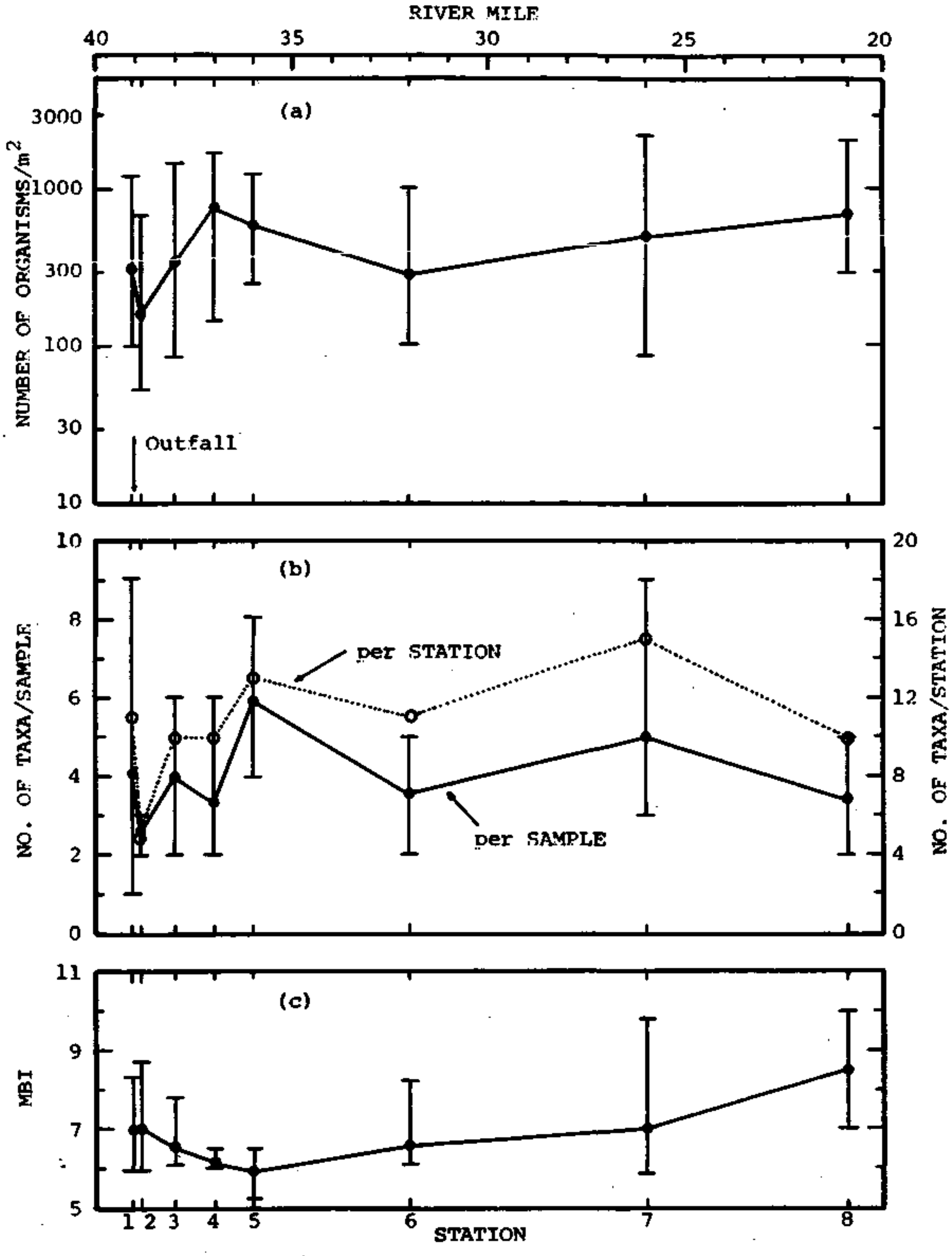

Figure 28. Benthic macroinvertebrates (number of organisms, number of taxa, and MBI values) in Crooked Creek

Macroinvertebrate Biotic Index. Figure 28c shows the range and average MBI value for each station. The MBI at St 1 ranged from 5.9 to 8.3 with a mean of 7.0. The range and mean MBI at St 2 were found to be similar to those at St 1. Solely in terms of the MBI, there was no difference between St 2 and St 1.

Nevertheless, the mean MBI value decreased at, and below, St 3. In fact, St 5 was clearly the best in benthic quality. St 5 had the lowest MBI and highest diversity. St 8 had the highest (worst) MBI (8.5) and was low in mean number of taxa per sample. St 8 is considered worst in macroinvertebrate quality, which might be because it receives wastewater treatment plant effluent from Sewer Creek and Grand Point Creek (figure 12).

According to IEPA's report (IEPA, 1984), MBI values of 5.0 and less indicate relatively good water quality, and those of 6.0 and higher suggest relatively poor water quality. No sediment samples collected from Crooked Creek had an MBI of 5.0 or less. Fifty-one out of 56 samples (91 percent) had MBI values of 6.0 or greater. On the basis of MBI values the water quality of Crooked Creek at all eight sampling stations is classified as polluted (poor).

In terms of the parameters of particle size distribution, percent of moisture and volatile content, total iron and aluminum concentrations, and macroinvertebrate types, diversity, and density, the sediment quality at St 2 was found to be changed from that at St 1. However, MBI values showed no difference between St 1 and St 2.

Summary

- The bottom sediments at eight stations, located upstream and downstream of the waste outfall, were examined seven times each for particle size distribution, moisture and volatile content, total aluminum and iron concentrations, and macroinvertebrates.

- The impact of the waste discharges on bottom sediments, as measured by their physical, chemical, and biological characteristics, was limited to St 2 which is located 980 feet downstream of the outfall. No impact was observed at St 3 (1 mile downstream).

- In comparison with St 1, St 2 showed increasing compositions of silt (from 43 to 59 percent) and clay (13 to 17 percent) and a decreasing sand portion (from 41 to 16.4 percent); increasing liquidity (from 27 to 58 percent) and volatile content (from 2.6 to 5.6 percent); increasing aluminum and iron concentrations (by 2.40-fold and 1.54-fold, respectively); and decreasing macroinvertebrate density (geometric mean from 315 to $160/m^2$), number of taxa per sample (from 4.1 to 2.6), and number of taxa per station (from 11 to 5).

- There was essentially no difference in the macroinvertebrate biotic index between St 2 (7.1) and the control, St 1 (7.0).

- Chaoborus, which is classified as a lake organism, was observed 3 times at St 2, but not at St 1. This organism might have been introduced from the raw water source of Raccoon Lake.

CONCLUSIONS

This study has been an effort to determine the quantity and characteristics of wastes generated in a small water treatment plant employing the clarification process, and to assess the impact, if any, of the discharges of plant wastes on a small creek. The methods used are applicable to other water plants and, with some modification, to other streams.

In developing a solids balance for the water treatment plant, there was a problem in evaluating the quantity of wastes from clarifiers that operated on intermittent blow-down cycles. The on-and-off cycles of clarifier blow-downs were adjusted frequently to meet treatment needs.

The major sources of wastes in the water treatment plant at Centralia are blow-down from the clarifiers and backwash from the activated carbon mixed-media filters. During this study the total suspended solids of the raw water were measured daily. TSS loads to the plant could be accurately determined. Sequential filter backwash sampling gave the quantity of waste released from filters. The difference between the plant loads and filter waste production was assumed to be the waste quantity from the clarifiers.

At the Centralia water plant the average pumpage was 3.78 MGD. The waste solids generated were approximately 360 pounds (163 kg) per day. About 9.1 percent of the solids was derived from alum coagulation, with the remainder originating from TSS in the raw water. During backwashes, the filters released 15.7 percent of the total solids produced. Volatile (organic) portions of wastes averaged 38 and 13 percent for the filters and clarifiers, respectively.

The average volume of wastes generated from the plant was 134,000 gpd, with about 94 percent of the waste volume originating from the activated carbon mixed-media filters. The mean volume of wastes represents about 3.8 percent of the average daily volume of water treated. The mean volume of settleable solids from the plant was estimated at 3730 gpd, while the majority (85 percent) were from the clarifier blow-down.

In order to evaluate the influence and characteristics of waste discharges on Crooked Creek water, 14 water quality parameters were measured in samples from eight creek stations, the two clarifiers, and two filters. In comparison with streamwater, clarifier blow-down had higher concentrations of TSS, VSS, settleable solids, turbidity, iron, aluminum, and BOD_5; filter backwash was higher in VSS, settleable solids, DO, and aluminum. The iron content is probably inherent in the suspended solids of the raw water. The concentrations of aluminum are derived from the alum coagulation process.

Even after receiving plant wastes, St 2 (located 980 feet downstream of the outfall) had levels of TSS, turbidity, alkalinity, and total iron that were significantly (95 percent confidence level) decreased from those at the control station, St 1. This might be due to the coagulation and sedimentation occurring in the vicinity of the outfall. No one parameter measured at St 2 was statistically higher than that at St 1.

There were no significant differences in the 14 water quality parameters measured at stations 3 through 8 from those at St 1. It was concluded that no adverse impact on Crooked Creek water was caused by waste discharges. In fact, some benefits were found.

The impact of the waste discharges was readily detectable in the bottom sediments at St 2 (but not in those at stations 3 through 8) by increased chemical concentrations, by changes in particle size distribution, and by a shifting diversity and abundance of macroinvertebrates. At St 2 the average percentages of moisture and volatile content were more than double those at St 1; and aluminum and iron concentrations increased about 2.40-fold and 1.54-fold above the mean concentrations at St 1 of 6910 and 11,300 mg/kg, respectively.

In comparisons of St 1 and St 2, significant modifications of grain size distribution were observed. On the average sand decreased from 40.7 to 16.4 percent, and silt increased from 43.3 to 59.4 percent. However, despite the change in sediment particle size distribution there were no measurable residue deposits at St 2.

In terms of density and total number of taxa of macroinvertebrates, only St 2, and not St 3 through 8, was influenced by waste loads. Chaoborus (possibly from Raccoon Lake raw water) occurred three times at St 2. Even though silt portions increased at St 2, the abundance and diversity of benthic macroinvertebrates was significantly reduced at St 2 from St 1. At St 2 the geometric mean density was reduced to about one-half that at St 1; the average number of taxa per sample was reduced from 9 at St 1 to 3 at St 2; and the total number of taxa observed was reduced from 11 at St 1 to 5 at St 2. These decreases in abundance and diversity of macroinvertebrates are considered to be due to the changes in chemical constituents. The MBI values, which are an indicator of water quality used by the IEPA, showed no difference between St 1 and St 2.

On the basis of biological, chemical, and physical parameters measured at the stream sampling stations, the influence of the water plant discharges was observed to extend between 980 and 5200 feet below the outfall (between stations 2 and 3).

