ENVIRONMENTAL PROTECTION AGENCY

OFFICE OF ENFORCEMENT

REPORT ON

EFFECTS OF WASTE DISCHARGES ON WATER QUALITY OF THE SOUTH PLATTE RIVER DENVER METROPOLITAN AREA

NATIONAL FIELD INVESTIGATIONS CENTER-DENVER

AND

REGION VIII DENVER, COLORADO

JUNE 1972

CLEAN WATER

ENVIRONMENTAL PROTECTION AGENCY
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National Field Investigations Center-Denver
and
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Denver, Colorado

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GLOSSARY OF TERMS

BOD - Biochemical Oxygen Demand, 5-Day

COD - Chemical Oxygen Demand

DO - Dissolved Oxygen

MPN - Most Probable Number

NH_3N - Ammonia Nitrogen

NO_2-NO_3-N - Nitrite Nitrate Nitrogen

p - Phosphorus

PO_4 - Orthophosphate

TOC - Total Organic Carbon

TSS - Total Suspended Solids

VSS - Volatile Suspended Solids

cfs - flow rate given in cubic feet per second

gpm - flow rate given in gallons per minute

mgd - flow rate given in million gallons per day

mg/l - concentration given in milligrams per liter

μmhos/cm - unit of specific conductance (mho -- the inverse of the standard unit of electrical resistance, the ohm) measured over a 1-centimeter distance, conventionally made at 25°C

RM - river mileage

I. INTRODUCTION

Water quality investigations were conducted in the South Platte River Basin during August-December, 1971. Studies included an evaluation of the waste-treatment practices at the Metropolitan Denver Sewage Disposal District Plant #1 (Metro), the North Denver Wastewater Treatment Plant (Denver Northside), and other satellite plants [Figure 1]. Subsequently, stream surveys were conducted on the South Platte River (SPR) to determine the impact of waste loads on water quality. The primary objectives of the survey were to:

1. Determine if established State and Federal water quality standards [Appendix A] were being met.
2. Ascertain if adequate treatment were provided in accordance with established treatment requirements.
3. Determine the extent of water quality improvement in the South Platte River Basin since the 1966 State-Federal Enforcement Conference.[1/]
4. Recommend water quality improvement measures.

The in-plant survey was conducted at Metro during August 1-9, 1971, to measure the waste removal efficiency and waste loads discharged. Effluent from the Denver Northside Plant constitutes the major portion of flows received at Metro.

This report will discuss the results of the in-plant evaluations and the subsequent stream surveys in relation to the aforementioned objectives.

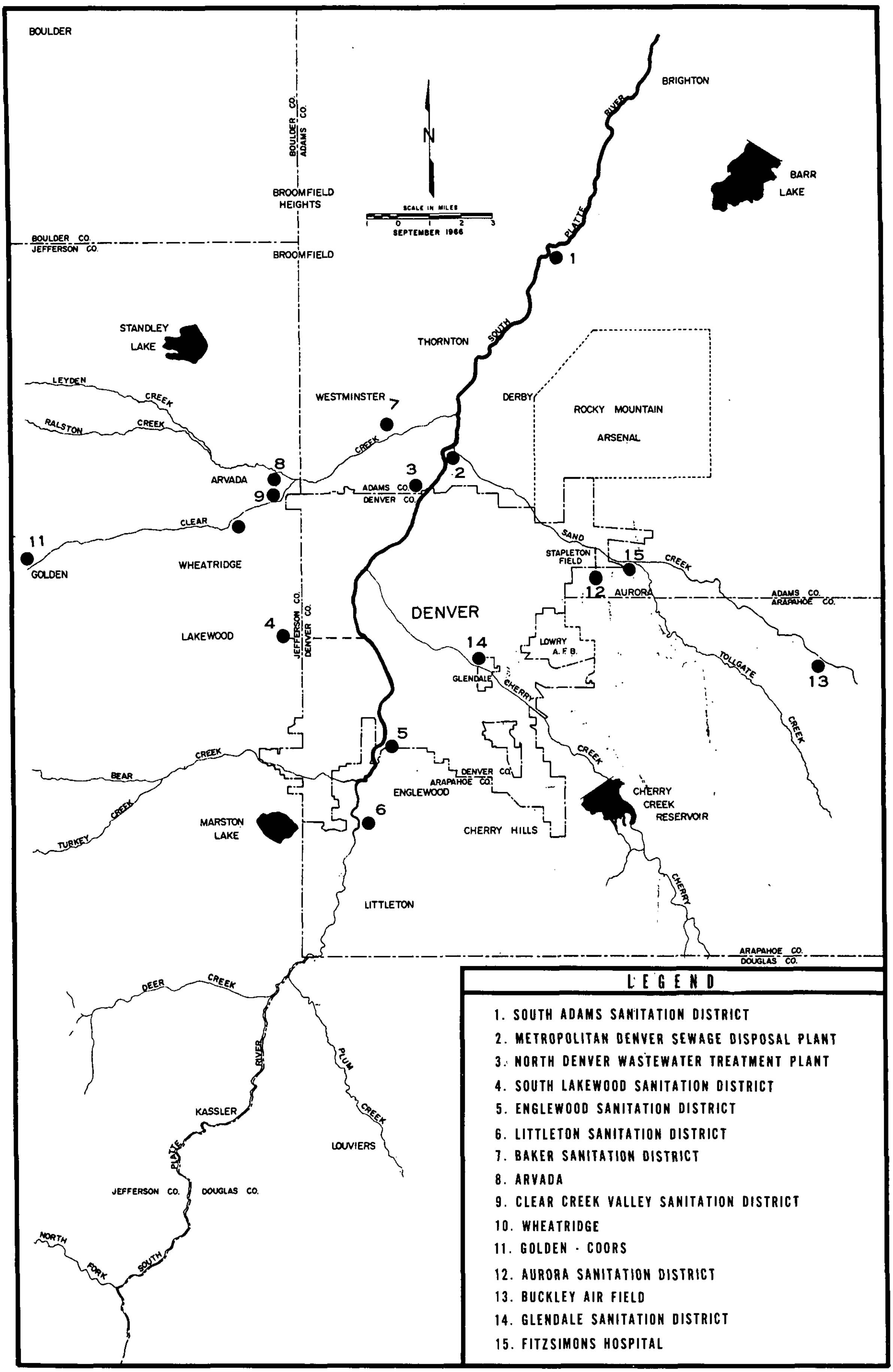


Figure 1. Municipal Wastewater Treatment Facilities Metropolitan Denver Area

II. SUMMARY AND CONCLUSIONS

1. The Denver Northside Sewage Treatment Plant had BOD removal efficiencies ranging from minus 11 percent (increase in BOD) to 58 percent and suspended solids removal efficiencies ranging from 6 percent to 96 percent. Plant records for a 6-month period, from January to June 1971, showed average removals between 22 and 36 percent for BOD and 39 and 60 percent for suspended solids. Bypassing from an interceptor connected to the Denver Northside plant was evidenced by sludge banks in the South Platte River downstream from Franklin Street. Inadequate primary treatment at Denver Northside significantly affects removal efficencies at the Metropolitan Denver Disposal District Plant #1 facility. The Colorado Department of Health and EPA are working with the staff at the Denver Northside waste treatment plant to improve treatment methods at this plant, thereby reducing the wasteload contributed to the Denver Metro facility.

2. The Metro plant is overloaded hydraulically and organically. The plant is designed for 117 mgd. Peak flows of 180 mgd were recorded during the survey. The average BOD loading observed (182,000 lb/day) was 110 percent of the design loading. Four of the twelve aeration basins are being used for sludge digestion instead of for their intended use.

3. Adequate treatment was not being provided by the Metro plant for BOD and suspended solids removal resulting in the average discharge of approximately 30,200 lb/day of BOD and 119,000 lb/day of suspended solids to the South Platte River. Including removals at the Northside plant, BOD removals for Denver Metro ranged from 63 percent to 96 percent on a daily average and were below the State requirement of 80 percent BOD

removal 20 percent of the time. Suspended solids removal ranged between 39 and 95 percent. Removals were highest during the weekend when the overloading conditions were minimal. Moreover, adequate disinfection was not provided, as shown by the low chlorine residuals and the high bacteria concentrations in the effluent. Fecal coliform bacteria in the effluent ranged from 230-430,000 organisms/100 ml. The Colorado Department of Health recommendation for a residual chlorine value of 1 mg/l after 15 minutes at maximum hourly flow was not maintained during the study.

4. Scouring velocities occurred in the final clarifiers at the Metro plant during peak flows owing to the hydraulic overload and to the inadequate placement of the weirs. The lack of skimmers on the final clarifiers resulted in floating solids being discharged into the receiving waters.

5. Thirteen other, small treatment plants treat less than 15 percent of the liquid waste in the Metro area. Of these, nine plants were evaluated:

South Adams Sanitation District
South Lakewood Sanitation District
Englewood Sanitation District
Littleton Sanitation District
Baker Sanitation District
Arvada
Clear Creek Valley Sanitation District
Wheatridge
Coors-Golden

Of these, the Clear Creek Valley Sanitation District and Arvada were the only facilities meeting the present State requirement of a minimum 80 percent BOD removal.

6. Sludge-handling capacity at Metro continues to be a problem; its inadequacy affects plant performance by causing an effluent high in suspended solids.

7. Mercury discharges vary from 0.2 to 0.9 lb/day. The majority of the mercury comes from unknown sources discharging to the Denver Northside wastewater treatment facility.

8. Minor changes in concentrations of ammonia and the sum of nitrate and nitrite concentrations occur during treatment by Denver Northside and Metro, indicating no significant reductions in total nitrogen through the treatment process. Total phosphorus is reduced approximately 28 percent. The total nitrogen and phosphate loads discharged to the South Platte River, during the survey, averaged 20,000 and 7,000 lb/day, respectively. Removal of nitrogen and phosphorus at existing and proposed treatment facilities may be necessary in the future to protect the water quality of the South Platte River.

9. Raw sewage discharges were observed at 47th Avenue and at Franklin Street. The Franklin Street discharge was corrected in September 1971. The 47th Avenue sewer continues to discharge raw sewage occasionally. Facilities to abate the 47th Avenue discharge are under construction, to be completed by December 31, 1972.

10. However, attainment of a consistent minimum 5-day BOD removal of 80 percent at the Metro plant will not meet official State-Federal

water quality standards for the South Platte River. To meet water quality criteria for dissolved oxygen in the South Platte River the present effluent from the Metro facility should not exceed an average of 10,000 lb/day with a maximum instantaneous limit equivalent to 15,000 lb/day of 5-day BOD. This average limit is equivalent to an effluent concentration of 10 mg/l of BOD and would require an estimated 95 percent BOD reduction based on present influent values.

11. Since the studies conducted by the South Platte River Project in 1964-65 there has been some improvement of water quality conditions in the South Platte River. Lowering of BOD and coliform concentrations and the increase in DO levels is due mainly to the construction and operation of the Metropolitan Denver Disposal District Plant #1.

12. Violation of the bacterial standard occurred in the South Platte River at York Street. *Salmonella* were isolated in the main stem, South Platte River, and Burlington Ditch, indicating fecal contamination in the River.

13. The South Platte River quality, upstream of the Metro effluent, would be improved if all necessary upstream abatement measures were accomplished (e.g., elimination of bypassing and upgrading of upstream treatment facilities).

III. WASTE SOURCE EVALUATIONS

A. NORTH DENVER WASTEWATER TREATMENT PLANT

General

The North Denver plant is a primary wastewater treatment facility with a design capacity of 120 mgd. The plant was constructed in 1936, with additional clarifiers being constructed in 1946 and 1965. Effluent and digested sludge from this facility are piped separately to the Metro plant for additional treatment.