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Appendix A1. Water Quality of Filter 1 Backwash

May 14, 1985
Hours of Operation: 57.0
Water Filtered: 1.425 MG
Backwash Rate: 4,444 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	5	2	tr
1.00	466	196	70
1.25	380	156	63
1.50	264	104	39
1.75	---	---	44
2.00	208	92	31
2.25	160	68	24
2.50	104	60	15
2.75	112	60	20
3.00	94	48	14
3.50	66	38	8.5
4.00	48	28	4.0
5.00	24	16	0.4
6.00	7	6	0.1
9.00	5	3	0.1

June 25, 1985
Hours of Operation: 62.75
Water Filtered: 1.428 MG
Backwash Rate: 4,640 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	2	2	0
0.50	78	36	4.4
0.67	112	44	6.3
0.83	140	64	9.4
1.00	204	88	17.8
1.17	244	96	24
1.33	276	104	27.2
1.50	260	108	24.1
1.75	264	104	21.5
2.00	188	76	13.7
2.50	152	64	10.3
3.00	76	38	3.6
4.00	34	20	1.0
5.00	23	10	0.1
6.50	5	2	0.06
8.83	3	2	0.01

November 5, 1985
Hours of Operation: 46.0
Water Filtered: 1.169 MG
Backwash Rate: 4,560 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	3	2	tr
0.25	28	19	0.04
0.50	40	16	0.03
0.67	52	28	0.45
0.83	76	28	5.2
1.00	136	52	15.1
1.17	176	80	26.5
1.33	196	88	27.8
1.50	240	88	36.9
1.75	256	88	44
2.00	230	92	37.5
2.50	164	60	18.5
3.00	104	48	9.4
4.00	42	18	0.08
5.50	19	9	0.01
8.78	5	4	tr

Appendix A1. Continued

December 18, 1985
Hours of Operation: 28.13
Water Filtered: 0.775 MG
Backwash Rate: 4,960 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	9	5	0.05
0.25	76	26	0.04
0.50	106	40	2.2
0.67	124	48	3.1
0.83	340	92	19.5
1.00	240	72	11.9
1.17	400	108	20.2
1.33	444	116	19.9
1.50	416	112	23.4
1.75	388	96	21.0
2.00	324	88	16.1
2.50	200	64	6.9
3.00	134	40	1.7
4.00	62	26	0.02
5.50	29	12	0.01
8.87	13	8	tr

January 7, 1986
Hours of Operation: 46.3
Water Filtered: 1.226 MG
Backwash Rate: 4,800 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	5	2	tr
0.25	25	8	0.01
0.50	40	12	0.01
0.67	36	12	0.01
0.83	62	20	0.1
1.00	116	28	4.5
1.17	108	40	3.5
1.33	136	40	5.2
1.50	206	62	14
1.75	280	72	22
2.00	296	76	20
2.50	212	56	13
3.00	156	48	6.5
4.00	72	24	0.5
5.50	14	8	0.01
9.17	7	5	tr

March 5, 1986
Hours of Operation: 30.8
Water Filtered: 0.789 MG
Backwash Rate: 4,900 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	5.5	3.5	tr
0.25	6.5	4	tr
0.50	16	8	0.01
0.67	34	13	0.02
0.83	27	13	0.02
1.00	66	20	0.04
1.17	84	34	1.0
1.33	108	38	2.6
1.50	140	60	4.2
1.75	128	44	3.4
2.00	98	42	2.3
2.50	68	30	0.12
3.00	50	20	0.08
4.00	28	11	0.02
5.50	14	7	0.02
7.75	7	5	0.01

Appendix A1. Concluded

March 18,1986
Hours of Operation: 42.8
Water Filtered: 1.060 MG
Backwash Rate: 5,050 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	2.5	0	tr
0.25	36	10	0.08
0.50	*66*	14	1.2
0.67	124	8	6.1
0.83	180	40	10.5
1.00	220	56	17.9
1.17	252	60	19
1.33	248	60	15.5
1.50	208	40	13.4
1.75	184	36	9.5
2.00	148	32	6.8
2.50	100	28	4.2
3.00	80	16	2.3
4.00	48	0	0.7
5.50	24	0	0.05
8.12	18	7	0.04

Appendix A2. Water Quality of Filter 2 Backwash

May 14, 1985
Hours of Operation: 48.75
Water Filtered: 1.236 MG
Backwash Rate: 4,970 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00		43	0
0.25	19	13	0.1
0.50	88	42	11.5
0.75	168	60	24.5
1.00	188	64	26
1.25	200	68	29
1.50	188	76	26
1.75	176	60	21
2.00	144	60	17
2.50	88	44	10
3.00	50	26	4.3
4.00	21	11	1
6.00	6	4	0.2
8.25	3	2	0.1

July 11, 1985
Hours of Operation: 42.5
Water Filtered: 1.327 MG
Backwash Rate: 4,970 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	10	4	0.01
0.25	24	10	0.01
0.50	44	16	1.2
0.67	216	64	26.1
0.83	288	92	42
1.00	400	128	64.5
1.25	492	160	79
1.50	452	156	71
1.75	396	136	59
2.50	224	88	39.5
3.00	108	40	14.4
4.00	64	44	4.2
5.50	19	13	0.11
7.58	6	4	0.02
8.25	5	4	0.01

August 6, 1985
Hours of Operation: 51.33
Water Filtered: 1.462 MG
Backwash Rate: 4,870 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	13	8	0.3
0.25	17	11	0.2
0.50	152	62	13.2
0.67	256	112	28
0.83	536	212	66
1.00	704	148	52
1.17	424	148	54
1.33	408	148	53
1.50	340	136	41
1.75	304	116	38
2.00	240	88	29.3
2.50	164	72	17
3.00	86	40	9.3
4.00	48	16	1.5
5.50	14	5	0.02
8.42	5	2	0.01

Appendix A2. Continued

August 20, 1985
Hours of Operation: 55.1
Water Filtered: 1.492 MG
Backwash Rate: 4,870 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	2	1	0.1
0.25	30	22	0.35
0.50	95	35	6.5
0.67	144	64	16.5
0.83	212	96	26.3
1.00	328	132	42
1.17	400	160	52
1.33	416	160	60
1.50	392	156	53
1.75	348	140	44
2.00	304	124	35.5
2.50	184	76	21.8
3.00	120	48	12.7
4.00	52	24	2.8
5.50	16	10	0.12
8.62	3	1	0.01

November 19, 1985
Hdurs of Operation: 49.9
Water Filtered: 1.268 MG
Backwash Rate: 5,000 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	3	2	tr
0.25	28	9	0.02
0.50	148	52	6.5
0.67	260	72	6.6
0.83	312	100	18.6
1.00	332	92	19.9
1.17	332	88	18.9
1.33	292	80	15.1
1.50	260	72	14.1
1.75	236	68	12.3
2.00	196	56	8.6
2.50	132	40	4.7
3.00	80	26	1.7
4.00	36	11	0.1
5.50	14	6	0.01
8.00	8	6	tr

February 13, 1986
Hours of Operation: 34.25
Water Filtered: 0.859 MG
Backwash Rate: 4,880 gpm

Time, min	TSS, mg/L.	VSS, mg/L	Set. S, mL/L
0.00	7	5	tr
0.25	9	5	tr
0.50	52	21	1.7
0.67	132	60	11.2
0.83	260	100	29
1.00	364	120	41
1.17	432	132	48
1.33	512	156	54
1.50	456	136	52
1.75	372	108	41
2.00	324	112	32
2.50	228	80	32.2
3.00	160	76	11.8
4.00	62	28	2.1
5.50	17	10	0.02
10.25	2	2	0.02

Appendix A2. Concluded

March 5, 1986
Hours of Operation: 30.75
Water Filtered: 0.790 MG
Backwash Rate: 4,920 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	4.5	3	tr
0.25	5	2.5	tr
0.50	20	4	tr
0.67	62	26	0.12
0.83	78	24	1.8
1.00	124	52	3.9
1.17	136	60	6.4
1.33	148	60	7.6
1.50	160	60	6.2
1.75	120	40	4.1
2.00	112	48	2.5
2.50	66	16	0.62
3.00	52	24	0.80
4.00	25	11	0.04
5.50	10	4	0.01
8.33	6.5	3.5	tr

April 1, 1986
Hours of Operation: 59.2
Water Filtered: 1.210 MG
Backwash Rate: 4,850 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	3	2	tr
0.25	14	5	0.01
0.50	42	12	0.45
0.67	136	36	7.0
0.83	236	72	12.5
1.00	280	68	19.2
1.17	288	72	18.5
1.33	272	76	15.4
1.50	264	60	12.5
1.75	204	56	10.1
2.00	164	40	7.7
2.50	104	32	3.1
3.00	68	26	1.8
4.00	37	15	0.49
5.50	17	6	0.12
8.25	11	2	0.10

April 16, 1986
Hours of Operation: 46.33
Water Filtered: 1.108 MG
Backwash Rate: 3,940 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	3	0.5	tr
0.25	16	4	0.02
0.50	136	32	8
0.67	200	32	14.8
0.83	456	108	37
1.00	532	120	39.5
1.17	628	144	42
1.33	556	124	38.8
1.50	444	96	27.9
1.75	320	80	21.9
2.00	256	60	17.2
2.50	164	40	8.5
3.00	116	36	5.1
4.00	40	12	0.5
5.50	14	3	0.12
8.12	14	5	0.05

Appendix A3. Water Quality of Filter 3 Backwash

June 12, 1985
Hours of Operation: 40.0
Water Filtered: 0.998 MG
Backwash Rate: 5,520 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	4	3	0
0.25	49	32	0.2
0.50	368	144	65
0.67	396	160	70
0.83	372	152	67
1.00	380	156	65
1.17	300	124	50
1.33	288	120	48
1.50	208	84	31
2.00	172	52	0
2.50	90	30	20.05
3.00	70	32	6
4.00	27	9	0.1
6.00	8	2	0.01
8.33	7	1	0.01

July 11, 1985
Hours of Operation: 40.6
Water Filtered: 1.206 MG
Backwash Rate: 5,180 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	5	3	0.01
0.25	24	8	0.09
0.50	48	18	1.2
0.67	370	84	34.1
0.83	520	180	84.1
1.00	656	236	105
1.17	608	212	92
1.33	572	192	81.2
1.50	500	160	69.1
1.75	416	140	48.2
2.00	328	112	36.6
2.50	196	60	15.5
3.00	104	24	9.1
4.00	42	12	1.7
6.50	12	5	0.08
8.88	6	4	0.01

August 20, 1985
Hours of Operation: 51.4
Water Filtered: 1.396 MG
Backwash Rate: 4,850 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	5	2	0.1
0.25	20	11	1.2
0.50	20	14	0.08
0.67	100	52	9.6
0.83	136	72	22
1.00	276	100	42
1.17	308	112	49
1.33	340	120	48
1.50	288	100	40
1.75	236	84	26.9
2.00	192	76	20.5
2.50	120	52	6.3
3.00	76	40	3.9
4.00	24	16	0.08
5.50	7	6	0.02
8.45	4	2	0.01

Appendix A3. Continued

September 4, 1985
Hours of Operation: 60.9
Water Filtered: 1.719 MG
Backwash Rate: 4,420 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	4	3	0.08
0.25	11	8	0.2
0.50	56	36	2.3
0.67	204	92	31.8
0.83	480	212	85
1.00	480	208	87
1.17	432	184	88
1.33	392	172	71
1.50	308	132	59
1.75	344	144	57
2.00	244	108	42
2.50	188	96	20.5
3.00	132	76	10.5
4.00	60	48	2.75
5.50	20	15	0.25
8.83	12	11	0.04

September 17, 1985
Hours of Operation: 54.33
Water Filtered: 1.596 MG
Backwash Rate: 5,020 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	7	4	0.1
0.25	9	4	0.7
0.50	78	34	2.5
0.67	*66*	16	13.4
0.83	268	84	37.7
1.00	388	104	57
1.17	444	116	*69*
1.33	456	132	67
1.50	456	132	65
1.75	424	108	51
2.00	368	108	34.8
2.50	216	56	16.1
3.00	140	56	7.5
4.00	48	24	1.3
5.50	19	8	0.3
7.97	14	10	0.04

December 3, 1985
Hours of Operation: 41.97
Water Filtered: 1.128 MG
Backwash Rate: 4,960 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	4	3	tr
0.25	7	4	tr
0.50	8	7	tr
0.67	108	32	1.2
0.83	196	52	9.1
1.00	264	72	13.0
1.17	296	76	15.8
1.33	324	88	17.7
1.50	324	76	17.5
1.75	300	80	14.2
2.00	262	78	11.9
2.50	120	44	4.0
3.00	76	24	1.5
4.00	24	14	0.05
5.50	12	8	0.01
9.28	4	3	tr

Appendix A3. Continued

January 7, 1986
Hours of Operation: 43.72
Water Filtered: 1.160 MG
Backwash Rate: 5,130 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	6	4	tr
0.25	23	7	tr
0.50	30	26	0.1
0.67	224	56	13
0.83	288	88	20
1.00	288	80	21
1.17	312	88	22
1.33	312	88	23
1.50	312	92	22
1.75	264	62	19
2.00	196	56	12
2.50	116	32	3.5
3.00	60	24	0.2
4.00	21	8	tr
5.50	10	5	tr
8.00	5	3	tr

February 19, 1986
Hours of Operation: 38.83
Water Filtered: 0.728 MG
Backwash Rate: 5,190 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	6	5	tr
0.25	9	6	tr
0.50	136	48	12.8
0.67	304	92	33.8
0.83	384	132	37.2
1.00	408	132	42
1.17	440	136	47
1.33	424	136	44
1.50	392	124	38.5
1.75	328	108	34.5
2.00	248	96	29.2
2.50	144	60	11.2
3.00	64	40	1.6
4.00	20	18	0.02
5.50	10	6	tr
7.90	9	7	tr

March 18, 1986
Hours of. Operation: 34.72
Water Filtered: 0.844 MG
Backwash Rate: 5,040 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	3	0	tr
0.25	4	0	0.01
0.50	9	3	tr
0.67	56	16	0.8
0.83	88	20	2.5
1.00	112	16	4.85
1.17	120	24	5.3
1.33	108	24	3.2
1.50	104	36	3.0
1.75	72	16	0.65
2.00	72	20	2.2
2.50	56	20	0.55
3.00	52	16	1.6
4.00	26	12	0.18
5.50	26	6	0.05
9.53	12	3	0.04

Appendix A3. Concluded

April 15, 1986
Hours of Operation: 50.45
Water Filtered: 1.333 MG
Backwash Rate: 5,860 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	2	0	tr
0.25	15	2	0.05
0.50	22	0	0.05
0.67	116	8	6.1
0.83	272	48	18.9
1.00	296	52	20.8
1.17	296	56	19.8
1.33	276	56	17.8
1.50	252	44	17.1
1.75	196	32	12.2
2.00	164	32	8.4
2.50	88	12	3.4
3.00	56	8	1.2
4.00	22	8	0.32
5.50	12	5	0.15
6.83	7	0	0.05

May 12, 1986
Hours of Operation: 50.92
Water Filtered: 1.328 MG
Backwash Rate: 5,130 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	2	2	0.01
0.25	4	4	0.02
0.50	13	12	0.01
0.67	92	64	14.2
0.83	244	124	52
1.00	372	184	70
1.17	450	250	95
1.33	420	220	89
1.50	400	220	85
1.75	340	190	65
2.00	270	160	50
2.50	154	74	22.5
3.00	96	64	11.2
4.00	28	24	0.25
5.50	19	18	0.10
7.80	6.5	5.5	0.02

Appendix A4. Water Quality of Filter 4 Backwash

June 11, 1985
Hours of Operation: 62.5
Water Filtered: 1.589 MG
Backwash Rate: 5,090 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	1	1	0
0.25	2	1	0.01
0.50	35	10	0.25
0.75	148	132	14.5
1.00	224	160	24
1.25	224	92	25.5
1.50	204	*16*	18
1.75	156	64	14.8
2.00	120	60	11
2.50	76	40	7.7
3.00	42	27	0.5
4.00	22	13	0.02
5.50	6	5	0.02
7.00	7	5	0.01
8.25	2	1	0.01

July 24, 1985
Hours of Operation: 45.7
Water Filtered: 1.367 MG
Backwash Rate: 5,010 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	9	6	0.1
0.25	25	22	0.05
0.50	36	16	0.31
0.67	180	72	21
0.83	272	108	37.2
1.00	328	124	50
1.17	348	136	49
1.33	368	104	45
1.50	292	116	35.2
1.75	220	80	26.5
2.00	196	88	19.4
2.50	108	48	8.1
3.00	68	28	2.2
4.00	34	14	0.3
5.50	7	6	0.01
8.38	5	4	0.01

October 2, 1985
Hours of Operation: 41.83
Water Filtered: 1.156 MG
Backwash Rate: 5,000 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	8	4	0.01
0.25	13	7	0.25
0.50	23	12	0.01
0.67	76	34	4.6
0.83	240	*96*	28
1.00	336	120	41
1.17	376	132	47
1.33	384	152	45
1.50	340	132	41
1.75	288	120	33.5
2.00	208	84	18.5
2.50	152	68	10.5
3.00	106	68	4.9
4.00	46	28	0.15
5.50	20	6	0.20
8.20	10	4	0.02

Appendix A4. Continued

October 15, 1985
Hours of Operation: 45.1
Water Filtered: 1.174 MG
Backwash Rate: 5,340 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	5	2	0.01
0.25	10	4	0.1
0.50	16	4	0.1
0.67	56	18	0.8
0.83	94	38	2.5
1.00	128	48	8.4
1.17	124	40	6.7
1.33	116	40	5.3
1.50	112	40	4.1
1.75	100	32	2.7
2.00	76	24	1.7
2.50	60	20	0.7
3.00	50	24	0.3
4.00	24	11	0.1
5.50	9	2	tr
8.05	7	3	tr

November 5, 1985
Hours of Operation: 51.0
Water Filtered: 1.295 MG
Backwash Rate: 5,130 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	4	3	tr
0.25	9	8	tr
0.50	14	9	tr
0.67	48	20	0.05
0.83	80	44	5.1
1.00	124	56	12.8
1.17	128	56	11.9
1.33	148	76	12.3
1.50	120	56	9.9
1.75	100	44	5.3
2.00	74	38	0.21
2.50	50	22	0.02
3.00	32	16	0.01
4.00	14	10	tr
5.50	8	5	tr
8.00	5	4	tr

December 3, 1985
Hours of Operation: 45.63
Water Filtered: 1.228 MG
Backwash Rate: 4,750 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	3	2	tr
0.25	3	2	tr
0.50	9	6	tr
0.67	32	10	0.01
0.83	96	24	5.0
1.00	148	44	6.2
1.17	164	40	6.7
1.33	164	32	6.4
1.50	140	36	4.4
1.75	128	36	3.2
2.00	132	48	2.1
2.50	54	30	0.19
3.00	56	24	0.02
4.00	27	17	0.01
5.50	16	12	0.01
9.05	3	2	tr

Appendix A4. Concluded

January 21, 1986
Hours of Operation: 43.35
Water Filtered: 1.121 MG
Backwash Rate: 5,100 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	2	1	tr
0.25	3	2	tr
0.50	7	3	tr
0.67	36	10	0.2
0.83	92	24	7
1.00	120	36	11
1.17	140	36	11
1.33	132	36	8
1.50	124	46	6
1.75	112	36	5
2.00	64	16	1.8
2.50	56	16	0.3
3.00	30	6	0.2
4.00	13	4	tr
5.50	8	2	tr
8.03	5	3	tr

February 4, 1986
Hours of Operation: 29.13
Water Filtered: 0.779 MG
Backwash Rate: 5,160 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	4	0	tr
0.25	5	2.5	tr
0.50	34	13	0.1
0.67	70	23	2.5
0.83	128	40	8.7
1.00	140	40	12.7
1.17	172	52	13.5
1.33	166	46	11.5
1.50	166	46	11.2
1.75	136	34	9.1
2.00	100	26	5.8
2.50	62	18	2.1
3.00	40	14	0.37
4.00	16	5	0.05
5.50	7.5	2	0.02
7.95	5	2	0.01

April 1, 1986
Hours of Operation: 58.53
Water Filtered: 1.464 MG
Backwash Rate: 4,110 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	4	3	tr
0.25	6	3	0.05
0.50	8	4	0.01
0.67	25	8	0.04
0.83	78	24	1.7
1.00	128	36	5.5
1.17	138	34	5.8
1.33	136	40	5.9
1.50	138	32	5.4
1.75	120	36	4.6
2.00	100	32	1.6
2.50	60	18	0.5
3.00	40	10	0.2
4.00	16	6	tr
5.50	8	4	tr
9.73	7	2	tr

Appendix A5. Water Quality of Filter 5 Backwash

May 28, 1985
Hours of Operation: 60.5
Water Filtered: 1.769 MG
Backwash Rate: 4,820 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	7	6	0.01
0.17	10	7	0.01
0.33	23	9	0.05
0.50	22	19	0.01
0.67	32	25	0.03
0.83	44	16	0.73
1.00	102	38	4.5
1.25	140	48	6.5
lv50	176	64	8.4
1.75	132	40	7.5
2.00	156	68	6.0
2.50	124	30	4.3
3.00	120	64	1.9
4.00	60	40	0.1
6.00	9	6	0.01
7.67	8	6	0.01

June 25, 1985
Hours of Operation: 60.42
Water Filtered: 1.643 MG
Backwash Rate: 4,030 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	3	2	0.01
0.25	5	3	0.01
0.50	8	5	0.2
0.67	30	18	0.4
0.83	60	32	2.7
1.00	76	44	8.8
1.25	*96*	40	9.1
1.50	92	48	7.7
1.75	104	48	8.5
2.00	80	28	6.2
2.50	80	36	3.8
3.00	52	20	1.5
4.00	38	18	0.3
5.50	13	2	0.1
7.58	8	3	0.02
10.67	9	3	0.01

August 6, 1985
Hours of Operation: 48.75
Water Filtered: 1.392 MG
Backwash Rate: 4,330 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	7	4	0.1
0.25	11	6	0.48
0.50	36	16	0.5
0.67	88	36	9.0
0.83	84	32	13.7
1.00	120	40	15.1
1.17	152	49	18.2
1.33	164	64	19.7
1.50	152	56	15.3
1.75	140	56	13.0
2.00	136	52	12.1
2.50	100	32	7.51
3.00	76	34	4.3
4.00	42	20	0.9
5.50	15	8	0.1
9.23	6	4	0.05

Appendix A5. Concluded

September 4, 1985
Hours of Operation: 59.75
Water Filtered: 1.687 MG
Backwash Rate: 4,210 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	10	6	0.01
0.25	15	12	0.1
0.50	32	26	0.05
0.67	62	36	4.8
0.83	88	68	9.0
1.00	88	56	8.6
1.17	108	60	10.2
1.33	136	72	13.8
1.50	140	68	13.2
1.75	136	72	13.0
2.00	112	56	10.1
2.50	120	48	4.8
3.00	56	44	1.3
4.00	22	14	0.1
5.50	8	7	0.01
8.78	4	4	0.01

September 17, 1985
Hours of Operation: 51.67
Water Filtered: 1.525 MG
Backwash Rate: 5,140 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	6	4	0.01
0.25	5	4	0.01
0.50	16	9	0.02
0.67	76	34	6.5
0.83	116	52	12.8
1.00	120	44	13.0
1.17	160	80	13.0
1.33	116	60	9.5
1.50	120	40	*6.6*
1.75	120	48	4.7
2.00	86	28	3.2
2.50	58	22	0.4
3.00	43	20	0.08
4.00	16	7	0.03
5.50	8	3	0.01
7.98	5	2	0.01

October 16, 1985
Hours of Operation: 49.25
Water Filtered: 1.286 MG
Backwash Rate: 5,450 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	5	4	tr
0.25	4	3	tr
0.50	38	16	0.01
0.67	80	44	1.1
0.83	100	44	6.5
1.00	116	60	7.0
1.17	108	32	4.1
1.33	108	40	4.7
1.50	92	36	0.98
1.75	84	24	0.28
2.00	68	20	0.1
2.50	46	20	0.08
3.00	32	12	0.01
4.00	16	4	tr
5.50	9	3	tr
8.08	6	2	tr

Appendix A6. Water Quality of Filter 6 Backwash

May 29, 1985
Hours of Operation: 62.42
Water Filtered: 1.825 MG
Backwash Rate: 5,090 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	2	1	0.01
0.25	11	6	0.01
0.50	244	164	9
0.67	288	156	18
0.83	244	*96*	16.5
1.00	320	140	14.0
1.25	332	192	13.1
1.50	228	128	9.2
1.75	172	108	7.1
2.00	132	88	5.5
2.50	85	43	2.3
3.00	60	46	0.6
4.00	40	32	0.05
6.00	29	25	0.01
8.25	29	8	0.01

July 23, 1985
Hours of Operation: 47.4
Water Filtered: 1.406 MG
Backwash Rate: 5,070 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	5	3	0.01
0.25	6	4	0.01
0.50	18	8	0.01
0.67	128	52	12.0
0.83	92	40	17.2
1.00	188	72	22.6
1.17	244	88	26.2
1.33	232	108	26.8
1.50	180	80	18.0
1.75	156	76	13.7
2.00	104	60	6.7
2.50	56	28	1.0
3.00	48	28	0.6
4.00	16	9	0.02
5.50	9	8	0.01
8.48	6	4	0.01

October 2, 1985
Hours of Operation: 42.33
Water Filtered: 1.169 MG
Backwash Rate: 5,160 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	7	2	tr
0.25	18	8	0.2
0.50	64	22	0.19
0.67	106	40	5.6
0.83	184	52	15.7
1.00	220	44	15.9
1.17	288	132	18.1
1.33	240	72	26.1
1.50	148	44	10.5
1.75	120	32	6.5
2.00	108	36	3.8
2.50	58	22	0.6
3.00	46	16	0.19
4.00	19	7	0.16
5.50	14	7	0.01
7.37	10	5	0.01