This plant is staffed with a superintendent, an operations foreman, and 30 operators. Some of these operators have Class "C" and "D" Operator's Licenses.* A laboratory staff of eight chemists monitors treatment efficiency within the plant. Samples from approximately 80 industrial wastewaters discharged to the Northside plant are analyzed, and the results are used as a basis for determining customer charges. According to plant officials, 130 industries discharge waste to the North Denver plant. Wastewater samples collected by the Denver County Health Department are also analyzed in this laboratory.

Wastewater Treatment Facilities

The operation of the Northside plant has changed since it was evaluated during the South Platte River Basin Project Studies;[2/] the effluent now is pumped to the Metro plant for further treatment instead of being chlorinated and discharged to the South Platte River. [The flow diagram

* The State of Colorado has a Volunteer Certification Program for Wastewater Treatment Operators, Class "A" being the highest and a Class "D" the lowest level of certification. There are no operators with Class "A" or Class "B" certification at Northside.

for this facility is shown in Figure 2.] The Northside flow constitutes about 75 percent of the total flow to Metro. The principal components of the system are as follows:

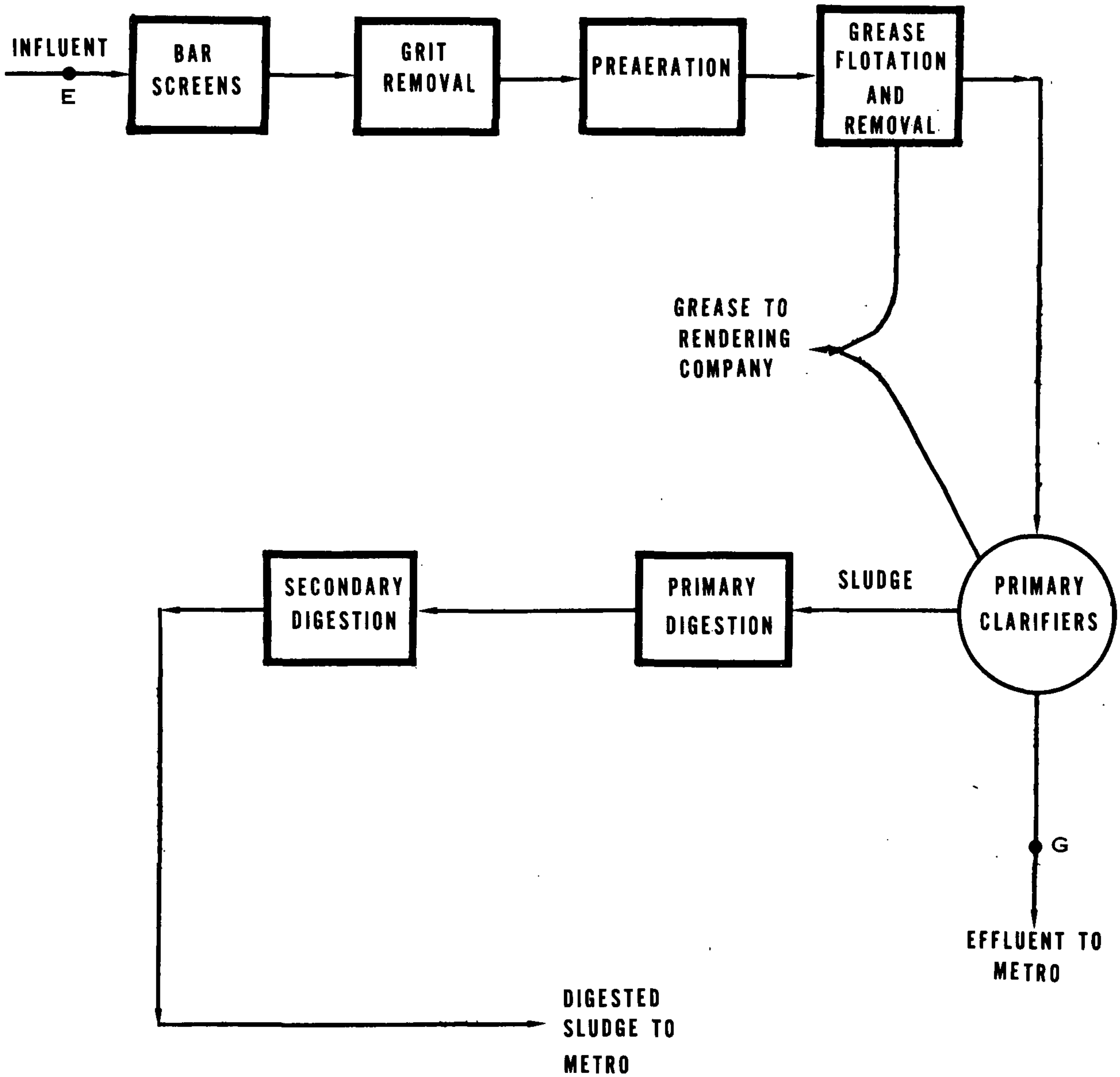
1. Preliminary treatment - bar screens, grit chambers (5), pre-aeration basins (3), grease flotation and removal.
2. Primary clarifiers (8) - 150 feet in diameter and 14 feet deep with skimming arm to remove floating materials.
3. Digesters (heated) - 6 primary, 2 secondary; each 85 feet in diameter and 30 feet deep.

As indicated above, sludge is pumped to the Metro plant for further treatment (i.e., secondary digestion). Denver Northside plant officials claim that a volatile solids reduction of 65 percent is obtained in the digestion process.

Discussion of In-Plant Survey and Findings

The North Denver wastewater treatment plant was evaluated during the period from August 1 to 9, 1971. Influent samples were collected upstream of the point of supernatant return [Figure 2-Station E]. Effluent samples from the Northside plant were collected at the point where the wastewater enters Metro plant [Figure 2-Station G]. All samples were analyzed at the NFIC-D laboratory for BOD, COD, TOC, and solids (total, suspended, volatile suspended, and settleable). Nutrients were determined for the influent samples only. Influent samples were also analyzed for selected heavy metals in order to ascertain if concentrations were at levels which could affect biological processes.

As previously stated, 130 industries discharge wastewater to the



LEGEND

STATION	DESCRIPTION
E	DENVER NORTHSIDE INFLUENT
G	DENVER NORTHSIDE PRIMARY (SAMPLED AT DENVER METRO PLANT)

Figure 2. Flow Diagram North Denver Wastewater Treatment Plant.

North Denver plant (estimated at 8-10 percent of the total flow), which was designed for peak flows of 120 mgd; if exceeded, the excess is by-passed to the South Platte River. Although no by-passing was observed at the plant during the survey, an interceptor carrying wastewater to the Denver Northside plant was observed to be overflowing to the South Platte River at Franklin Street. Although the total flow by-passed could not be ascertained, it was evident from the sludge bank in the river that the interceptor had been overflowing for a prolonged period. Another raw sewage discharge was observed at 47th Avenue.* An official of the City and County of Denver stated that the latter by-pass results from overloading of the Broadway sewer. The amount of by-passed flow was not available from the official. It was reported that a faulty valve was causing this condition and that it was corrected during September 1971. A contract has been let to install additional interceptor capacity by December 31, 1972. This new interceptor should eliminate the by-passing of raw sewage to the South Platte River at 47th Avenue.

Analyses of influent and effluent data for this plant indicate BOD and suspended solids removal ranges of -11 to 58 percent and 6 to 96 percent, respectively** [Table 1]. A review of plant records for the period January 1-June 30, 1971, shows that monthly removal efficiencies averaged between 22 and 36 percent for BOD, and between 39 and 60 percent for suspended solids [Table 2]. Concentrations of heavy

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* This discharge was observed and sampled in 1966 by the South Platte River Basin Project. The raw sewage was being discharged to the South Platte River.3/

** The negative BOD removal is attributed to carryover of solids from the primary clarifiers.

TABLE 1

SUMMARY OF ANALYTICAL RESULTS AND FIELD MEASUREMENTS FOR THE DENVER NORTHSIDE WASTEWATER TREATMENT PLANT
August 1-9, 1971

Parameter	Value		Percent
	Influent	Effluent	Reduction (Range)
Flow (MGD)[a/]		76.7-92.5	
pH	7.2-8.8		
Temperature (°C)	18-24		
Conductivity (μmhos)	1000-1500		
Biochemical Oxygen Demand (BOD)(mg/l)	180-430	105-310	(11)[b/]-58
Suspended Solids (mg/l)	320-1240	30-300	6-96
Volatile Suspended Solids (mg/l)	240-1200	30-160	67-96
Settleable Solids (mg/l)	3.5-5.0	0.2-0.7	86-90
Chemical Oxygen Demand (COD)(mg/l)	590-1800	160-270	73-85

a/ Flow measured at Metro plant. Northside effluent samples collected at Metro (Station G-Figure 3). Flow recording equipment at Denver Northside not considered accurate.

b/ The numbers in parentheses are negative numbers.

TABLE 2

MONTHLY AVERAGES OF BIOCHEMICAL OXYGEN DEMAND AND SUSPENDED SOLIDS REMOVALS AT THE NORTH DENVER WASTEWATER TREATMENT PLANT FOR 1971[a]

Month[b]	Percent BOD Removal	Percent Suspended Solids Removal
January	35	60
February	36	55
March	25	44
April	23	39
May	32	53
June	22	60

a/ Efficiencies were calculated on the basis of data provided by Northside officials.

b/ Supernatant was returned upstream of the pre-aeration chambers. January-April and returned upstream of the bar screens May-June [Figure 2].

metals were low and would not affect biological treatment processes. Plant officials do not know the source of these heavy metals.

B. METROPOLITAN DENVER SEWAGE DISPOSAL PLANT

General

The Metropolitan Denver Sewage Disposal District encompasses most of the communities in the Denver area. The District includes:

Alameda Sanitation District

Applewood Sanitation District

City of Arvada

City of Aurora

Baker Water and Sanitation District

Bancroft Sanitation District

Berkeley Sanitation District

City and County of Denver

East Lakewood Sanitation District

Fruitdale Sanitation District

Highland Park Sanitation District

North Pecos Sanitation District

North Table Mountain Sanitation District

North Washington Street Sanitation District

Northwest Lakewood Sanitation District

Pleasant View Sanitation District

City of Thornton

Westminster Sanitation District

Westridge Sanitation District

Wheatridge Sanitation District

Wastewaters from these component municipalities and sanitation districts are treated by the Metro plant.* The Metro plant is a secondary treatment facility that began operation in May 1966. It has a primary and secondary treatment design capacity of 27 and 117 mgd, respectively. The design BOD load is 166,350 lb/day. The estimated population served by this plant is 870,000.

The operating staff includes nine shift supervisors (9 with Class "A" certification) and 40 operators (most have Class "C" and "D" certifications). In addition, the laboratory has 12 employees (chemists, microbiologists, and technicians) to collect and analyze in-plant and stream samples. (Four of these have Class "A" certification.)

Primary treated effluent from the Denver Northside plant comprises about 75 percent of the average daily flow received. Raw municipal wastes are received from the Sand Creek and Clear Creek interceptors. Industrial wastes (less than one percent of the total flow) are received directly from the Packaging Corporation of America.

A portion of waste flows from three satellite treatment facilities (Arvada, Wheatridge, and Baker Water and Sanitation District) is diverted to Metro also [Figure 1]. The average waste flow treated and the average waste flow diverted at each of these plants during the evaluation period is shown in Table 3. Cost of treatment for these satellite plants and for Clear Creek Valley Sanitation District is also shown. During in-plant evaluations, Baker Sanitation District and Wheatridge were not meeting the State requirements for 80-percent BOD removal.

* Some of the wastewaters receive primary treatment prior to being discharged to the Metro plant.