Appendix A6. Continued

November 19, 1985
Hours of Operation: 46.0
Water Filtered: 1.171 MG
Backwash Rate: 4,930 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	4	3	tr
0.25	10	5	0.01
0.50	17	7	0.01
0.67	35	17	0.01
0.83	64	24	0.29
1.00	82	26	0.98
1.17	86	26	2.1
1.33	100	38	3.1
1.50	96	40	1.9
1.75	82	28	0.39
2.00	68	26	0.20
2.50	40	18	0.10
3.00	23	9	0.02
4.00	24	14	0.01
5.50	5	4	tr
8.12	5	4	tr

December 18, 1985
Hours of Operation: 31.83
Water Filtered: 0.875 MG
Backwash Rate: 4,620 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	6	2	tr
0.25	7	3	tr
0.50	10	4	tr
0.67	47	17	0.01
0.83	104	54	0.03
1.00	158	70	0.04
1.17	132	32	0.22
1.33	180	72	0.61
1.50	116	37	0.08
1.75	108	36	0.02
2.00	82	18	0.01
2.50	54	18	tr
3.00	32	11	tr
4.00	18	7	tr
5.50	9	4	tr
8.88	7	5	tr

January 21, 1986
Hours of Operation: 38.2
Water Filtered: 0.992 MG
Backwash Rate: 4,970 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	3	1	tr
0.25	4	1	0.01
0.50	5	1	0.01
0.67	26	7	0.01
0.83	52	12	0.2
1.00	64	20	1.8
1.17	76	24	1.4
1.33	52	12	2.0
1.50	54	14	0.8
1.75	44	12	0.2
2.00	36	10	0.02
2.50	22	6	0.01
3.00	14	4	tr
4.00	13	5	tr
5.50	5	3	tr
8.25	9	4	tr

Appendix A6. Concluded

February 4, 1986
Hours of Operation: 34.58
Water Filtered: 0.920 MG
Backwash Rate: 5,290 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	9.5	6.5	tr
0.25	12.5	--	tr
0.50	23	14	0.01
0.67	65	23	1.9
0.83	83	38	3.8
1.00	104	38	5.1
1.17	120	40	6.3
1.33	126	44	9.1
1.50	59	22	9.6
1.75	*96*	36	5.8
2.00	82	30	3.5
2.50	54	28	1.0
3.00	34	14	0.2
4.00	15.5	7.5	0.01
5.50	10.5	6	0.01
7.75	9.5	4.5	tr

May 12, 1986
Hours of Operation: 50.33
Water Filtered: 1.312 MG
Backwash Rate: 5,150 gpm

Time, min	TSS, mg/L	VSS, mg/L	Set. S, mL/L
0.00	2	2	tr
0.25	3	3	tr
0.50	22	13	tr
0.67	108	56	12.2
0.83	152	72	19.5
1.00	180	68	27.1
1.17	224	96	36.0
1.33	240	104	36.1
1.50	208	108	34.4
1.75	144	72	29.0
2.00	116	76	17.5
2.50	76	48	6.7
3.00	50	30	0.7
4.00	24	18	0.1
5.50	7	7	0.02
7.77	4	4	0.01

Appendix B. Characteristics of Filter Backwash Wastewater

Filter/ Date	Temp,* °C	DO, mg/L	Turb, NTU	pH	Alka, mg/L	SO_4, mg/L	Mois, %	Spec. gr.	DS, mg/L	TSS, mg/L	VSS, mg/L	Set.S, mL/L	Fe, mg/L	Al, mg/L
Filter 1														
5/14/85	22.0	8.60	58	7.40	50	78	99.97	1.0000	204	90	30	4.00	1.98	8.30
6/25/85	24.6	8.30	45	7.38	70	75	99.97	1.0005	254	72	20	0.72	1.56	7.28
11/5/85	12.0	10.10	55	7.31	59	65	99.97	0.9997	218	62	28	0.95	1.50	6.50
12/18/85	2.1	13.45	108	6.95	30	64	99.97	1.0009	204	91	24	0.01	2.54	5.37
1/7/86	4.7	11.90	74	7.30	52	106	99.97	1.0015	240	72	22	0.10	2.06	5.95
3/5/86	4.9	11.55	32	7.13	36	84	99.97	1.0007	262	42	22	0.02	0.75	2.47
3/18/86	10.2	11.75	53	7.32	44	102	99.97	1.0015	260	64	14	0.07	1.58	4.27
Filter 2														
5/14/85	22.0	7.70	48	7.30	50	74	99.98	0.9998	202	54	22	0.25	1.09	4.70
7/11/85	26.4	9.50	60	7.62	72	76	99.97	1.0010	264	108	52	8.80	1.75	12.90
8/6/85	26.3	8.35	52	7.15	68	83	99.97	1.0005	258	89	31	6.50	1.57	9.09
8/20/85	25.2	8.28	78	7.54	78	91	99.97	0.9997	230	96	40	11.20	1.36	9.30
11/19/85	14.4	10.20	78	6.85	33	53	99.98	1.0007	170	73	24	0.10	1.92	5.22
2/18/86	4.3	11.90	108	6.80	27	88	99.97	1.0019	206	84	18	2.20	2.48	10.30
3/5/86	4.5	12.85	33	7.25	38	82	99.97	1.0011	254	44	22	0.01	0.83	2.88
4/1/86	13.7	9.70	56	6.98	32	90	99.97	0.9997	244	52	12	0.20	1.66	4.40
4/15/86	14.0	10.15	118	7.13	39	103	99.97	1.0005	226	126	34	6.80	3.57	9.30
Filter 3														
6/11/85	21.8	8.90	82	7.20	61	83	99.97	1.0015	220	106	42	7.02	3.13	11.39
7/11/85	26.2	8.80	60	7.43	71	78	99.96	1.0000	274	100	36	9.50	1.90	12.90
8/20/85	25.2	8.50	58	7.45	78	90	99.97	1.0001	226	76	40	5.00	0.95	6.72
9/4/85	26.4	7.97	89	7.33	65	87	99.97	1.0010	290	156	64	16.40	1.45	13.60
9/17/85	22.0	8.46	83	7.35	70	63	99.97	1.0010	264	114	44	7.90	2.02	11.50
12/3/85	5.6	12.25	96	6.97	29	58	99.98	1.0011	170	81	26	0.02	2.62	5.94
1/7/86	5.2	12.05	66	7.05	48	106	99.97	1.0006	254	62	21	0.10	1.64	5.01
2/18/86	4.8	11.90	96	6.80	25	88	99.97	1.0015	206	70	10	0.12	2.45	8.71
3/18/86	10.5	11.75	27	7.35	41	106	99.97	1.0013	254	40	8	0.01	0.63	1.84
4/15/86	15.6	8.90	98	7.13	37	97	99.97	1.0001	230	92	24	4.00	2.91	7.01
5/12/86	22.5	7.75	83	7.14	53	106	99.96	1.0003	306	96	80	7.10	1.56	10.58

Appendix B. Concluded

Filter/ Date	Temp, °C	DO, mg/L	Turb, NTU	pH	Alka, mg/L	SO_4, mg/L	Mois, %	Spec. gr.	DS, rag/L	TSS, mg/L	VSS, mg/L	Set.S, mL/L	Fe, mg/L	Al, mg/L
Filter 4														
6/11/85	23.6	8.55	50	7.60	60	80	99.97	1.0007	216	56	28	0.02	1.67	11.39
7/23/85	26.8	8.53	44	7.44	73	80	99.97	1.0018	254	64	22	2.20	1.00	5.54
10/2/85	16.9	9.75	72	7.35	65	68	99.97	1.0005	228	112	31	5.20	2.05	8.62
10/15/85	18.1	8.91	28	7.56	68	68	99.98	1.0009	234	32	16	0.04	0.80	2.87
11/5/85	12.1	10.60	29	7.49	61	62	99.97	1.0001	216	29	15	0.05	0.86	2.92
12/3/85	5.2	12.05	39	6.83	28	67	99.98	1.0003	176	32	13	0.01	0.86	2.16
1/21/86	5.3	11.60	32	7.28	43	72	99.98	1.0013	220	31	14	tr	0.59	2.57
2/4/86	7.4	11.10	51	6.82	19	89	99.98	1.0004	178	48	13	0.05	0.92	7.08
4/1/86	13.9	9.75	36	6.95	31	86	99.98	0.9996	242	30	4	0.02	1.05	2.62
Filter 5														
5/28/85	21.5	10.50	34	7.33	61	71	99.97	1.0014	224	56	28	0.01	1.27	3.94
6/25/85	24.5	8.21	23	7.41	67	71	99.97	1.0003	252	34	10	0.02	0.87	3.22
8/6/85	26.4	7.72	31	7.15	64	84	99.95	1.0005	248	58	18	0.20	0.81	5.12
9/4/85	26.6	7.80	34	7.38	66	75	99.97	1.0011	282	46	20	0.20	0.44	3.76
9/17/85	21.9	8.78	27	7.35	70	67	99.97	1.0010	226	38	18	0.02	0.60	3.31
10/15/85	18.0	9.42	26	7.48	64	67	99.98	1.0004	230	29	12	0.02	0.66	2.35
Filter 6														
5/28/85	21.2	8.41	46	7.55	63	70	99.97	1.0020	216	68	30	0.03	1.68	4.93
7/23/85	26.8	7.52	30	7.42	73	80	99.97	1.0020	250	46	16	0.12	0.73	3.96
10/2/85	16.7	9.48	33	7.38	67	71	99.98	1.0005	226	48	16	0.01	2.20	3.40
11/19/85	14.8	9.90	36	6.80	25	50	99.98	1.0006	146	31	8	tr	0.82	2.17
12/18/85	2.2	13.65	36	6.97	31	59	99.98	1.0011	206	30	10	tr	0.75	1.64
1/21/86	5.6	11.95	21	6.95	41	80	99.98	1.0013	214	23	13	tr	0.45	1.57
2/4/86	7.6	11.10	35	6.62	18	87	99.98	1.0002	186	34	8	0.02.	0.64	5.25
5/12/86	22.0	8.15	68	7.18	54	106	99.97	0.9997	308	56	56	5.10	1.93	7.23

*Note: Temp = temperature; DO = dissolved oxygen; Turb = turbidity; SO_4 = sulfate; Alka = total alkalinity as $CaCO_3$; Mois = percent of moisture; Spec. gr. = specific gravity; DS = dissolved solids; TSS = total suspended solids; VSS = volatile suspended solids; Set. S. = settleable solids; Fe = iron; Al = aluminum.

Appendix C1. Total Suspended Solids Concentrations (mg/L) in Water Plant Wastewater and in Crooked Creek Water

Date	St 1	C1	C2	Fa	Fb	St 2	St 3	St 4	St 5	St 6	St 7	St 8
1985												
5/14	51	1980	2180	90	54	25			48	57	56	84
5/28	45	3330	2410	56	68	34	39	42	29	45	47	54
6/11	392	1920	1920	106	56	230	106	72	80	118	123	224
6/25	59	1710	3220	72	34	40	37	28	38	77	90	64
7/11	62	1510	1950	108	100	49	46	47	59	137	119	125
7/23	78	1740	2415	64	46	95	65	59	60	52	118	106
8/6	414	1500	1610	89	58	254	408	426	392	358	396	264
8/20	76	1320	1380	96	76	59	56	46	59	66	16	15
9/4	43	1140	970	156	46	34	44	26	34	51	56	73
9/17	38	1730	1530	114	238	37	16	20	28	31	35	49
10/2	29	1960	1770	112	48	20	22	18	14	19	19	34
10/15	44	1790	2100	32	29	30	26	14	12	19	22	76
11/5	12	1280	1180	62	29	15	15	15	16	15	18	18
11/19	273	4010	4330	73	31	256	222	200	222	198	102	276
12/3	42	5180	4270	81	32	60	48	42	46	46	66	36
12/17	31	4380	4870	91	30	45	35	26	29	26	29	25
1986												
1/7	25	4630	3270	72	62	22	21	12	15	16	13	15
1/21	38	3490	2320	31	23	20	21	35	29	20	15	19
2/4	174	6760	15070	48	34	118	48	94	94	96	70	71
2/18	194	3480	3490	84	70	208	268	232	206	73	83	80
3/5	18	4160	4650	42	44	19	17	14	21	15	17	21
3/18	40	5990	7780	64	40	54	77	93	532	140	1510	172
4/1	43	5370	14840	52	30	42	41	31	39	42	83	91
4/15	29	4190	5880	126	92	22	24	26	30	26	44	68
5/12	15	1410	1880	96	56	25	16	12	13	23	32	33
Geo. Mean	55	2620	2930			48	44	40	46	48	55	59
Max.	414	6760	15070	156	238	256	408	426	532	358	1510	276
Min.	12	1140	970	31	23	15	15	12	12	15	13	15
Geo. SD	2.57	1.75	2.03			2.38	2.46	2.61	2.79	2.38	2.98	2.39

Appendix C2. Volatile Suspended Solids (mg/L) in Water Plant Wastewater and in Crooked Creek Water

Date	St 1	C1	C2	Fa	Fb	St 2	St 3	St 4	St 5	St 6	St 7	St 8
1985												
5/14	6	560	600	30	22	5			9	10	9	15
5/28	12	910	680	28	30	12	20	14	13	11	13	17
6/11	30	580	580	42	28	22	16	16	14	14	14	30
6/25	6	570	1120	20	10	4	5	3	5	10	9	5
7/11	17	510	650	52	36	12	11	12	12	23	15	17
7/23	13	575	785	22	16	12	10	11	10	7	14	15
8/6	24	480	560	31	18	26	32	36	28	31	20	12
8/20	12	390	460	40	40	11	8	7	10	12	9	8
9/4	8	400	360	64	20	6	7	8	8	10	12	12
9/17	7	540	480	44	18	8	5	8	8	5	5	12
10/2	9	540	500	31	16	4	6	7	2	5	4	7
10/15	16	570	670	16	12	9	11	6	5	5	4	20
11/5	6	460	410	28	15	8	3	6	6	7	6	2
11/19	33	650	590	24	8	40	32	30	32	28	22	42
12/3	18	980	810	26	13	22	16	16	16	10	14	16
12/17	12	800	880	24	10	14	10	9	12	10	9	8
1986												
1/7	6	920	670	22	21	7	7	6	7	8	7	6
1/21	13	930	640	14	13	9	10	8	9	8	9	10
2/4	14	840	1730	13	8	12	8	8	10	14	10	10
2/18	9	650	650	18	10	8	16	15	14	12	4	5
3/5	7	900	1010	22	22	7	9	8	4	7	6	9
3/18	6	1370	1630	14	8	9	6	7	32		70	8
4/1	8	760	1940	12	4	7	6	7	7	7	14	13
4/15	6	750	1060	34	24	5	8	7	8	11	7	8
5/12	15	610	830	80	56	16	12	12	13	18	15	16
Average	13	690	812	30	19	12	11	11	12	12	13	13
Max.	33	1370	1940	80	56	40	32	36	32	31	70	42
Min.	6	390	360	12	4	4	3	3	2	5	4	2
SD	7.4	226	410			8.2	7.6	7.6	7.9	6.9	12.8	8.4

Appendix C3. Settleable Solids (mg/L) in Water Plant Wastewater and in Crooked Creek Water

Date	St 1	C1	C1	Fa	Fb	St 2	St 3	St 4	St 5	St 6	St 7	St 8
1985												
5/14	0.15	400	410	4.00	0.25	0.05			0.10	0.15	0.15	0.15
5/28	0.12	700	280	0.01	0.03	0.10	0.04	0.08	0.11	0.15	0.15	0.09
6/11	0.40	490	495	7.02	0.02	0.35	0.02	0.01	0.05	0.05	0.05	0.15
6/25	0.04	320	705	0.72	0.02	0.01	0.01	0.01	0.02	0.06	0.08	0.03
7/11	0.21	350	610	8.80	9.50	0.03	0.05	0.08	0.05	0.14	0.10	0.08
7/23	0.05	380	540	2.20	0.12	0.10	0.10	0.05	0.03	0.02	0.05	0.07
8/6	0.70	310	348	6.50	0.20	0.80	0.75	1.00	0.80	0.70	0.85	0.55
8/20	0.05	250	245	11.20	5.00	0.04	0.03	0.05	0.07	0.03	0.01	0.01
9/4	0.02	295	145	16.40	0.20	0.01	0.01	0.01	0.01	0.01	0.01	0.01
9/17	0.03	355	310	7.90	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.01
10/2	tr	390	345	5.20	0.01	0.01	tr	tr	tr	tr	tr	tr
10/15	0.01	340	400	0.04	0.02	tr	tr	tr	tr	tr	tr	0.20
11/5	tr	300	285	0.95	0.05	tr	tr	tr	tr	tr	tr	0.02
11/19	0.15	185	155	0.10	tr	0.12	0.09	0.15	0.15	0.19	0.05	0.03
12/3	tr	305	251	0.02	0.01	tr	tr	tr	tr	tr	0.08	tr
12/17	tr	390	315	0.01	tr	0.01	tr	tr	tr	tr	tr	tr
1986												
1/7	tr	350	255	0.10	0.10	tr	tr	tr	tr	tr	tr	tr
1/21	tr	425	260	tr	tr	tr	tr	0.01	tr	tr	tr	tr
2/4	0.05	205	390	0.05	0.02	0.05	tr	tr	0.01	0.01	0.01	0.02
2/18	0.25	410	395	2.20	0.12	0.45	0.60	0.50	0.45	0.02	0.08	0.01
3/5	tr	345	365	0.02	0.01	tr	tr	tr	tr	tr	tr	tr
3/18	tr	490	780	0.07	0.01	0.02	0.05	0.04	0.52	0.12	1.60	0.09
4/1	tr	320	820	0.20	0.02	0.02	0.05	tr	0.01	tr	0.05	tr
4/15	tr	350	595	6.80	4.00	tr	tr	tr	tr	tr	tr	tr
5/12	tr	520	370	7.10	5.10	tr	tr	tr	tr	tr	tr	tr
Average	0.09	367	403	3.50	0.99	0.09	0.08	0.08	0.10	0.07	0.13	0.06
Max.	0.70	700	820	16.40	9.50	0.80	0.75	1.00	0.80	0.70	1.60	0.55
Min.	tr	185	145	tr	tr	tr	tr	tr	tr	tr	tr	tr
SD	0.16	106	181			0.18	0.19	0.22	0.20	0.14	0.35	0.12

Appendix C4. Dissolved Solids Concentrations (mg/L) in Water Plant Wastewater and in Crooked Creek Water

Date	St 1	C1	C2	Fa	Fb	St 2	St 3	St 4	St 5	St 6	St 7	St 8
1985												
5/14	444	188	196	204	202	420			468	512	466	520
5/28	574	200	200	224	216	578	620	678	574	706	590	606
6/11	270	176	180	220	216	296	304	342	344	320	282	378
6/25	384	240	232	254	252	348	378	376	370	422	402	474
7/11	363	268	244	264	274	350	366	364	390	440	410	476
7/23	436	220	204	254	250	424	456	258	242	230	396	340
8/6	84	240	240	258	248	88	86	92	86	108	148	136
8/20	240	190	196	230	226	232	224	218	222	204	250	290
9/4	376	264	514	290	282	342	320	324	336	346	338	474
9/17	466	262	228	264	226	466	428	478	436	488	482	480
10/2	954	212	226	228	226	678	690	570	524	496	452	508
10/15	514	206	214	234	230	462	520	530	592	750	536	386
11/5	726	194	196	218	216	624	600	800	826	902	454	418
11/19	76	142	136	170	146	92	84	100	104	120	120	72
12/3	350	150	146	170	176	324	274	278	270	290	334	326
12/17	452	184	180	204	206	460	454	450	418	434	404	448
1986												
1/7	964	214	190	240	254	944	780	716	770	1036	930	872
1/21	756	198	190	220	214	730	712	722	758	784	778	778
2/4	148	138	144	178	186	156	146	146	142	122	138	144
2/18	304	166	164	206	206	310	552	560	624	620	436	504
3/5	932	262	268	262	254	878	898	768	800	834	838	397
3/18	436	254	242	260	254	440	418	418	392	190	256	392
4/1	698	234	244	244	242	698	750	746	740	746	726	680
4/15	754	224	218	226	230	702	662	668	696	772	816	792
5/12	712	280	266	306	308	778	722	674	690	694	712	768
Geo. Mean	417	212	218	233	230	405	407	404	405	419	410	411
Max.	964	280	514	306	308	944	898	800	826	1036	930	872
Min.	76	138	136	170	146	88	84	92	86	108	120	72
Geo. SD	1.97	41	71			1.87	1.92	1.87	1.87	1.95	1.74	1.78

Appendix C5. Temperature (°C) in Water Plant Wastewater and in Crooked Creek Water

Date	St 1	C1	C2	Fa	Fb	St 2	St 3	St 4	St 5	St 6	St 7	St 8
1985												
5/14	22.6	22.0	22.0	22.0	22.0	22.6			22.7	23.2	23.0	23.0
5/28	21.5	21.0	21.0	21.5	21.2	22.0	22.0	21.0	22.1	22.0	22.5	22.5
6/11	19.2	23.0	23.0	21.8	23.6	19.2	21.3	21.6	21.6	22.6	22.2	21.6
6/25	24.7	24.4	24.1	24.6	24.5	24.9	25.9	26.5	26.1	25.3	26.1	26.3
7/11	26.0	26.2	26.4	26.4	26.2	27.4	26.9	27.4	27.2	27.2	27.2	27.2
7/23	24.8	27.1	27.1	26.8	26.8	25.1	25.2	26.0	25.4	26.4	26.1	26.0
8/6	23.1	25.9	25.9	26.3	26.4	23.4	23.1	23.1	23.1	23.1	22.7	23.1
8/20	23.1	25.8	26.0	25.2	25.2	24.5	23.1	25.4	23.8	23.9	24.6	23.6
9/4	24.5	26.2	26.1	26.4	26.6	24.4	24.5	24.7	24.7	25.2	25.0	24.8
9/17	21.7	21.7	22.5	22.0	21.9	21.3	22.9	22.5	21.9	21.&	21.6	22.9
10/2	13.1	15.7	16.4	16.9	16.7	15.4	13.3	16.0	13.5	13.9	13.5	13.5
10/15	21.8	17.8	17.6	18.1	18.0	19.1	18.9	18.9	19.8	19.3	18.4	18.2
11/5	9.9	11.6	11.8	12.0	12.1	10.2	10.0	9.8	9.3	9.5	9.1	9.1
11/19	15.9	14.6	14.8	14.4	14.8	16.0	16.4	15.2	15.3	15.2	15.6	16.1
12/3	1.4	5.0	5.0	5.6	5.2	1.4	0.4	1.5	0.6	1.2	1.5	0.9
12/17	0	1.2	1.2	2.1	2.2	0	0	0	0	0	0	0
1986												
1/7	0	3.8	3.6	4.7	5.2	0	0	0	0	0	0	0
1/21	2.4	4.4	4.5	5.3	5.6	3.2	3.5	2.9	3.9	4.1	3.9	4.1
2/4	9.2	6.8	6.8	7.4	7.6	9.2	8.9	8.9	8.8	8.8	8.8	9.1
2/18	2.8	2.8	2.5	4.3	4.8	2.8	3.2	2.7	2.8	3.2	3.2	2.8
3/5	4.8	4.2	4.2	4.9	4.5	4.4	5.2	4.4	5.2	5.2	5.6	5.2
3/18	8.5	9.8	9.8	10.2	10.5	8.8	8.8	9.0	9.1	8.5	9.0	9.0
4/1	16.5	11.8	12.2	13.7	13.9	15.9	15.9	15.9	15.9	15.9	15.9	15.9
4/15	12.2	15.2	15.2	14.0	15.6	12.0	12.2	12.8	12.5	11.2	12.0	12.0
5/12	22.9	22.5	22.6	22.5	22.0	23.5	24.5	24.9	24.0	25.1	24.0	24.0
Average	14.8	15.6	15.7	16.0	16.1	15.0	14.8	15.0	15.1	15.2	15.2	15.1
Max.	26.0	27.1	27.1	26.8	26.8	27.4	26.9	27.4	27.2	27.2	27.2	27.2
Min.	0	1.2	1.2	2.1	2.2	0	0	0	0	0	0	0
SD	9.2	8.9	8.9			9.2	9.4	9.6	9.4	9.5	9.4	9.5