TABLE 3

WASTE TREATMENT FLOWS AND COSTS AT SELECTED PLANTS

Map Key[a]	Name of Plant	River Mile	Design Capacity mgd	Flow Observed mgd[b]	Flow Diverted to Denver mgd	Cost of Treatment[d] $/mil gal	Metro Cost of Treating[e] $/mil gal
7	Baker Water & San. District	305.5/3.0	1.0	0.9	0.8	63	155[f]
9	Clear Creek San. District	305.5/7.0	2.2	2.48[c]	None[j]	185	123-192[g]
8	Arvada	305.5/6.2/0.3	1.2	1.09	3.5	102	173[h]
10	Wheatridge	305.5/7.5	1.75	2.2	0.03[i]	168	123-192[g]

a/ See Figure 1 for location.
b/ Treated flow observed during plant evaluation.
c/ Receives waste from Sigman Meat Company.
d/ Based on design flows and annual operation cost figures provided by plant officials.
e/ Metro officials estimate the charge to customers for each million gallons delivered as $112/mil gal. The exact charge is based on $53/mil gal flow, $46/ton BOD, and $40/ton suspended solids.
f/ Based on annual cost figures of $45,000 provided by plant officials and assuming 0.8 mgd diverted to Metro.
g/ Based on influent BOD and suspended solids concentrations of 200-350.
h/ Based on annual cost figures of $221,000 provided by plant officials and assuming 3.5 mgd diverted to Denver.
i/ Plant officials indicate that flow is diverted to Metro approximately 10 minutes twice a day (between 0800-0900 and 1500-1600) to facilitate cleaning of headworks.
j/ Presently are not connected to Metro facility; plant located in close proximity to Clear Creek Interceptor.

District members are charged according to the amount of BOD, suspended solids, and flow received by the Metro plant. These charges, according to plant officials, are \$46.43 per ton BOD, \$40.23 per ton suspended solids, and \$53.13 per million gallons. This combined cost amounts to approximately \$112 per million gallon delivered. The cost per family is about \$15 per year. On the basis of the cost information provided by officials of Wheatridge and Clear Creek Valley Sanitation District [Table 3] and influent BOD and suspended solids concentrations, treatment costs for these sanitation districts are similar to the Metro treatment cost rate.

The estimated operation and maintenance costs at the Arvada and the Baker plants were provided for 1971 [Table 3]. It appears wastewater is presently treated at these plants at much less cost than at Metro. However, the cost of expanding these plants to take all incoming flows would increase the treatment cost. For example, the cost of a trickling filter plant (primary treatment and sludge digester included) of 1.0 mgd is estimated at about \$500,000.[5/] At an interest rate of 7 percent and with a 20-year life expectancy, the annual cost including amortization of capital costs and maintenance is estimated at \$47,000. If the community receives a 30 percent Federal grant, the annual cost would be about \$33,000. Therefore, at design flow, the cost to treat one mgd varies from \$90 with a grant to \$130 without a grant. When labor, chemical, and other costs are added, the cost per million gallons treated is comparable to that of the Metro plant.

In addition to these four plants, nine plants operate independently

TABLE 4

OTHER WASTEWATER TREATMENT FACILITIES IN THE METROPOLITAN DENVER AREA

Map a/ Key	Name	Flow Observed During Evaluation (mgd)	Receiving Stream	River Mile	Remarks
12	Aurora Sanitation District	b/	Sand Creek	306.8/5.5/1.15	Discharges sludge to Metro.
13	Buckley Air National Guard Field	b/	Sand Creek	306.8/11.9	
5	Englewood Sanitation District	8.6	South Platte River	319.7	Additional treatment facilities under construction.
15	Fitzsimons General Hospital (U. S. Army)		Toll Gate Creek Tributary to Sand Creek		Treated wastewater is used for irrigation on the hospital grounds, excess is discharged to Sand Creek.
14	Glendale Sanitation District	b/	Cherry Creek		
11	Coors - Golden	3.0 Coors 2.0 Golden	Clear Creek	305.5/15.5	Interceptor has been constructed to deliver Coors Porcelain Plant and Golden wastes to Metro according to sources at Coors.
6	Littleton Sanitation District	5.2	South Platte River	323.5	
1	South Adams Sanitation District	1.8	South Platte River	301.2	
4	South Lakewood Sanitation District	1.8	South Platte River	314.1/2.1W	

a/ See Figure 1 for location.
b/ Flows were not measured.

of the Metro system [Table 4 and Figure 1]. The South Lakewood Sanitation District, for example, operates as a contact stabilization plant located at 700 Depew Street, Lakewood, Colorado. Effluent from this plant is discharged to the South Platte River. The facility is designed for 1.2 mgd, but presently receives 1.8 mgd. The plant is being expanded to increase capacity to 1.8 mgd with the assistance of an EPA construction grant.

The total waste being treated by the aforementioned plants is less than 15 mgd, which would represent about 12 percent of the flow now treated by Metro. Of the five plants evaluated [Table 4], none were meeting the State requirements for 80-percent BOD removal. The planned expansion at Metro should include provisions for the collection and treatment of the wastewaters presently treated at the small plants and schedules should be developed to phase out these small plants. No further construction should be initiated at these plants unless it can be shown that such an expansion will provide for the continued protection and enhancement of the South Platte River and tributaries.

Wastewater Treatment Facilities

The principal components for the Metropolitan Denver Sewage Disposal District Plant #1 are as follows [the flow diagram is presented in Figure 3]:

1. Preliminary treatment - bar screens, grit chambers, grease flotation and removal.
2. Primary clarifiers (4) - each 106 feet in diameter with an 8-foot, 9-inch side water depth. Each clarifier has a skimmer to remove floating solids.

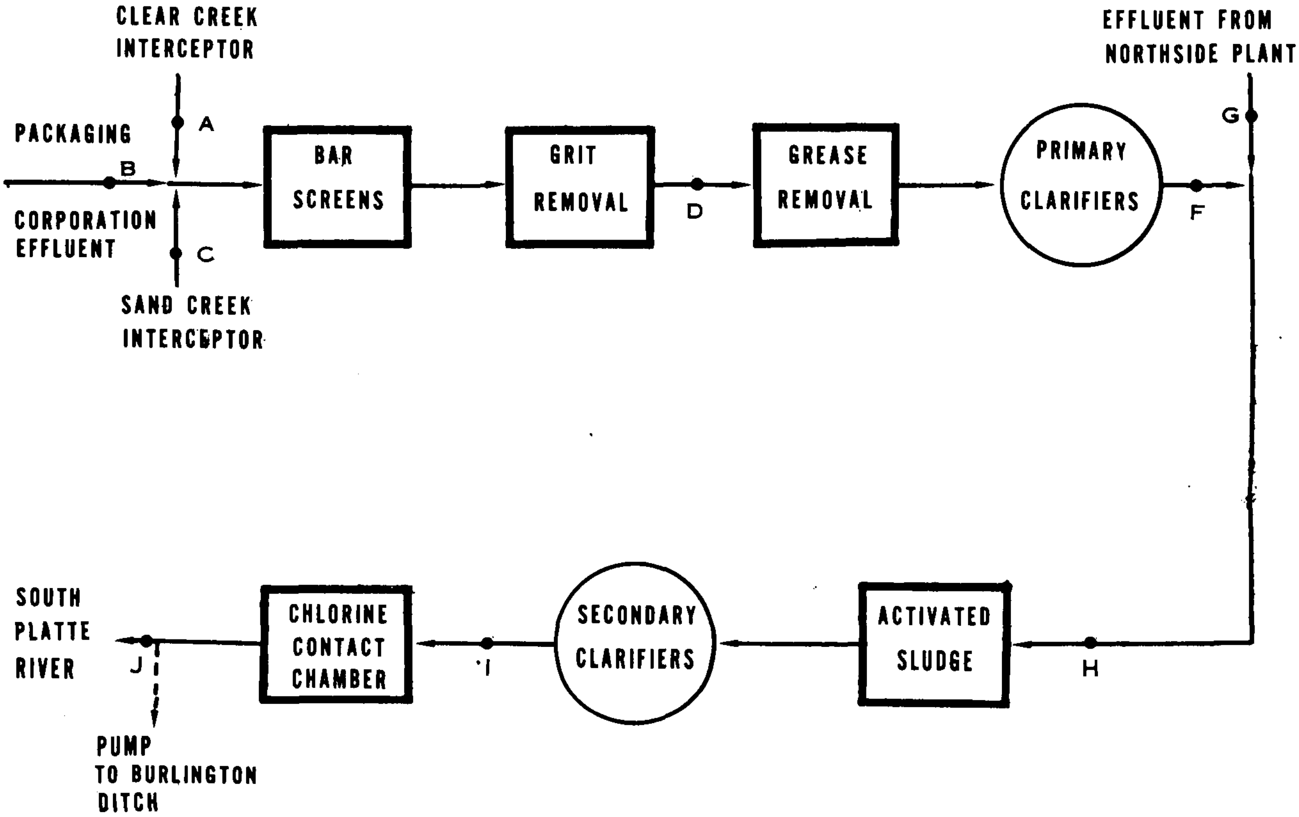
3. Activated sludge units - 12 aeration basins each consisting of 3 tanks 210 feet long, 30 feet wide, and 15 feet deep.
4. Secondary clarifiers (12) - each 130 feet in diameter with a side water depth of 10 feet. There are no skimmers on these units.
5. Chlorine contact chambers (3) - each 240 feet long, 30 feet wide, and 15 feet deep.
6. Sludge digesters and furnaces.

The activated sludge units and secondary clarifiers are divided into four separate systems by piping, pumps, and control buildings. Each of these systems, consisting of three aeration basins and three clarifiers, functions as a separate secondary plant. In effect, there are four secondary treatment facilities at Metro which are operated separately [Figure 1 in Appendix B]. No attempt was made to determine the efficiency of each of these "plants" during this survey. However, composite samples were collected at the influent channel to the four plants and at the combined effluent channel before and after chlorination.

<u>Discussion of In-Plant Survey and Findings</u>

The Metro plant was evaluated August 1 through 9, 1971. All samples were analyzed at the NFIC-D laboratory for BOD, TOC, COD, and solids (total, suspended, volatile suspended, and settleable). Samples for selected stations were also analyzed for nutrients and heavy metals [Tables 5, 6, B-1, B-2, and B-3*]. Bacteriological samples were collected periodically for the final effluent [Table 7]. Field measurements of the Metro

* Tables B-1, B-2, and B-3 are located in Appendix B.



LEGEND

STATION	DESCRIPTION
A	CLEAR CREEK RAW INFLUENT
B	PACKAGING CORPORATION EFFLUENT
C	SAND CREEK RAW INFLUENT
D	COMBINED RAW INFLUENT TO METRO
F	METRO PRIMARY EFFLUENT
G	DENVER NORTHSIDE PRIMARY EFFLUENT
H	INFLUENT TO SECONDARY UNITS
I	INFLUENT TO $C1_2$ CONTACT CHAMBER
J	METRO FINAL EFFLUENT

Figure 3.-Flow Diagram Metropolitan Denver Sewage Treatment Plant

TABLE 5

SUMMARY OF ORGANIC AND NUTRIENT DATA FOR METROPOLITAN AND NORTH DENVER WASTEWATER TREATMENT PLANTS[a]
AUGUST 1-9, 1971

Station	Description	Flow mgd	BOD mg/l	Susp. Solids mg/l	Vol. Susp. Solids mg/l	Settl. Solids mg/l	COD mg/l	NH_3 mg/l	Total (KJ)[b] N mg/l	NO_2+NO_3 mg/l	P mg/l
A	Clear Creek Raw Influent	18.9	187	334	283	5.3	475	18	27	0.04	10.5
B	Packaging Corporation Effluent	0.4	398	344	287		1030	1.4	5.8	2.2	0.9
C	Sand Creek Raw Influent	10.3	211	349	305	6.2	695	19	30	0.11	13.0
E	Denver Northside Influent	86.7	295	680	620	5.9	1250	17	25	0.08	9.4
G	Denver Northside Primary Effluent	86.7	175	120	80	1.0	230				
I	Influent to Cl_2 Contact Chamber	116.3	41	98	100	0.9	213				
J	Final Effluent from Metro	116.3	31	123	117	1.7	160	15	20	0.73	7.1

a/ Values listed are averages.
b/ Kjeldahl nitrogen.