Appendix C6. Dissolved Oxygen Concentrations (mg/L) in Water Plant Wastewater and in Crooked Creek Water

Date	St 1	C1	C2	Fa	Fb	St 2	St 3	St 4	St 5	St 6	St 7	St 8
1985												
5/14	6.75	7.30	9.20	8.60	7.70	6.75			10.55	8.50	8.50	5.90
5/28	6.60	10.80	7.00	10.50	8.41	7.40	7.50	6.50	10.31	9.03	6.32	8.52
6/11	6.10	6.80	6.40	8.90	8.55	5.60	5.40	4.50	5.40	4.70	4.50	4.10
6/25	5.22	6.40	6.45	8.30	8.21	4.65	5.42	6.56	6.60	5.81	4.08	4.00
7/11	6.00	7.60	7.50	9.50	8.80	6.40	7.75	8.10	9.10	5.05	3.95	3.45
7/23	6.05	8.04	6.72	8.53	7.52	5.60	6.11	4.81	5.51	4.32	5.70	4.75
8/6	5.30	6.95	5.65	8.35	7.72	5.45	5.61	5.22	5.51	5.36	5.11	5.28
8/20	4.14	7.32	6.86	8.28	8.50	5.77	4.25	3.35	4.95	3.07	1.75	2.65
9/4	4.05	7.15	7.42	7.97	7.80	4.50	4.55	4.37	5.65	4.90	4.85	4.90
9/17	7.18	8.18	7.78	8.46	8.78	7.98	6.55	7.45	7.65	7.02	8.35	7.68
10/2	10.51	8.70	8.57	9.75	9.48	8.70	6.97	6.62	8.94	7.95	8.95	8.08
10/15	2.90	7.90	7.81	8.91	9.42	4.94	5.77	3.00	3.93	2.46	2.22	0.60
11/5	6.61	9.78	9.95	10.10	10.60	6.60	5.90	5.53	6.35	7.20	8.65	7.60
11/19	10.15	8.65	8.90	10.20	9.90	9.22	8.55	8.00	8.60	7.92	7.55	7.39
12/3	10.70	11.42	11.10	12.25	12.05	11.05	11.35	12.05	11.45	11.15	11.85	11.50
12/17	12.45	11.40	11.65	13.45	13.65	13.05	12.30	12.75	13.12	12.60	12.22	12.00
1986												
1/7	11.30	9.40	8.52	11.90	12.05	11.55	12.05	11.60	12.45	12.05	11.20	11.20
1/21	11.50	10.30	10.65	11.60	11.95	11.80	11.85	11.75	11.80	11.90	11.75	11.80
2/4	9.45	10.60	10.40	11.10	11.10	9.65	9.30	9.50	9.50	9.55	9.20	9.10
2/18	11.55	10.95	10.90	11.90	11.90	11.70	11.75	11.45	11.60	11.90	11.97	11.82
3/5	14.10	11.95	11.30	11.55	12.85	14.50	13.65	13.40	15.25	16.85	15.70	12.32
3/18	10.15	10.70	11.50	11.75	11.75	10.55	10.20	10.00	10.35	10.25	10.05	10.25
4/1	11.90	9.60	9.30	9.70	9.75	11.82	12.50	11.55	12.55	13.00	12.30	10.90
4/15	7.65	8.88	8.22	10.15	8.90	7.70	8.88	11.75	12.30	10.37	8.00	8.00
5/12	5.60	7.25	7.70	7.75	8.15	6.30	5.05	6.25	6.30	7.31	3.72	4.80
Average	8.16	8.96	8.70	9.98	9.82	8.37	8.30	8.17	9.03	8.41	7.94	7.54
Max.	14.10	11.95	11.65	13.45	13.65	14.50	13.65	13.40	15.25	16.85	15.70	12.32
Min.	2.90	6.40	5.65	7.75	7.52	4.50	4.25	3.00	3.93	2.46	1.75	0.60
SD	3.08	1.69	1.81			2.93	2.97	3.26	3.10	3.55	3.65	3.38

Appendix C7. Turbidity (NTU) in Water Plant Wastewater and in Crooked Creek Water

Date	St 1	C1	C2	Fa	Fb	St 2	St 3	St 4	St 5	St 6	St 7	St 8
1985												
5/14	22	564	537	58	48	19			22	34	35	50
5/28	30	116	236	34	46	23	27	28	21	30	33	39
6/11	280	522	514	82	50	206	97	67	76	119	120	192
6/25	44	1040	2130	45	23	36	30	25	30	53	69	72
7/11	42	800	1025	60	60	34	40	40	43	96	87	91
7/23	58	1060	1340	44	30	52	50	53	59	55	79	87
8/6	344	780	840	52	31	350	350	356	352	305	297	238
8/20	86	1030	990	78	58	64	68	56	65	70	23	28
9/4	36	770	710	89	34	26	33	24	28	46	49	67
9/17	26	1500	1200	83	27	20	14	17	22	27	31	46
10/2	18	1650	1380	72	33	16	13	13	11	16	16	34
10/15	31	1610	1780	28	26	24	24	11	12	13	19	85
11/5	17	1080	1010	55	29	22	23	23	23	13	30	25
11/19	364	4840	4500	78	36	360	334	292	297	260	162	396
12/3	100	6530	5460	96	39	117	108	100	98	92	97	84
12/17	48	5700	6220	108	36	60	54	49	50	53	64	57
1986												
1/7	20	5120	3740	74	66	22	16	10	12	13	11	12
1/21	36	3610	2420	32	21	20	16	22	20	20	20	21
2/4	218	8725	19450	51	35	198	168	190	194	218	196	190
2/18	142	4250	4290	108	96	153	162	148	130	70	86	96
3/5	18	4400	4720	32	33	20	18	17	17	15	19	22
3/18	85	6020	8200	53	27	88	98	115	368	190	190	199
4/1	35	6030	14440	56	36	31	33	28	31	34	59	73
4/15	26	4200	5570	118	98	24	20	23	25	23	41	71
5/12	22	1100	1330	84	68	24	20	16	17	27	34	41
Geo. Mean	51	1882	2129			47	45	41	43	49	52	66
Max.	364	8725	19450	118	98	360	350	356	368	305	297	396
Min.	17	116	236	28	21	16	13	10	11	13	11	12
Geo. SD	2.61	2.89	2.99			2.67	2.69	2.79	2.92	2.56	2.39	2.32

Appendix C8. pH Values in Water Plant Wastewater and in Crooked Creek Water

Date	St 1	C1	C2	Fa	Fb	St 2	St 3	St 4	St 5	St 6	St 7	St 8
1985												
5/14	7.70	6.70	6.70	7.40	7.30	7.75			8.00	8.00	7.90	7.70
5/28	7.70	6.92	7.01	7.33	7.55	7.70	8.20	7.90	7.90	7.90	7.60	7.80
6/11	7.60	6.60	6.50	7.20	7.60	7.50	7.20	7.30	7.20	6.60	7.20	7.20
6/25	7.52	6.81	6.91	7.38	7.41	7.48	7.61	7.64	7.73	7.64	7.45	7.58
7/11	7.92	6.97	6.97	7.62	7.43	7.92	7.86	8.08	8.05	7.77	7.51	7.71
7/23	7.83	6.84	6.82	7.44	7.42	7.83	7.75	7.40	7.40	7.31	7.50	7.44
8/6	7.05	6.67	6.69	7.15	7.15	7.05	7.00	6.99	6.99	7.10	7.25	7.25
8/20	7.39	6.92	6.88	7.54	7.45	7.39	7.32	7.35	7.35	7.38	7.35	7.33
9/4	7.43	6.95	6.03	7.33	7.38	7.38	7.43	7.55	7.65	7.62	7.50	7.50
9/17	7.65	7.05	7.10	7.35	7.35	7.65	7.60	7.79	7.80	7.80	7.89	7.89
10/2	7.51	6.90	6.82	7.35	7.38	7.71	7.69	7.62	7.90	7.92	7.72	7.65
10/15	7.59	6.90	6.86	7.56	7.48	7.55	7.66	7.82	7.46	7.72	7.79	7.55
11/5	7.57	6.77	6.92	7.31	7.49	7.68	7.60	7.61	7.65	7.65	7.67	7.53
11/19	7.15	6.21	5.64	6.85	6.80	7.11	6.95	6.88	6.75	6.60	6.85	6.90
12/3	7.48	6.43	6.13	6.97	6.83	7.48	7.67	7.60	7.60	7.45	7.40	7.35
12/17	7.48	6.15	6.25	6.95	6.97	7.45	7.45	7.68	7.70	7.68	7.68	7.68
1986												
1/7	7.52	6.35	6.30	7.30	7.05	7.70	7.72	7.70	7.70	7.70	7.65	7.65
1/21	7.55	6.63	6.25	7.28	6.95	7.55	7.59	7.59	7.59	7.60	7.65	7.70
2/4	7.19	4.80	4.88	6.82	6.62	7.00	7.22	7.22	7.22	7.15	7.10	7.05
2/18	7.43	5.45	5.50	6.80	6.80	7.45	7.63	7.65	7.65	7.65	7.65	7.60
3/5	7.85	6.38	6.33	7.13	7.25	7.79	7.82	7.80	7.95	8.02	8.02	7.65
3/18	7.53	6.62	6.65	7.32	7.35	7.65	7.62	7.60	7.57	7.55	7.30	7.40
4/1	8.22	6.22	6.08	6.98	6.95	7.85	8.17	8.15	8.18	8.32	8.20	7.88
4/15	7.92	6.80	6.58	7.13	7.13	7.80	7.95	8.22	8.40	8.35	7.82	7.80
5/12	7.72	7.10	6.60	7.14	7.18	7.78	7.42	7.55	7.51	6.45	7.58	7.58
Median	7.55	6.70	6.60	7.30	7.30	7.65	7.61	7.61	7.65	7.65	7.60	7.58
Max.	8.22	7.10	7.10	7.62	7.60	7.92	7.70	8.22	8.40	8.35	8.20	7.89
Min.	7.05	4.80	4.88	6.80	6.62	7.00	6.95	6.88	6.75	6.45	6.85	6.90

Appendix C9. Total Alkalinity (mg/L as $CaCO_3$) in Water Plant Wastewater and in Crooked Creek water

Date	St 1	C1	C2	Fa	Fb	St 2	St 3	St 4	St 5	St 6	St 7	St 8
1985												
5/14	123	76	82	50	50	121			123	124	119	133
5/28	162	117	95	61	63	154	145	143	151	162	145	145
6/11	76	78	86	61	60	86	91	86	80	73	71	82
6/25	119	128	132	70	67	98	110	106	103	110	102	121
7/11	105	93	111	72	71	99	105	104	104	105	111	131
7/23	140	110	115	73	73	139	143	87	84	62	105	67
8/6	26	86	93	68	64	26	26	29	27	41	42	43
8/20	83	101	96	78	78	78	75	77	77	76	85	73
9/4	107	84	156	65	66	94	93	93	93	98	107	114
9/17	126	106	91	70	70	114	111	117	114	105	114	127
10/2	160	108	112	65	67	120	149	149	134	121	167	165
10/15	188	92	93	68	64	147	133	120	123	126	127	108
11/5	180	52	88	59	61	157	146	162	158	170	139	131
11/19	30	44	17	33	25	32	29	30	29	36	32	26
12/3	75	58	50	29	28	75	75	74	75	80	78	75
12/17	98	73	81	30	31	95	93	93	92	84	76	76
1986												
1/7	174	95	84	52	48	170	162	161	160	161	154	155
1/21	159	104	86	43	41	159	172	160	158	153	155	145
2/4	33	23	43	19	18	33	33	31	32	29	29	29
2/18	69	67	71	27	25	81	118	115	115	113	79	88
3/5	142	146	134	36	38	139	138	146	133	132	126	129
3/18	93	132	138	44	41	92	88	86	80	80	50	77
4/1	146	108	143	32	31	136	139	140	136	135	128	138
4/15	176	139	147	39	37	165	161	165	167	170	173	173
5/12	142	75	94	53	54	154	146	144	139	139	159	184
Average	117	92	98	52	51	106	112	109	107	107	107	109
Max.	188	146	156	78	78	170	172	165	167	170	173	184
Min.	26	23	17	19	18	26	26	29	27	29	29	26
SD	48	30	33			42	42	42	41	41	42	44