TABLE 6

SUMMARY OF HEAVY METALS DATA FOR METROPOLITAN AND NORTH DENVER WASTEWATER TREATMENT PLANTS
August 1-9, 1971

Station	Description	Flow mgd	Cadmium mg/l Average	Chromium mg/l Average	Copper mg/l Average	Lead mg/l Average	Zinc mg/l Average	Mercury µg/l Average
A	Clear Creek Raw Influent	18.9	< 0.03	< 0.04	0.08	0.11	0.18	< 0.30
B	Packaging Corporation Effluent	0.4	0.02	0.15	0.13	1.05	3.14	< 0.57
C	Sand Creek Raw Influent	10.3	0.02	0.30	0.31	0.09	0.29	0.55
E	Denver Northside Influent	86.7	< 0.14	0.10	0.22	0.17	1.01	0.58
G	Denver Northside Primary Effluent	86.7	< 0.02	0.08	0.16	< 0.06	0.28	0.53
I	Influent to Cl_2 Contact Chamber	116.3						
J	Final Effluent from Metro	116.3	< 0.02	0.06	0.10	< 0.04	0.20	0.50

< = Less Than

TABLE 7

BACTERIOLOGICAL AND CHLORINE RESIDUAL DATA
METROPOLITAN DENVER SEWAGE DISPOSAL PLANT

Date/Time Sampled		Chlorine Residual mg/l	Coliform Count/100 ml Total	Fecal
August 2	0400	0.01	86,000	1,100
	0600	0.01	550,000	13,000
	1000	0.40	37,000	390
	1200		14,000,000	430,000
	1400		9,800,000	72,000
August 3	0200	0.06	860,000	74,000
	0400	0.04	170,000	20,000
	0600	0.04	660,000	37,000
	1000	0.01	7,300,000	96,000
	1200		540,000	30,000
	1400	0.06	370,000	6,600
August 4	0000	0.06	410,000	90,000
	0200	0.08	210,000	18,000
	0400	0.08	72,000	7,800
	0600	0.08	380,000	17,000
	1600		31,000	< 2,000
	1800		36,000	< 2,000
	2000	0.08	19,000	< 4,000
August 5	1200	0.64	9,200	230
	1400	0.32	26,000	450
	1700	0.28	29,000	540
August 6	0000	0.03	17,000	1,600
	0200	0.03	330,000	16,000
	0400	0.03	200,000	3,200
	0600	0.01	21,000	2,800
	0800	0.02	27,000	270
	1000	0.16	48,000	880
	1200	0.21	6,600	720

effluent showed: pH, 7.0-7.8; temperature, 19.0°-23.0°C; and conductivity, 875-1,200 μmhos/cm.

Daily, during the survey, large amounts of suspended solids were observed passing over the final clarifier weirs during periods of peak flow. This solids carry-over resulted from the scouring velocities which prevail during peak flows.

Large accumulations of floating material were observed daily in all treatment units. Solids were observed in the final effluent also. The solids discharged could be reduced by the addition of skimmers on the final clarifier.

The removal efficiency observed at the Northside and Metro facilities [Table 8] indicated that BOD removal at the Northside plant ranged from -11 to 58 percent.* If the Metro plant is considered alone (i.e., without the BOD removal afforded by Denver Northside), the BOD removal efficiency ranged from 48 to 86 and 39 to 94 percent before and after chlorination, respectively. Under these conditions, the BOD removal efficiency at the Denver Metro facility alone was below State standards 33 percent of the time. If the Northside plant is considered as part of the overall Metro system, the range of BOD efficiency increases between 66 and 91 percent before chlorination and between 63 and 96 percent after chlorination. The daily BOD removal efficiency including both facilities was below State standards 20 percent of the time. Metro was designed for a BOD load of 166,350 lb/day. During the survey period, the influent BOD varied from 92,000 to 279,000 lb/day with an average of 182,000 lb/day.

* The negative BOD removal was due to sludge blanket losses from the clarifiers at Northside.

TABLE 8

REMOVAL EFFICIENCIES FOR DENVER METRO AND DENVER NORTHSIDE FACILITIES[a/]

August 1-9, 1971

Degree of Treatment for	BOD Range %	Susp. Solids Range %	Vol. Susp. Solids Range %	Settleable Solids Range %
Northside	(11)[b/]-58	6-95	66-95	11-81
Metro before Cl_2	42-86	(11)[b/]-88	(36)[b/]-80	89-91
Metro after Cl_2	39-94	(16)[b/]-78	(36)[b/]-66	(50)[b/]-91
Metro plus Northside before Cl_2	66-91	27-97	32-96	92-98
Metro plus Northside after Cl_2	63-96	39-95	31-95	54-96

a/ Overall efficiencies were calculated by summing the load into and out of the plant.

b/ Numbers in parentheses are negative numbers. These negative values are due to sludge blanket losses from clarifiers.

Influent BOD loads were less than the design load during the weekend only.

Solids concentrations increase through the chlorine contact chamber. Solids accumulate in the chamber and scour during peak flow periods. The combined chlorine residual in the effluent varied from 0.01 to 0.64 mg/l, significantly lower than the level (1.0 mg/l after 15 minutes' detention) specified by the Colorado Department of Health.[4/] Fecal coliform concentrations in the effluent ranged from 230 to 430,000/100 ml, indicating inadequate disinfection [Table 7]. According to plant officials, about one ton/day of chlorine is used (two mg/l dosage rate at design flow). The Colorado State Criteria recommend a minimum dosage rate of eight mg/l for activated sludge plant effluents.

Concentrations of heavy metals discharged in the final effluent were generally insignificant. The mercury concentrations discharged ranged from 0.2 to 1.0 μg/l (0.18 to 0.87 lb/day), with an average of 0.5 μg/l (0.48 lb/day). The majority of the mercury received by Metro is contained in the North Denver plant effluent. Officials of the North Denver plant do not know the source(s) of this mercury.

The nutrient data show that only a small amount of nitrification takes place during treatment. Total phosphorus was reduced approximately 28 percent. The total nitrogen and phosphate loads discharged to the South Platte River averaged 34,700 and 6,900 lb/day, respectively.

Bi-weekly operational data for the period May 30 through December 31, 1971 [Table 9] were obtained from Metro officials. The data for the period July 25, 1971, through August 7, 1971, showed average BOD and suspended solids removals of about 84 and 1 percent, respectively. Plant

TABLE 9

BI-WEEKLY AVERAGES OF BIOCHEMICAL OXYGEN DEMAND AND SUSPENDED SOLIDS REMOVALS AT THE METROPOLITAN DENVER SEWAGE DISPOSAL PLANT[a]
1971

Bi-Weekly Period	Percent BOD Removal	Percent Suspended Solids Removal
May 30-June 12	86.1	60.2
June 13-June 26	75.5	38.3
June 27-July 10	79.1	53.7
July 11-July 24	77.8	48.3
July 25-August 7	83.8	0.8
August 8-August 21	76.3	1.8
August 22-September 4	64.5	24.9
September 5-September 18	75.7	31.0
September 19-October 2	79.6	47.0
October 3-October 16	80.8	47.5
October 17-October 30	75.9	39.0
October 31-November 13	74.5	37.3
November 14-November 27	73.7	48.3
November 28-December 11	75.8	41.6
December 12-December 25	81.3	63.1
December 26-December 31	68.0	36.0

a/ Data were provided by Metro officials. These data do not include BOD and suspended solids removed by the Denver Northside Plant.

officials indicated that during this 2-week period, the sludge furnaces were shut down and the digesters were loaded to capacity. Sludge was being disposed of through landfill operations. Because of inadequate trucking capacity, excess sludge was stored in the final clarifiers. Sludge that had been stored in the final clarifiers was scoured from these clarifiers during peak flow periods.

During 12 of the 16 bi-weekly periods [Table 9], the plant was operating below the minimum 80-percent-BOD-removal requirement specified in the Colorado State Water Quality Standards. These standards also require that adequate disinfection be provided.

Operation of the Northside plant has a marked influence on the operation and performance of the Metro plant. Since all wastes from Northside are discharged to Metro and constitute the majority of the flow received, failure to remove grease, for example, at the Northside plant can cause operational difficulties at Metro. Operations of both plants need to be under the control of a single agency in order that the combined operations can be controlled to produce the best final effluent quality.

During the survey, Metro personnel were observed cleaning an insecticide tank. The wash-water containing the insecticide was flowing to a storm drain that discharges to the South Platte River. Plant officials indicated that this practice would be discontinued. The effluent from the storm drain appeared black and had the odor of burnt carbon. Further investigation revealed that effluent from two ash disposal ponds (ashes from sludge furnaces) was discharged to the drain. This practice has been discontinued because the sludge furnaces are no longer in use.

An in-plant study was conducted by EPA investigators during the period October 1969 to February 1970, in order to evaluate plant operations and provide technical assistance [Appendix B]. Weirs on the final clarifier are inadequately placed, thus allowing "scouring" velocities to be attained. Moreover, it was determined that clarification capacity of the final clarifier was not adequate. Also, there is no reserve capacity of clarifiers; i.e., if a clarifier is out of service, solids are not effectively removed and are discharged in the effluent. There is no method of measuring the flow to each clarifier; therefore, it is difficult to obtain a balance. Surface skimmers were also recommended.

During the October-February study investigators found deficiencies in the aeration basins -- detention time is not sufficient, i.e., it is always less than four hours. Further, there is difficulty in balancing the flow to the basin. Two of the twelve aeration basins were being used for grease removal, an operation that should have been accomplished in the primary units. This practice has been discontinued and, during the recent survey, four aeration basins (one in each area) were being used as aerobic digesters.

IV. STREAM SURVEYS

A. GENERAL

Previous Studies

In August 1964, December 1964 through March 1965, and September and October 1965, surveys of the South Platte River were conducted by the South Platte River Basin Project. During these periods stream flows at the 19th Street station averaged 140, 50, 380, and 305 cfs, respectively. Average dissolved oxygen values ranged from 6 to greater than 10 mg/l at 19th Street; from 1.5 to 3.0 mg/l at York Street; and from about 0.2 to 4.0 mg/l in the vicinity of 88th Avenue. Bacterial densities were high at all three stations, exceeding one million total and fecal coliform organisms/100 ml at York Street and 88th Avenue. The average BOD levels ranged from 10 to 20 mg/l at 19th Street; from 50 to 170 mg/l at York Street; and from 45 to greater than 100 mg/l in the vicinity of 88th Avenue.[1/]

As a result of the above studies, it was recommended to the Second Session of the South Platte River Basin Conference that the following water quality objectives be established:[6/]

1. In the main stream of the South Platte River, from the City of Littleton to the point of discharge of the Metro Denver sewage treatment plant, the dissolved oxygen content be maintained at not less than 5 mg/l; a five-day biochemical oxygen demand level not be allowed to exceed 10 mg/l; and the total and fecal coliform level not be allowed to exceed 2,400 and 500 bacteria per 100 ml, respectively.

2. In the main stream of the South Platte River, from just downstream of the Metro discharge to just upstream of the Brighton Great Western Sugar Company discharge, that the dissolved oxygen content be maintained at not less than 4 mg/l; the five-day BOD level not be allowed to exceed 20 mg/l; and the total and fecal coliform levels not be allowed to exceed 5,000 and 1,000 bacteria per 100 ml, respectively.

The Colorado Water Pollution Control Commission, pursuant to the Federal Water Pollution Control Act, as amended,[7/] classified the South Platte River and established water quality standards [Appendix A] for the following reaches:

South Platte River from Exposition Avenue (RM 321.9) to York Street (RM 313.4) -

B_2 - Warm Water Fishery
C - Industrial Water Supply
D_1 - Irrigation Water Supply

South Platte River from York Street (RM 313.4) to Colorado-Nebraska State Line (RM 83.7)

C - Industrial Water Supply
D_1 - Irrigation Water Supply

Sand Creek throughout its length -

Basic Standards applicable to all waters of the State apply.

Clear Creek from point of diversion of Farmers Highline Canal (RM 311.1/16.8) to confluence with South Platte River (RM 311.1) -

A - Potable Water Supply
C - Industrial Water Supply
D_1 - Irrigation Water Supply

The discharge from the Metro plant enters the South Platte River downstream from Burlington Ditch. Facilities are available to pump 150 cfs of effluent to Burlington Ditch if, at the point of diversion, there is not sufficient flow in the river to satisfy water rights. At the time of the 1964-65 studies, the Metro plant was under construction. The major source of pollution in the Denver area was the Northside plant (RM 314.4) which discharged wastes upstream of the Burlington Ditch diversion. Subsequently, the Northside plant discharged all wastes to Metro (RM 312.2), thus moving the discharge downstream from the diversion. There is presently a controversy over the ownership of the Metro effluent. The Farmers Reservoir and Irrigation Company, et al, have filed suit against the Metropolitan Denver Sewage Disposal District Plant #1, contending that it has interfered with their lawfully decreed rights as appropriators of water from the South Platte River. The trial court entered "final judgement" against the District on August 30, 1968, which decision the District appealed to the Colorado Supreme Court. A decision is pending.

Present Studies

During the period August 30 to September 2, 1971, a water quality survey was conducted on the South Platte River from Waterton to Platteville, Colorado. A bacteriological survey was conducted,during November 17-21, 1971, in order to determine quality of the South Platte River upstream and downstream from the Metro discharge (19th Street-RM 317.3, Colorado 224-RM 310.9) and in order to evaluate Burlington Ditch. Sampling was conducted at selected stations to determine whether or not *Salmonella* were present. Another stream survey was conducted in the same reach, during December 13 through 17, 1971, to determine chemical quality [Figure 4].

During the in-plant survey and the three stream surveys the total Metro effluent was being discharged to the South Platte River. This effluent comprised about 30 to 35 percent, 65 to 95 percent, and 95 percent of the flow in the South Platte River, respectively for each survey, at the point of discharge. From August 30 to September 2 flow conditions in the South Platte River were above normal. Survey findings are discussed below.

Findings of August-September Survey

The August survey revealed that the South Platte River at 19th Street (RM 317.3) was degraded [Table 10]. The benthos at this station were dominated by pollution-tolerant forms, such as sludgeworms and midges.

Raw municipal wastes are occasionally by-passed to the South Platte River in that reach from Denver Northside (314.4) downstream to York Street (313.4) (see page 6). Water samples collected at York Street were severely contaminated by fecal matter. The number of fecal coliform bacteria was greater than 13,000/100 ml (log mean value); numbers of total coliform exceeded 100,000/100 ml. The levels of organic matter and suspended solids also were high in this reach. The DO levels at this station ranged from 5.7 to 7.4 mg/l.

The Metro plant (RM 312.2) treats most of the domestic wastes of the Denver area and is one of the most significant pollution sources in the South Platte River Basin. Wastewaters discharged during the survey period contained about 60 mg/l BOD (62,000 lb/day), and 85 mg/l suspended solids (88,000 lb/day) [Table 10]. Total- and fecal-coliform bacteria

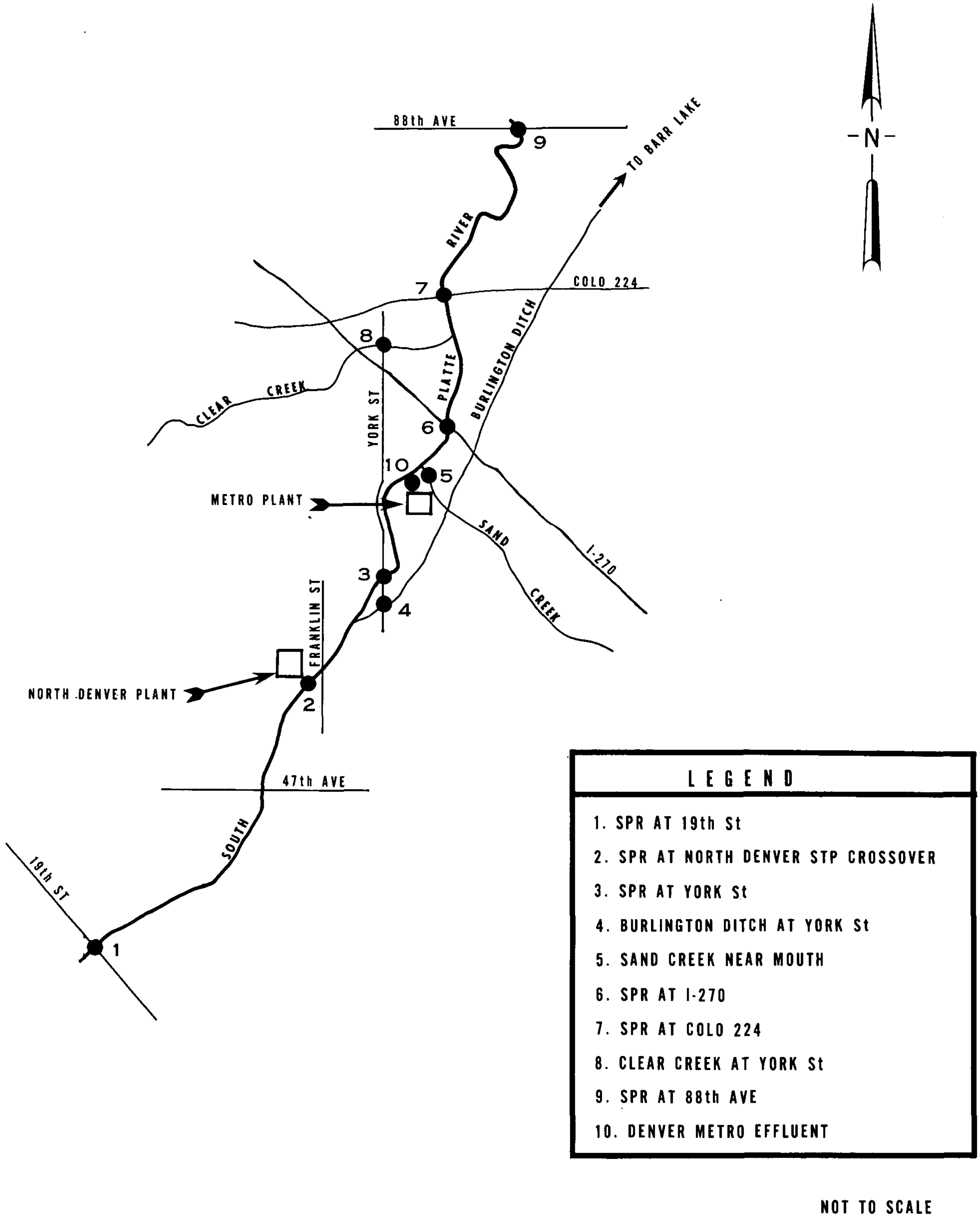


Figure 4. South Platte River from 19th St to 88th Ave

TABLE 10

SUMMARY OF ANALYTICAL RESULTS AND FIELD MEASUREMENTS FOR THE SOUTH PLATTE RIVER
19th Street to 88th Avenue
August 30-September 2, 1971

Station	Date	Flow cfs Avg	Temp. °C Range	pH S.U. Range	Cond. μmhos/cm Range	DO mg/l Range	DO mg/l Avg	BOD_5 mg/l Avg	Total Solids mg/l Avg	Susp. Solids mg/l Avg
SPR at 19th St. (RM 317.3)	8/30-9/2/71	413	17-24	7.2-8.3	375-600	6.0-7.6	7.0	6	405	< 80
SPR at York St. (RM 313.2)	8/30-9/2/71	210[a/]	17-22	7.4-8.1	360-580	5.7-7.4	6.9	7	543	260
Denver Metro Effluent[b/] (RM 312.2)	8/30-9/2/71	192						56		85
Sand Creek at Mouth (RM 312.1/0.1)	8/30/9/2/71	100[a/]	17-21	7.5-8.0	420-600	6.4-7.3	6.8	8	570	203
Clear Creek at York Street (RM 311.1/0.3)	8/30-9/2/71	21	16-21	7.3-8.4	470-600	4.8-8.7	6.7	4	383	< 30
SPR at 88th Avenue (RM 308.8)	8/30-9/2/71	700[a/]	18-22	7.3-7.6	600-800	3.3-5.7	4.5	29	690	233

a/ Estimated flow.
b/ **Data provided by Denver Metro personnel.**

levels, during the in-plant survey, ranged from 6,600 to 14,000,000 per 100 ml and 230 to 430,000 per 100 ml, respectively [Table 7].

During the August survey the flow in Sand Creek (RM 312.1/0.1) was comprised primarily of overflow from the Burlington Ditch. The creek smelled of sewage and was gray in color because Burlington Ditch carried by-passed raw municipal sewage from the 47th Avenue sewer discharge to the South Platte River. Log mean concentrations of total and fecal coliform bacteria were greater than 110,000 and 8,800/100 ml, respectively. Sand Creek transported large amounts of organic matter, and this resulted in a BOD as high as 9 mg/l. Benthic invertebrates, dominated by pollution-tolerant sludgeworms, inhabited the creek bottom in dense populations (1,494/square foot). The diversity of organisms was limited to six kinds, most of which were pollution-tolerant or facultative forms.

The South Platte River became severely polluted downstream from these waste sources. At RM 311.5 (upstream of Clear Creek) the odor of sewage was strong, and the water was gray, turbid, and covered with soap suds. The river bed was covered with organic sludge. The benthic community was reduced to seven kinds and consisted mostly of pollution-tolerant sludgeworms and snails.

Clear Creek intersects the South Platte River at RM 311.1. The water in Clear Creek is of a better quality than that observed in the South Platte River. The addition of Clear Creek water somewhat improves the quality of the South Platte River waters.

The pollutants discharged to the South Platte River from the sewage treatment facilities and from polluted Sand Creek settled to the river bottom forming sludge beds that were evident from Sand Creek downstream - approximately 23 river miles. Throughout this river reach water quality was degraded severely. Fecal coliforms numbered more than 7,900/100 ml and total coliforms numbered more than 320,000/100 ml.

At 88th Avenue (RM 308.8) the number of benthic invertebrates increased to 732/square foot with a variety of only eight kinds. Ninety-two percent of these organisms were pollution-tolerant sludgeworms.

B. FINDINGS OF NOVEMBER BACTERIOLOGICAL SURVEY

Bacteriological data [Table 11], for the November survey, showed that the standards for a warm water fishery (B_2) were being met at the 19th Street Station with a log mean coliform bacteria density of 490/100 ml and with no more than 10 percent of the samples exceeding 2,000/100 ml. Bacterial quality remained within the standards until York Street, where the log mean density increased to 790/100 ml; however, more than 10 percent of the samples exceeded 2,000/100 ml. From York Street downstream there are at present no bacterial standards for the South Platte River.*

Salmonella tests were conducted in the South Platte River at York Street (RM 313.2) just downstream from the Denver Metro effluent (RM 312.15) and in Burlington Ditch at York Street in order to determine

* The Colorado Water Pollution Control Commission adopted bacterial water quality standards for the South Platte River, downstream from York Street to the Colorado-Nebraska state line, in September 1971, by classifying this reach of river suitable for a potable water supply (Class 'A'). The State Attorney General advised the Commission that any change in stream classification required a public hearing. The Commission subsequently removed the "A" classification.