Appendix C10. Sulfate Concentrations (mg/L) in Water Plant Wastewater and in Crooked Creek Water

Date	St 1	C1	C2	Fa	Fb	St 2	St 3	St 4	St 5	St 6	St 7	St 8
1985												
1/14	116	68	65	78	74	107			117	110	103	116
5/28	150	70	69	71	70	140	156	154	148	169	136	138
6/11	84	75	75	83	80	86	83	88	86	77	71	107
6/25	98	70	68	75	71	94	96	95	98	96	94	118
7/11	84	75	76	76	78	78	83	84	83	92	86	105
7/23	91	74	86	80	80	89	101	68	72	22	80	86
8/6	18	82	90	83	84	18	18	18	18	29	32	33
8/20	58	82	82	91	90	64	17	33	41	43	43	29
9/4	116	72	75	87	75	86	111	105	106	99	100	123
9/17	80	58	58	63	67	80	77	70	80	100	72	77
10/2	111	71	74	68	71	97	96	95	95	94	78	99
10/15	106	66	61	68	67	93	86	88	96	84	80	99
11/5	96	64	62	65	62	91	76	81	82	98	87	90
11/19	8	52	50	53	50	13	8	8	21	41	16	5
12/3	78	60	58	58	67	84	81	82	91	103	91	91
12/17	125	66	65	64	59	131	124	111	118	112	94	112
1986												
1/7	216	98	102	106	106	208	206	243	227	236	234	246
1/21	222	72	73	72	80	216	208	218	204	208	195	213
2/4	60	76	89	89	87	58	58	56	55	55	43	56
2/18	94	82	80	88	88	101	164	168	178	184	115	140
3/5	216	82	84	84	82	204	210	210	210	198	193	216
3/18	139	105	110	102	106	132	137	130	126	120	106	129
4/1	202	90	94	90	86	204	205	194	198	192	174	208
4/15	230	97	96	103	97	216	206	194	199	201	213	214
5/12	184	105	105	106	106	190	186	182	167	152	181	189
Geo. Mean	98	75	76			97	92	92	99	99	93	99
Max.	230	105	110	106	106	216	210	243	227	236	234	246
Min.	8	52	50	53	50	13	8	8	18	22	16	5
Geo. SD	2.14	1.20	1.23			1.98	2.33	2.24	1.93	1.87	1.87	2.27

Appendix C11. Total Iron Concentrations (mg/L) in Water Plant Wastewater and in Crooked Creek Water

Date	St 1	C1	C2	Fa	Fb	St 2	St 3	St 4	St 5	St 6	St 7	St 8
1985												
5/14	1.36	51.5	57.0	1.98	1.09	0.82			1.04	1.63	1.74	2.01
5/28	1.38	94.0	59.0	1.27	1.68	1.08	0.97	1.24	0.85	1.46	1.38	1.66
6/11	11.62	44.3	38.4	3.13	1.67	9.02	4.23	2.80	3.42	4.80	5.00	7.49
6/25	1.85	36.9	74.5	1.56	0.87	1.56	1.39	1.03	1.28	2.42	2.99	3.04
7/11	1.73	28.5	39.6	1.75	1.90	1.28	1.46	1.28	1.61	3.52	3.44	3.71
7/23	2.38	21.4	29.6	1.00	0.73	2.05	1.48	1.79	2.01	2.07	2.70	2.85
8/6	9.90	27.0	23.6	1.57	0.81	9.86	8.88	10.00	10.20	8.83	8.99	7.71
8/20	2.56	14.3	17.8	1.36	0.95	1.90	1.82	1.52	1.97	1.72	0.29	0.42
9/4	0.99	7.3	2.6	1.45	0.44	0.73	2.25	0.75	0.80	1.41	1.34	1.85
9/17	0.91	32.6	29.5	2.02	0.60	0.62	0.35	0.42	0.69	0.91	1.15	1.39
10/2	0.47	61.5	34.0	2.05	2.20	0.40	0.35	0.40	0.26	0.45	0.42	1.03
10/15	1.36	42.0	52.0	0.80	0.66	0.93	0.77	0.44	0.50	0.89	0.87	2.80
11/5	1.08	30.0	28.0	1.50	0.86	1.20	1.39	1.33	1.15	0.67	0.82	0.82
11/19	9.43	126.0	113.0	1.92	0.82	8.40	7.64	6.45	7.06	6.65	4.08	8.98
12/3	2.82	165.0	158.0	2.62	0.86	3.11	2.84	2.64	2.66	2.66	2.90	2.43
12/17	1.71	122.0	131.0	2.54	0.75	1.86	1.87	1.62	1.74	1.81	2.07	1.87
1986												
1/7	1.17	72.4	75.2	2.06	1.64	1.16	0.95	0.60	0.70	0.82	0.54	0.52
1/21	1.59	76.7	48.3	0.59	0.45	0.95	0.83	1.17	1.05	1.05	0.79	0.80
2/4	6.92	173.0	419.0	0.92	0.64	6.22	5.10	5.10	5.80	6.22	5.38	5.24
2/18	5.36	102.0	103.0	2.48	2.45	5.83	6.42	5.95	5.48	2.41	3.08	3.08
3/5	0.87	119.0	129.0	0.75	0.83	0.90	0.94	0.75	0.87	0.75	0.67	0.94
3/18	2.79	171.0	220.0	1.58	0.63	2.99	3.23	3.77	13.60	5.92	26.40	6.16
4/1	1.32	190.0	459.0	1.66	1.05	1.29	0.21	1.15	1.32	1.35	2.06	2.60
4/15	1.06	130.0	190.0	3.57	2.91	0.86	0.72	0.70	0.90	0.78	1.46	2.41
5/12	0.49	22.7	20.8	1.56	1.93	0.60	0.46	0.27	0.53	0.79	0.97	1.54
Geo. Mean	1.93	57.0	60.0			1.68	1.48	1.40	1.60	1.77	1.83	2.16
Max.	11.62	190.0	459.0	3.57	2.91	9.86	8.88	10.00	13.60	8.88	26.40	8.98
Min.	0.49	7.3	2.6	0.59	0.44	0.40	0.21	0.27	0.26	0.45	0.29	0.42
Geo. SD	2.41	2.39	3.03			2.49	2.73	2.61	2.70	2.27	2.75	2.27

Appendix C12. Total Aluminum Concentrations (mg/L) in Water Plant Wastewater and in Crooked Creek Water

Date	St 1	C1	C2	Fa	Fb	St 2	St 3	St 4	St 5	St 6	St 7	St 8
1985												
5/14	0.80	224	266	8.30	4.70	0.66			0.66	0.61	0.75	1.60
5/28	1.29	305	226	3.94	4.93	1.08	1.08	1.20	0.96	1.42	1.25	1.63
6/11	14.00	216	210	11.39	11.39	11.40	4.46	3.09	4.10	6.25	6.94	8.82
6/25	1.46	189	393	7.28	3.22	1.25	0.99	0.87	1.16	2.04	2.49	2.84
7/11	1.53	210	263	12.90	12.90	1.25	1.57	1.29	1.37	3.47	3.24	3.39
7/23	1.96	144	187	5.54	3.96	1.75	1.66	1.70	1.88	1.74	2.42	2.87
8/6	8.94	200	166	9.09	5.12	8.00	7.60	9.60	9.30	7.70	7.50	6.40
8/20	2.20	126	128	9.30	6.72	1.56	1.64	1.22	1.54	1.60	0.62	0.76
9/4	1.04	123	109	13.60	3.76	0.96	1.36	0.80	0.88	1.04	1.15	1.60
9/17	0.95	214	148	11.50	3.31	0.85	0.34	0.41	0.58	0.80	0.91	1.50
10/2	0.30	225	180	8.62	3.40	0.40	0.21	0.30	0.17	0.43	0.17	0.91
10/15	0.90	164	202	2.87	2.35	1.15	0.55	0.90	0.30	0.55	0.64	2.94
11/5	0.38	142	133	6.50	2.92	0.81	0.47	0.55	0.47	0.47	0.60	0.78
11/19	9.50	265	227	5.22	2.17	9.36	8.80	8.94	8.22	7.58	5.52	10.20
12/3	2.70	343	327	5.94	2.16	3.67	3.20	2.51	3.33	3.22	3.34	2.31
12/17	1.27	261	287	5.37	1.64	1.70	1.64	1.27	1.35	1.44	2.05	1.64
1986												
1/7	0.45	198	236	5.95	5.01	0.60	0.53	0.19	0.15	0.26	0.19	0.19
1/21	1.17	272	192	2.57	1.57	0.58	0.48	0.37	0.21	0.29	0.37	0.45
2/4	9.04	326	695	7.08	5.25	8.37	6.87	6.29	7.87	7.96	7.37	6.87
2/18	5.55	303	287	10.30	8.71	6.88	7.51	6.66	5.93	2.76	3.44	3.93
3/5	0.45	315	379	2.47	2.88	0.83	0.56	0.49	0.56	0.45	0.60	0.56
3/18	2.98	389	479	4.27	1.84	3.41	3.46	3.79	14.00	5.42	25.60	6.20
4/1	0.97	394	1044	4.40	2.62	1.46	0.26	1.06	1.15	1.15	2.31	3.02
4/15	0.55	316	489	9.30	7.01	0.75	0.46	0.39	0.55	0.39	1.24	2.48
5/12	0.85	151	197	10.58	7.23	0.77	0.48	0.25	0.51	0.66	1.30	1.56
Geo. Mean	1.56	228	255			1.64	1.26	1.19	1.23	1.38	1.61	2.04
Max.	14.00	394	1044	13.60	12.90	11.40	8.80	9.60	14.00	7.96	25.60	10.20
Min.	0.30	123	109	2.47	1.57	0.40	0.21	0.19	0.15	0.26	0.17	0.19
Geo. SD	2.92	1.41	1.71			2.69	3.15	3.15	3.62	2.97	3.34	2.63

Appendix C13. Biochemical Oxygen Demand (mg/L) in Water Plant Wastewater and in Crooked Creek Water

Date	St 1	C1	C2	Fa	Fb	St 2	St 3	St 4	St 5	St 6	St 7	St 8
1985												
7/11	4	37	63	2	4	3	5	7	4	3	3	4
7/23	4	48	52	3	5	4	4	4	3	4	1	3
8/6	6	37	43	2	5	8	5	6	6	7	7	6
8/20	9	28	28	4	6	2	2	2	5	3	4	7
9/4	4	35	25	8	2	2	2	3	3	4	3	5
9/17	2	44	38	3	1	7	1	3	2	2	1	3
10/2	4	31	32	2	2	1	2	2	1	2	1	3
10/15	12	39	43	2	1	6	7	4	3	4	4	10
11/5	7	16	17	2	1	4	6	6	6	5	5	4
11/19	5	13	8	2	1	2	4	4	3	3	2	4
12/3	3	12	13	1	2	3	4	4	3	2	2	2
12/17	1	12	14	2	2	1	2	2	2	2	2	3
1986												
1/7	2	8	6	1	1	2	2	2	3	2	2	2
1/21	3	59	44	1	1	3	2	3	3	3	3	5
2/4	2	6	11	1	1	2	1	1	1	1	1	1
2/18	5	10	9	1	<1	4	4	4	4	4	3	6
3/5	3	10	12	2	1	2	3	3	3	3	3	6
3/18	4	>38	>40	4	1	4	4	4	5	5	9	6
4/1	7	20	35	2	2	5	6	6	6	6	7	9
4/15	5	33	44	2	3	4	5	6	7	6	4	7
5/12	3	55	68	7	3	3	3	4	3	2	3	5
Average	5	28	31	3	2	3	4	4	4	3	3	5
Max.	12	59	68	8	6	8	7	7	7	7	9	10
Min.	1	6	6	1	<1	1	1	1	1	1	1	1
SD	2.58	16	19			1.86	1.72	1.63	1.66	1.60	2.15	2.29

Appendix C14. Fecal Coliform Densities (FC/100 mL) in Water Plant Wastewater and in Crooked Creek Water

Date	St 1	C1	C1	Fa	Fb	St 2	St 3	St 4	St 5	St 6	St 7	St 8
1985												
10/15	320	0	16	70	120		65	110	63	160	210	13000
1.1/5	480	3	33	73	59	280	180	250	240	130	88	250
11/19	6200	9	5	8	3	4100	3400	3500	3700	3200	2400	10000
12/3	1600	0	0	0	0	1800	1500	1500	1300	820	470	800
12/17	25	0	0	0	0	65	120	140	180	750	210	160
1986												
1/7	10	0	0	0	0	9	9	0	5	4	8	13
1/21	16	0	0	0	0	17	0	18	7	10	110	14
2/4	1000	0	0	0	0	720	480	700	690	560	630	600
2/18	450	0	0	0	0	440	780	620	120	510	430	380
3/5	20	0	0	0	0	0	10	16	0	0	120	0
3/18	140	0	0	0	0	65	200	270	510	210	1300	210
4/1	52	0	0	0	0	44	30	25	25	23	55	42
4/15	220	0	0	0	0	210	79	32	32	49	60	93
5/12	110	1	0	0	0	110	33	240	160	150	200	190
Geo. Mean	160	3	14			160	130	170	130	150	190	260
Max.	6200	9	33	73	120	4100	3400	3500	3700	3200	2400	13000
Min.	10	0	0	0	0	0	0	0	0	0	8	0
Geo. SD	6.70	3.00	2.59			6.22	6.25	5.57	7.09	6.70	4.23	8.18

Note: Fa indicates the filter with the lower identification number, and Fb indicates the filter with the higher identification number (see table 7).