TABLE 11

RESULTS OF BACTERIOLOGICAL ANALYSES-SOUTH PLATTE RIVER STREAM SURVEY
November 17-21, 1971

Map[a/] Key	Station	Total Coliforms Count/100 ml		Fecal Coliforms Count/100 ml		% of Sample ≥2000/100 ml	Fecal Strep. Count/100 ml	
		Range	Log Mean	Range	Log Mean		Range	Log Mean
1	South Platte River at 19th St. bridge	3,800->90,000	>11,000	170-4,000	490	10	160-27,000	1,600
2	South Platte River at Denver Northside plant	3,000-440,000	15,000	310-2,600	620	10	330-39,000	2,100
3	South Platte River[b/] at York St.	5,000-270,000	21,000	61-10,000	790	20	360-87,000	3,800
4	Burlington Ditch[b/] at York St.	3,200-210,000	16,000	410-6,500	850	20	570-77,000	3,500
6	South Platte River at I-270 Bridge	7,000-6,200,000	340,000	70-70,000	>7,000	70	150-160,000	14,000
7	South Platte River at Colorado 224	7,100-5,400,000	200,000	160->60,000	>3,300	60	980-98,000	8,200
8	Clear Creek at York St.	600-190,000	7,100	<10-5,300	<190	20	220-190,000	1,800
10	Denver Metro effluent[c/]	9,200-14,000,000		230-430,000				

a/ See Figure 4 for location.
b/ Isolated *salmonella* at this station.
c/ Data from in-plant survey August 1-9, 1971.

whether or not enteric pathogenic bacteria were present. The results at all three stations were positive. Particular serotypes isolated were *Salmonella anatum* (Burlington Ditch) and *S. senftenberg* (SPR stations). The presence of these pathogenic bacteria, in attendance with fecal coliforms, confirms that the water is contaminated by raw or inadequately treated sewage.

The effects of the Metro effluent, however, are very evident. Log mean fecal-coliform bacteria densities exceeded 7,000/100 ml downstream from Metro at the I-270 bridge (RM 312.0). Concentrations exceeding 3,300/100 ml (log mean) were observed at Colorado 224 (RM 310.9).

The bacterial standard for Clear Creek was violated at York Street. Although the fecal-coliform bacteria concentration (log mean) was low (<190/100 ml); more than 20 percent of the samples exceeded the 2,000/100 ml limitation required for a Class A waters.

Survey results showed some improvement, since the 1964-65 studies, in the bacterial quality of the South Platte River downstream from 19th Street. Total- and fecal-coliform bacterial levels were markedly lower in November than those observed in 1964-65. Downstream from York Street, the log mean total- and fecal-coliform bacteria numbers remained in excess of the levels recommended by the South Platte River Basin Project as water quality objectives (i.e., 5,000 total and 1,000 fecal/100 ml). Adequate disinfection of the Metro discharge and elimination of raw sewage by-passes would improve the bacterial quality of the river downstream from 19th Street.

C. FINDINGS OF THE DECEMBER SURVEY

Flows in the South Platte River during December were about one-fourth of those observed during August. Water samples were collected at selected stations from 19th Street downstream to Colorado Highway 224 and analyzed for BOD, solids (total and suspended), and DO [Table 12]. The average BOD at the background station (19th Street) was 18 mg/l. The level decreased to 14 mg/l at Denver Northside. At York Street the BOD averaged 9 mg/l, about 50 percent less than measured in Burlington Ditch at York Street. One factor that could account for this difference is the flow of the South Platte River at York Street primarily consisted of seepage because the entire river was being diverted to Burlington Ditch. Consequently, there was essentially a new river at York Street.

Downstream from Metro (I-270) the BOD level increased to an average of 44 mg/l -- about five times higher than the average observed at York Street. At this station, the river was mostly Metro effluent which contained an average BOD of 44 mg/l.

The BOD level at the new downstream station (Colorado 224) remained at 40 mg/l. This station is downstream from the confluence of Clear Creek which had an average BOD of 15 mg/l and an average flow of 54 cfs.

During the survey, the DO levels were well above the established standard (3.0 mg/l) at all stations, with concentrations ranging from 7.8 to 9.4 mg/l upstream of the Metro discharge and 6.0 to 6.4 downstream at I-270 bridge.

In summary, the survey results indicated an improvement in the

TABLE 12

SUMMARY OF ANALYTICAL RESULTS AND FIELD MEASUREMENTS FOR THE SOUTH PLATTE RIVER
19th Street to 88th Avenue
December 13-17, 1971

Station	Date	Flow cfs Avg	Temp. °C Range	pH Range	Cond. µmhos/cm Range	DO mg/l Range	DO mg/l Avg	BOD_5 mg/l Avg	Total Solids mg/l Avg	Susp. Solids mg/l Avg
SPR at 19th St. (RM 317.3)	12/13-17/71	107	3-6	7.6-7.9	775-875	8.5-10.0	9.4	18	675	40
SPR at Denver Northside plant (RM 314.5)	12/13-17/71	135[a]	3-6	7.4-7.9	825-1000	7.8-9.8	8.9	14	750	30
SPR at York St. (RM 313.2)	12/13-17/71	2[a]	3-5	7.7-7.8	750-1000	7.8-9.4	8.7	9	755	30
Burlington Ditch at York St.	12/13-17/71	142[b]	3-5	7.5-7.8	850-1000	7.7-9.6	8.8	14	725	40
Denver Metro effluent (RM 312.2)	12/13-17/71	153						44		
SPR at I-270 bridge (RM 312.0)	12/13-17/71	160[a]	15-15	7.1-7.4	1000-1100	6.0-6.4	6.1	44	890	95

TABLE 12 (Cont.)

SUMMARY OF ANALYTICAL RESULTS AND FIELD MEASUREMENTS FOR THE SOUTH PLATTE RIVER
19th Street to 88th Avenue
December 13-17, 1971

Station	Date	Flow cfs Avg	Temp. °C Range	pH Range	Cond. µmhos/cm Range	DO mg/l Range	DO mg/l Avg	BOD_5 mg/l Avg	Total Solids mg/l Avg	Susp. Solids mg/l Avg
Clear Creek at York St. (RM 311.1/0.3)	12/13-17/71	54	0.3-2	7.7-8.0	825-1000	9.2-10.5	9.8	15		45
SPR at Colo. 224 (70th Ave.) (RM 310.9)	12/13-17/71	220[a]	8-9	7.3-7.6	950-1050	7.4-8.0	7.8	40	820	70
SPR at 88th Ave. (RM 308.8)	12/13-17/71	200[a]	3-12	7.4-7.7	775-1100	6.7-7.3	7.0			

a/ This is a estimated flow value.
b/ Flow was measured at a gage located downstream from York Street near Sand Creek.

South Platte River quality downstream from Denver Northside compared to the 1964-65 studies. Obvious improvements include reduced BOD and higher DO values as a result of the elimination of the Northside primary effluent. However, the BOD load discharged by the Metro plant still results in BOD levels in the South Platte River more than twice the limits recommended (i.e., 20 mg/l) as a water quality objective in the South Platte River Basin Project report.

The quality of Clear Creek has also improved over that observed in 1964-65, and during the December survey, the BOD level (11-20 mg/l) was within the limits recommended.

V. WATER QUALITY IMPROVEMENT MEASURES

Adequate design, operation, and maintenance at the Metro plant should be an immediate priority in improving water quality in the South Platte River. To meet projected water quality criteria a BOD removal efficiency of greater than 90 percent will be required. Interim methods of improving the effluent, such as chemical precipitation, should be evaluated and initiated as soon as possible.

The dissolved oxygen concentration in the South Platte River has been evaluated on the basis of continual discharge of Metro effluent to the river and low-flow conditions. The 7-day, 10-year low flow at 19th Street is 20 cfs which, assuming no diversion, would make the low flow just upstream of the Metro effluent approximately 25 cfs. Waste loads from Metro were predicated on 30 mg/l BOD (August data) and 3 mg/l DO (assumed). The BOD loading to the river uunder these conditions is 29,100 lb/day with a residual stream BOD of an additional 810 lb/day (includes BOD loading from Sand Creek and Clear Creek). Calculations were made at 25°C, with the DO upstream of the Metro effluent assumed to be at saturation. The minimum DO that would occur is approximately 0.5 mg/l which is below the approved water quality standard of 3 mg/l [Figure 5]. This analysis did not include possible secondary oxygen demand from nitrification.

The same procedures were employed to determine the expected low DO value with the Metro effluent containing 10 mg/l BOD. All other factors remained the same. The minimum DO which would occur is approximately 3.5 mg/l [Figure 5].

Based on the above calculations, the effluent from Metro must not contain more than 10 mg/l BOD to prevent violation of water quality standards (DO of 3 mg/l). This will require the Metro wastewater treatment facility to provide at least 95 percent BOD reduction.

Water quality conditions could be further improved by diverting the Metro effluent to the Burlington Ditch and allowing normally diverted South Platte River flows to continue downstream. The Farmers Reservoir and Irrigation Company, which owns Burlington Ditch, has water rights of 377 cfs from the South Platte River. From May to September, the majority of the diverted water is used directly for irrigation, with any excess being stored in Barr Lake, a 350,000 acre-foot reservoir, located northeast of Denver [Figure 4]. Three other reservoirs, Horsecreek (17,000 acre-feet), Prospect (7,660 acre-feet), and Lord (1,000 acre-feet), also receive South Platte River water from diversions into the Burlington Ditch, generally from October to April. A flow of 130 cfs would be sufficient to fill these reservoirs. Based on projected Metro flows, 25-100 cfs would still have to be discharged to the river.

A study done on Barr Lake in 1964-65[8/] concluded that the lake was, in effect, a large wastewater stabilization lagoon. The BOD and Total N and Total PO_4 concentrations in the water entering Barr Lake ranged from 55 to 150; 12 to 37; and 11 to 21 mg/l, respectively. This study recommended that the Metro plant provide 90 percent BOD removal, which would be equivalent to about 20 mg/l BOD in the plant effluent.

During the irrigation season water demands would require flows in excess of the Metro effluent to be diverted from the South Platte River.

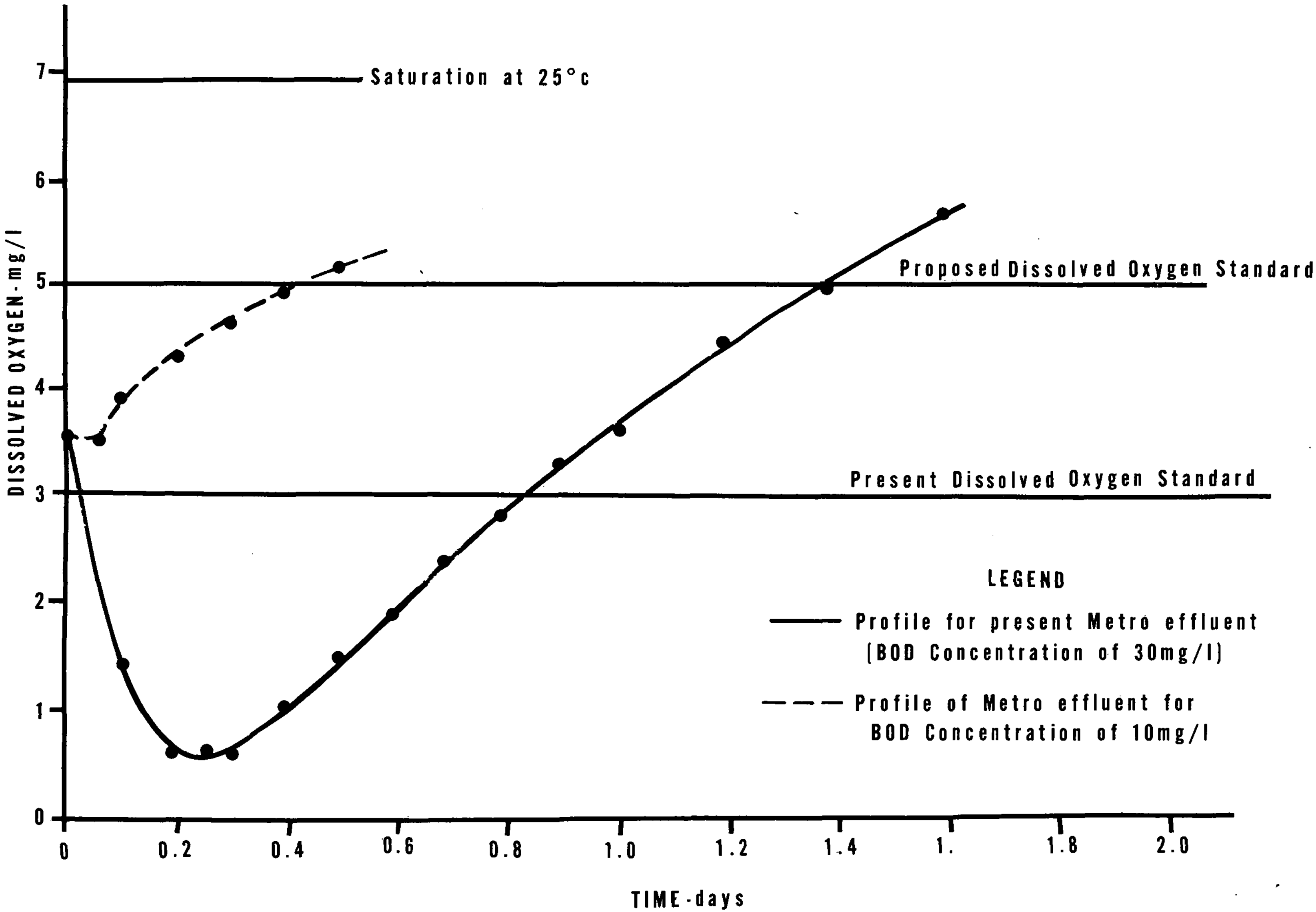


FIGURE 5 DISSOLVED OXYGEN PROFILE FOR SOUTH PLATTE RIVER DOWNSTREAM OF DENVER METRO EFFLUENT.

Adequate and reliable disinfection will be required at all times if the Metro effluent is to be used directly for irrigation.* A water quality monitoring system must be established at the point of first diversion for use.

In summary, the Metro plant must provide: (1) an effluent BOD of not greater than 20 mg/l when all effluent is pumped to Burlington Ditch, (2) an effluent BOD of not greater than 10 mg/l if all the effluent is discharged to the South Platte River assuming a low flow in the river of 20 cfs at 19th Street, and (3) effluent BOD levels between 10 and 20 mg/l when a portion of the effluent is being discharged to the river.

Improvements in the water quality of the South Platte River can be achieved by the elimination of occasional raw sewage discharges.

The water quality standards of the South Platte River downstream from York Street should be upgraded to encourage continued water quality enhancement. As DO concentrations observed at sampling stations were 5 mg/l or more, a warm water fishery (B_2) classification is feasible if adequate flow is maintained in the river (25 cfs).

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* The State of Colorado has not developed criteria for wastewater effluents used for irrigation of crops.

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APPENDIX A

COLORADO WATER QUALITY STANDARDS

COLORADO WATER QUALITY STANDARDS

Waters of the State, the quality of which exceeds the limits set in these standards, will be maintained at existing quality unless and until it can be demonstrated to the State that a change in quality is justified to provide necessary economic or social development. In that case, the best practicable degree of waste treatment to protect the current classification of such waters will be required. The appropriate Federal authority will be provided with information, from time to time, required to discharge his responsibilities under the Federal Water Pollution Control Act, as amended.

I. BASIC STANDARDS APPLICABLE TO ALL WATERS OF THE STATE:

A. All wastes capable of treatment or control prior to discharge into any waters of the state, shall receive secondary treatment with disinfection or its industrial waste equivalent, as determined by the State Water Pollution Control Commission. Lesser degrees of treatment or control may be permitted only where it can be demonstrated that the standards applicable to the classified use of the water can be attained. Greater degrees of treatment or control will be required where it can be demonstrated that it is necessary to comply with the standards applicable to the classified use of the water.

B. Free from substances attributable to municipal, domestic, or industrial wastes, or other controllable sources that will either settle to form unsightly, putrescent, or odorous bottom deposits, or will interfere with the classified use of the water.

C. Free from unsightly floating debris, oil, grease, scum, and other floating material attributable to municipal, domestic, or industrial wastes, or other controllable source.

D. Free from materials attributable to municipal, domestic or industrial wastes, or other controllable sources that will produce objectionable odor, color, taste, or turbidity in the water, or objectionable aquatic life which may result in eutrophication or other conditions that interfere with the classified use of the water.

E. Free from high temperatures, biocides, toxic, or other deleterious substances attributable to municipal, domestic, or industrial wastes, or other controllable sources in levels, concentrations, or combinations sufficient to be harmful to human or animal life.

F. Radioactive materials attributable to municipal, industrial or other controllable sources will be minimum concentrations that are physically and economically feasible to achieve. In no case shall such materials in the stream exceed the limits established in the current edition of the U. S. Public Health Service Drinking Water Standards or the limits approved by the Federal Radiation Council, or, in the absence of any limits specified by the U. S. Public Health Service or the Federal Radiation Council, 1/30 of the 168-hour-week values for other radio-active substances specified in the National Bureau of Standards Handbook 69.

II. SPECIFIC STANDARDS ESTABLISHED BY THE STATE OF COLORADO:

CLASS A - The following standards shall apply to water withdrawn for treatment as a potable supply:

a. Bacteria: Wastes or substances from controllable sources shall not be discharged into these waters in amounts which will cause the number of organisms of the fecal coliform group, as determined by either multiple tube fermentation or membrane filter techniques, to exceed a log mean of 1000 per 100 milliliters or exceed 2000 per 100 milliliters in more than 10 percent of the samples collected in any 30-day period.

b. Dissolved Oxygen: Dissolved oxygen shall not be less than 4 milligrams per liter.

c. pH: The pH shall be maintained between 6.0 and 9.0.

d. Taste and Odor: Free from materials attributable to municipal, domestic, or industrial wastes, or other controllable sources that will produce taste or odor in the water.

e. Dissolved Solids: Total dissolved solids, annual volume weighted average, should be less than 500 milligrams per liter.

f. Selected Chemical Constituents: The following substances shall not be present in such amounts as to exceed the specified concentrations in a potable water supply according to the mandatory requirements of the latest edition of the U. S. Public Health Service Drinking Water Standards:

Substance	Concentration - mg/l
Arsenic	0.05
Barium	1.00
Cadmium	0.01
Chromium (Hexavalent)	0.05
Cyanide	0.20
Lead	0.05
Selenium	0.01
Silver	0.05

CLASS B-2 - The following standards shall apply to waters classified for fish and wildlife (Warm Water Fishery):

a. Bacteria: Wastes or substances from controllable sources shall not be discharged into these waters in amounts which will cause the number of organisms of the fecal coliform group, as determined by either multiple tube fermentation or membrane filter techniques, to exceed a log mean of 1000 per 100 milliliters or exceed 2000 per 100 milliliters in more than 10 percent of the samples collected in any 30-day period.

b. Dissolved Oxygen: In warm water fisheries, dissolved oxygen content shall in no case go below 5 milligrams per liter.

c. pH: The pH shall be maintained between 6.5 and 8.5. No controllable pH change will be permitted which will interfere with fish and aquatic life.

d. Turbidity: No turbidity shall exist in concentrations that will impair natural and developed fisheries.

e. Temperature: In warm water fisheries the temperatures shall not exceed 90°F. No controllable temperature change will be permitted which will interfere with spawning and other aspects of fish life.

   Limits on temperature change have not been established due to lack of historical temperature data and lack of conclusive temperature change criteria for the aquatic biota of waters of the state. These factual data are being collected, however, to serve as a basis for setting limits. In the meantime, an abrupt change in temperature must be avoided and the normal pattern of diurnal and seasonal changes must be preserved. The maximum allowable temperature increase due to waste discharges in streams will be 5°F.

f. Toxic Material: Free from biocides, toxic, or other deleterious substances attributable to municipal, domestic, or industrial wastes, or other controllable sources in levels, concentrations, or combinations sufficient to be harmful to aquatic life.

g. Other Material: Free from materials attributable to municipal, domestic, or industrial wastes, or other controllable sources that will produce off-flavor in the flesh of fish.

CLASS C - The following standards shall apply to waters classified for industrial uses:

a. Dissolved Oxygen: Dissolved oxygen content shall not go below 3 milligrams per liter.

b. pH: The pH shall be maintained between 5.0 and 9.0.

c. Turbidity: No turbidity shall exist in concentrations that will interfere with established levels of treatment.

d. Temperature: The temperature shall not exceed 90°F.

CLASS D-1 - The following standards shall apply to waters classified for irrigation:

a. Total Dissolved Solids (Salt) Concentration: A time-weighted monthly mean at a monitoring station which exceeds the time-weighted monthly mean for a base period established by the Commission by more than two standard deviations shall be subject to review by the Commission.

b. Sodium Adsorption Ratio: A time-weighted monthly mean at a monitoring station which exceeds the time-weighted monthly mean for a base period established by the Commission by more than two standard deviations shall be subject to review by the Commission.

c. Toxic Material: Free from biocides, toxic, or other deleterious substances attributable to municipal, domestic, industrial wastes, or other controllable sources in concentrations or combinations which are harmful to crop life.

APPENDIX B

REPORT BY

ENVIRONMENTAL PROTECTION AGENCY
REGION VII, KANSAS CITY, MISSOURI

"FEDERAL ASSISTANCE PROJECT
METROPOLITAN DENVER SEWAGE
DISPOSAL DISTRICT NO. 1
OCTOBER 1969 - FEBRUARY 1970"

FEDERAL ASSISTANCE PROJECT
METROPOLITAN DENVER SEWAGE
DISPOSAL DISTRICT NO. 1
OCTOBER 1969 - FEBRUARY 1970

By

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And

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ENVIRONMENTAL PROTECTION AGENCY

WATER QUALITY OFFICE - REGION VII

911 WALNUT, KANSAS CITY, MO. 64106

MARCH 1971

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I. INTRODUCTION

The Metropolitan Denver Sewage Disposal District #1 (Metro Denver) plant was designed mainly as a secondary treatment facility (activated sludge) to treat wastes from the cities and sanitary districts in the Metropolitan Denver Area. The plant is administered by a Board of Directors who represent the various communities and districts that are served by the facility. The largest source of flow to the plant is the primary effluent from the City and County of Denver's North Side Sewage Treatment Plant.

The Metro Denver plant began operation in 1966 and since that time has continually experienced difficulties. Odor problems, insufficient sludge handling facilities, air pollution from sludge incineration; unavailability of land for sludge disposal sites, management, labor, and maintenance problems are the more significant of the difficulties that the plant has encountered. These problems have served to further increase the public's awareness of the Metro Denver plant.

In an effort to resolve this situation, the Board of Directors of the Metro Denver plant passed a resolution (see Appendix A) entitled "Concerning the Federal Government's Responsibilities in Constructing and Operating Sewage Disposal Facilities." In the resolution, Metro Denver petitioned the Congress of the United States and the appropriate Federal agencies to make available to the district a special team of scientists and engineers to serve as a task force to inspect the district's activated sludge treatment plant and make appropriate recommendations. As a result of this resolution, a three-man team from what was then the Federal Water Quality Administration was assigned to the Metro Denver treatment facility from October 1969 through February 1970. The project officer was Mr. Alfred West from the National Field Investigation Center (NFIC) in Cincinnati. He was assisted by Mr. Joseph Joslin and Mr. Bob Hegg of the Kansas City Regional Office.