Appendix D. Chemical Characteristics and Particle Size Distribution of Bottom Sediments

Date	Station	Al, mg/kg	Fe, mg/kg	% Moisture	% Volatile	Particle Size Distribution, % Gravel	Sand	Silt	Clay
5/14/85	1					1.3	50.0	41.3	7.4
	2					20.7	14.0	58.9	6.4
	5					73.6	23.6	2.8	0.0
	6					7.0	48.3	36.2	8.5
	7					7.1	39.7	41.1	12.1
	8					4.0	8.0	68.9	19.1
5/28/85	3					71.9	24.2	2.8	1.1
	4					61.5	36.7	1.4	0.4
6/11/85	1	7640	12000	28.4	2.6	4.8	27.6	49.4	18.2
	2	11800	15000	45.7	4.2	23.3	16.0	44.0	16.7
	3	9260	29000	18.1	3.1	37.6	33.2	20.3	8.9
	4	3460	11200	27.8	8.1	27.4	63.7	7.2	1.7
	5	3920	17200	17.4	3.0	71.3	26.0	1.6	1.1
	6	7990	19500	34.6	5.4	3.0	49.0	38.4	9.1
	7	9260	18200	36.1	5.3	54.8	18.0	20.4	6.8
	8	8530	18000	61.5	4.3	4.5	10.0	64.7	20.8
7/11/85	1	6170	10600	25.9	2.6	0.9	26.9	51.9	20.3
	2	15800	16200	64.9	6.9	3.4	4.9	76.9	14.8
	3	8410	30000	18.8	2.3	48.9	33.8.	12.8	4.5
	4	2650	7900	36.4	13.4	25.6	66.2	5.4	2.8
	5	3680	9500	17.2	4.0	49.1	41.5	7.1	2.3
	6	6740	14100	37.8	6.3	18.6	55.3	23.4	2.8
	7	7080	15000	43.3	7.6	2.0	38.4	45.0	14.6
	8	8810	14100	38.1	3.2	8.1	5.2	64.0	22.7
8/6/85	1	7520	13300	26.9	2.6	3.1	34.3	52.0	10.6
	2	16800	18500	60.3	5.7	0.4	2.7	72.9	24.0
	6	4750	12900	22.5	3.5	4.0	70.4	19.5	6.1
	8	9000	12400	36.9	3.7	9.7	5.1	65.3	19.9

Appendix D. Concluded

Date	Station	Al, mg/kg	Fe, mg/kg	% Moisture	% Volatile	Particle size distribution, % Gravel	Sand	Silt	Clay
8/20/85	3	9000	22400	21.3	3.4	40.9	44.3	10.6	4.2
	4	3560	10300	24.5	7.0	16.6	77.9	3.5	2.0
	5	4810	10800	17.5	3.3	33.1	57.8	6.6	2.5
	7	8380	14500	38.9	6.2	4.3	48.8	35.9	11.0
9/4/85	1	5560	8350	24.6	2.5	2.1	37.8	45.0	15.1
	2	24600	19500	67.8	6.8	0.5	3.3	75.5	20.7
	3	9200	20800	21.0	4.2	62.1	22.4	11.8	3.7
	4	3040	7600	22.4	3.8	5.1	57.4	28.2	9.3
	5	2640	10500	22.3	6.0	38.8	58.9	1.7	0.6
	6	5200	14600	22.7	2.1	3.0	72.2	18.9	5.9
	7	9240	13600	38.6	6.5	24.2	47.6	21.2	7.0
	8	11500	14700	40.5	3.9	2.3	26.7	51.0	20.0
10/2/85	1	7170	9750	26.5	2.4	0.9	34.0	49.7	15.4
	2	20000	20300	61.9	6.6	0.5	2.9	66.6	30.0
	3	3270	10000	19.2	3.7	51.8	44.1	3.0	1.1
	4	3180	7300	28.7	6.3	7.6	86.0	4.2	2.2
	5	4060	13800	20.8	3.1	36.8	59.2	2.8	1.2
	6	5560	10900	32.5	4.3	10.7	52.0	28.1	9.1
	7	7860	11800	36.5	4.6	17.7	25.0	47.1	10.1
	8	9260	12400	40.9	4.0	3.2	5.6	72.4	18.8
5/12/86	1	7390	13770	28.4	3.1	7.8	74.6	14.0	3.7
	2	6260	9290	44.3	3.1	4.5	71.3	21.3	3.0
	3	7820	38630	20.2	3.1	61.5	36.7	1.4	0.4
	4	4730	19810	31.6	4.4	8.4	89.3	1.8	0.4
	5	4680	86290	20.2	1.7	71.9	25.5	2.2	0.4
	6	5060	12650	30.4	2.4	43.3	48.5	7.1	1.1
	7	10740	13550	52.5	7.5	8.1	64.5	21.1	6.3
	8	9000	13930	36.2	3.8	2.6	20.2	58.6	18.6

Appendix E. Benthic Macroinvertebrates in Crooked Creek bottom sediments
(number of organisms per square meter)

Date/ Macroinvertebrates	Tolerance value	Station 1	2	3	4	5	6	7	8	No. of Stations occurred
5/11/85										
Corbicula	4			14	14	72				3
Perlesta placida	4					29				1
Stenonema	4					14				1
Cambaridae	5								14	1
Hexagenia limbata	5		29					14		2
Sphaerium	5	14			29					2
Caenis	6				29	14	14	14	14	5
Cheumatopsyche	6				57	144		14		3
Chironomidae	6	258	617	57	1234	445	72	215	115	8
Asellus	7				43					1
Ceratopogonidae	7	14						29	14	3
Stenelmis	7			29		100				2
Chaoborus	8		29							1
Tubificidae	10	57				29	14		273	4
Number of organisms		343	675	100	1406	847	100	286	430	
Number of taxa		4	3	3	6	8	3	5	5	
MBI		6.7	6.0	6.0	6.0	6.0	6.6	6.1	8.5	
6/11/85										
Stenonema	4	29						72		2
Cambaridae	5			29						1
Hexagenia limbata	5		14	14			57		57	4
Sphaerium	5	14								1
Caenis	6	14			14			29		3
Cheumatopsyche	6	14		57		43			43	4
Chironomidae	6	459	172	1177	1679	100	416	402	703	8
Asellus	7					14				1
Ceratopogonidae	7						14			1
Stenelmis	7			115	14	158				3
Tubificidae	10						29	86	273	3
Number of organisms		530	186	1392	1707	315	516	589	1076	
Number of taxa		5	2	5	3	4	4	4	4	
MBI		5.9	5.9	6.1	6.0	6.5	6.1	6.3	7.0	

Appendix E. Continued

Date/ Macroinvertebrate	Tolerance value	Station 1	2	3	4	5	6	7	8	No. of Stations occurred
7/11/85										
Psychomyiid Genus A	2							14		1
Corbicula	4					57				1
Stenonema	4					14		244		2
Hexagenia limbata	5	14								1
Hyalella	5			14						1
Sphaerium	5	14								1
Branchiura sowerbyi	6							14		1
Caenis	6			14	14	14		646		4
Cheumatopsyche	6			14		172		789		3
Chironomidae	6	43	43	273	761	201	273	474	43	8
Ischnura	6							43		1
Asellus	7					14		144	14	3
Stenelmis	7			144		316		43		3
Chaoborus	8		29							1
Tubificidae	10	72	14	14	43		14		230	6
Number of organisms		143	86	473	818	788	287	2411	287	
Number of taxa		4	3	6	3	7	2	9	3	
MBI		7.8	7.3	6.4	6.2	6.2	6.2	5.9	9.3	
8/6/85										
Centroptilum	2		14							1
Corbicula	4					244				1
Stenonema	4					14				1
Sphaerium	5						14			1
Branchiura sowerbyi	6					14		43		2
Chironomidae	6	43	29	100	129	57	129	115	230	8
Stenelmis	7				14	144				2
Chaoborus	8						14			1
Tubificidae	10	57	57	86			43	57	100	6
Number of organisms		100	100	186	143	473	200	215	330	
Number of taxa		2	3	2	2	5	4	3	2	
MBI		8.3	7.7	7.8	6.1	5.2	6.9	7.1	7.2	

Appendix E. Continued

Date/ Macroinvertebrate	Tolerance value	Station 1	2	3	4	5	6	7	8	No. of Stations occurred
9/4/85										
<u>Psychomyiid Genus</u> A	2	14								1
<u>Corbicula</u>	4			14		115				2
<u>Sialis</u>	4							14		1
<u>Stenonema</u>	4	43								1
<u>Hexagenia limbata</u>	5	14								1
<u>Sphaerium</u>	5	43				14				2
<u>Branchiura sowerbyi</u>	6	43				14	14	29	14	5
<u>Caenis</u>	6	14								1
<u>Cheumatopsyche</u>	6						14			1
Chironomidae	6	847	29	43	431	29	43		115	7
<u>Stenelmis</u>	7	29		14	29	72	43			5
Tubificidae	10	201	29	14	57		115	43	976	7
Number of organisms		1248	58	85	517	244	229	86	1105	
Number of taxa		9	2	4	3	5	5	3	3	
MBI		6.5	8.0	6.5	6.5	5.3	8.2	7.7	9.5	
10/2/85										
<u>Centroptilum</u>	2					14				1
<u>Psychomyiid Genus</u> A	2						14			1
<u>Anodonta grandis</u>	3				14					1
<u>Corbicula</u>	4					43				1
<u>Dubiraphia</u>	5				14					1
<u>Hexagenia limbata</u>	5	43					14			2
<u>Branchiura sowerbyi</u>	6	14				14		14		3
<u>Caenis</u>	6			43		14				2
<u>Cheumatopsyche</u>	6					14				1
Chironomidae	6	187	14	445	1033	1033	158	14	14	8
Ceratopogonidae	7							14		1
<u>Stenelmis</u>	7			29		57				2
<u>Chaoborus</u>	8		29							1
Tubificidae	10	230	43	29	14	43	43	675	2052	8
Number of organisms		474	86	546	1075	1232	229	717	2066	
Number of taxa		4	3	4	4	8	4	4	2	
MBI		7.9	8.7	6.3	6.0	6.1	6.4	9.8	10.0	

Appendix E. Concluded

Date/ Macroinvertebrate	Tolerance value	Station 1	2	3	4	5	6	7	8	No. of Stations occurred
5/12/86										
<u>Corbicula</u>	4					14				1
<u>Perlesta placida</u>	4			14						1
Cambaridae	5			14		14		57	14	4
<u>Sphaerium</u>	5							14		1
<u>Branchiura sowerbyi</u>	6							43	14	2
<u>Caenis</u>	6					14				1
Chironomidae	6	201	459	876	1148	588	990	1593	258	8
Ceratopogonidae	7							43		1
<u>Stenelmis</u>	7			172	14	273	14	14		5
<u>Chaoborus</u>	8								14	1
Tubificidae	10		29				14	72	459	4
Number of organisms		201	488	1076	1162	903	1018	1836	759	
Number of taxa		1	2	4	2	5	3	7	5	
MBI		6.0	6.2	6.1	6.0	6.3	6.1	6.1	8.4	