II. PURPOSE AND SCOPE

The most significant problem areas at the Metro Denver plant, leading to the request for assistance, were the sludge handling and sludge disposal problems. The major sludge handling problem was processing the volume and type of waste activated sludge generated by the secondary treatment process employed at the plant. The sludge disposal problem occurred because of the plant's inability to incinerate all of the sludge that was processed. It was decided at the on-set of the Federal Assistance Project to concentrate efforts on the sludge handling problem by attempting to effect the mass and characteristics of the sludge produced by the secondary treatment process.

Operational changes in the secondary treatment process, training in conducting various control tests and data evaluation were the major tasks performed during the assistance project. These functions were coupled with various operational recommendations for both short term and long term plant operation and control.

This report documents the findings of the Federal team. Also presented are the results of additional analyses of the data conducted after the conclusion of the project.

III. DESCRIPTION OF PLANT AND AREA

The Metro Denver activated sludge plant is located north of Denver in Commerce City, Colorado. The effluent from the plant is discharged to the South Platte River, an interstate stream. The State Water Quality Standards require a minimum of 80% removal of five-day 20°C BOD by the Metro Denver plant before discharge to the South Platte River. Since the plant began operation in 1966, it has generally achieved this required eighty percent reduction.

The Metro Denver plant is comprised of primary and secondary sewage treatment facilities and includes sludge processing facilities. A flow schematic is presented in Figure 1.

The primary treatment facilities were designed to treat an average flow of 27 million gallons per day (MGD) and a maximum flow of 50 MGD. These facilities consist of an inlet structure, bar screens, grit and grease removal units, sedimentation basins and a grease and scum incinerator.

The secondary treatment facilities were designed to treat an average flow of 117 MGD with a maximum flow of 234 MGD. The design (BOD_5) load is 166,350 pounds per day or an average influent concentration of 170 mg/l BOD_5. The secondary treatment facilities consist of aeration basins, the blower building, sedimentation basins and chlorine contact chambers.

The sludge processing facilities were designed to treat 37,400 pounds per day of raw primary sludge and 131,000 pounds per day of secondary sludge from the Metro Denver plant; and 92,700 pounds per day of digested primary sludge from the Denver North Side plant. These facilities consist of the waste activated sludge concentrators, sludge holding tanks and the sludge processing building which housed the vacuum filters and incinerators.

Pertinent design information about types and sizes of equipment is discussed, as necessary, in the following sections.

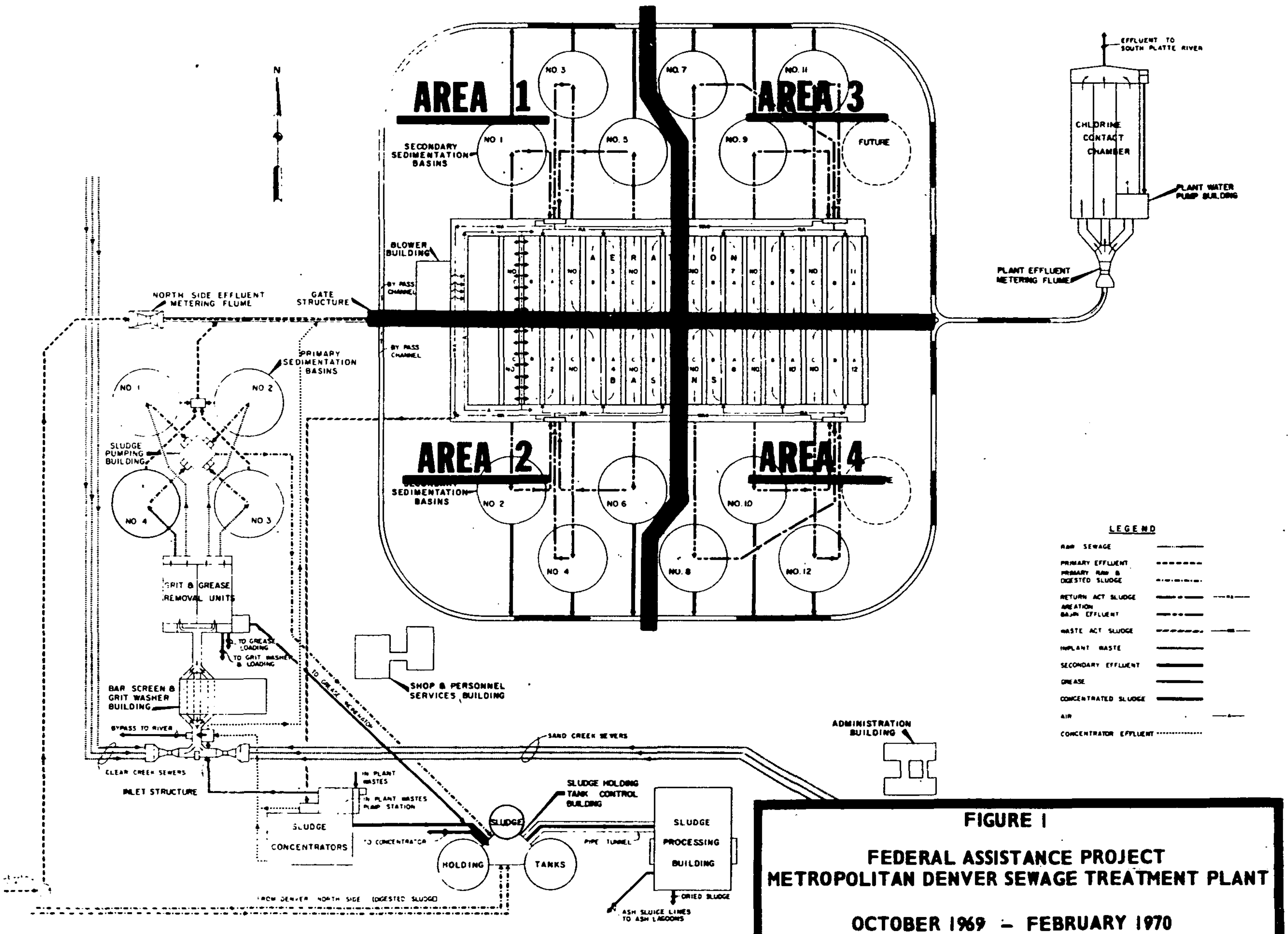


FIGURE I

FEDERAL ASSISTANCE PROJECT
METROPOLITAN DENVER SEWAGE TREATMENT PLANT

OCTOBER 1969 – FEBRUARY 1970

PLANT FLOW SCHEMATIC

IV. SUMMARY OF ASSISTANCE PROJECT

The major emphasis during the Federal Assistance Project was aimed at the biological (secondary) portion of the Metro Denver plant. As shown in Figure 1, the secondary portion is comprised of twelve aeration basins each of two million gallon capacity and twelve 1.16 million gallon final clarifiers. These twenty-four structures were equally divided into four separate areas by piping, pumps and other control devices. Throughout the project these four areas demonstrated characteristics of four different plants possibly due to undetected loading differences, flow characteristics, etc. For this reason, operational control of each of the areas was different and was based on the individual characteristics exhibited. Because excessive grease was contained in the influent to the Metro Denver plant, aeration basins No. 1 and No. 2 (located in Areas #1 and #2) were used as grease flotation units. This required that Areas #1 and #2 be operated using only two aeration basins in combination with their respective three clarifiers. Areas #3 and #4 were operated using all three aeration basins and three clarifiers in each area.

A. Control Testing Procedures and Results

The initial phase of the project involved instigating process control testing, as outlined by West (1), to monitor process performance. The basic control tests are the centrifuge test, the settleometer test, blanket depth measurements, turbidity measurements and dissolved oxygen concentration determinations. The main function of each of these procedures is:

1. Centrifuge tests were conducted on the effluent from the aeration basins and on the return sludge drawn from the final clarifiers. This test indicates the relative concentrations (by percent volume) of solids needed for determining the solids distribution in the activated sludge process. The results from the centrifuge test can also be used for other determinations. For example, the secondary clarifiers at the Metro plant are the "vacuum" type with twelve draw-off tubes in each clarifier. By using the centrifuge to determine the suspended solids concentrations, the height of each draw-off tube can be adjusted so that a uniform concentration of sludge can be drawn from the clarifier bottom.

   A relationship between percent solids by centrifuge and by weight (milligrams per liter) of total and volatile suspended solids (TSS & VSS) was obtained by comparing the results of a centrifuge test and a suspended solids analysis made on the same grab samples. This comparison was made on a daily basis throughout most of the project.
2. Settleometer testing was conducted on the effluent from the aeration basins to determine the settling rate and characteristics of the sludge. Visual observations of the sludge settling characteristics indicated the relative removals, flocculation properties, etc. of the sludges from the four areas. Analysis of the settleometer data coupled with centrifuge data also

allowed a determination of the dewatering or concentrating ability of the various mixed liquors. Settleometer data were normally collected four times per day at 5:00 A.M., 9:00 A.M., 1:00 P.M. and 9:00 P.M. During the last portion of the project, settleometer tests were run every two hours. Readings of the settled sludge volume (SSV), as indicated from the settleometer, were taken every five minutes for the first one-half hour and every ten minutes for the second one-half hour.

3. Blanket depth determinations (depth of sludge interface from surface) were taken on each of the final clarifiers to aid in determining the solids distribution and solids mass in the final clarifiers. During the last portion of the project, blanket readings were taken every two hours, twenty-four hours per day.
4. Turbidity measurements were taken on samples of settled and skimmed effluent from the final clarifiers and were used to indicate the relative effectiveness of the activated sludge process in producing a clarified effluent. The samples were settled and skimmed before turbidity measurements were made so that clarifier limitations could be eliminated from the analysis and only the relative effectiveness of the biological system could be judged.
5. Dissolved oxygen measurements were taken to assure that an adequate oxygen supply was available to support the process.

Plant operators were trained during the project to make the above control tests and to analyze and interpret the obtained data. Process control adjustments could then be made on a routine basis. In addition to conducting the control tests, the operators were required to take readings of various flow meters and to collect grab and composite samples so that the plant performance could be monitored.

B. Performance Evaluation-Procedures and Results

The Metro plant laboratory conducted various analyses on the collected samples to provide additional data for the project. Influent and effluent samples for the secondary treatment portion of the plant were composited and determinations were made for BOD_5 and TSS. In addition to overall plant influent and effluent samples, influent and effluent samples were collected and composited on each of the individual areas. Figure 2 illustrates the loading in pounds of BOD_5 applied to the secondary treatment (activated sludge) portion of the Metro Denver plant, as well as the seven day moving average of the overall plant effluent concentrations of BOD_5 and TSS.

The seven day moving average BOD_5 and TSS effluent concentrations are depicted on the lower portion of Figure 2. The BOD_5 in the effluent is closely related to the TSS concentration. This relationship emphasizes the effect of the difficulties encountered with final clarifiers at the Metro Denver plant. Without exception, each peak on the graph can be correlated with "bulking" problems in one or more of the areas. A portion of the "bulking" problem was due to a poor-settling sludge caused by process imbalance. However, many times an apparent good-settling sludge in settleometer testing was hydraulically "flushed" over the effluent weirs.

It is believed that the peaks or poor effluent quality depicted in Figure 2, prior to and during the initial phases of the Federal project, were caused by the above-average flow and BOD_5 loadings (See upper portion of Figure 2) that were received at the plant during the month of October 1969. The large peaks of effluent TSS and BOD_5 experienced in the latter part of November and in December were caused by a loss of process balance in Areas #1, #2 and #4. The exact reasons for these changes are not known. However, it may have been the type of loading being used, temperature effects, meter problems, etc. When Areas #2 and #4 were subsequently converted so that all the sewage was applied at the head of each aeration basin on December 12, 1969, the trend in the effluent concentrations of BOD_5 and TSS decreased. Area #1 was converted to this type of loading on January 5, 1970.

The peaks depicted in the month of January were caused by loss of control of Area #3. Excessive wasting of sludge and the breakdown of a clarifier were the main causes of this failure.

The peaks in February were caused by "bulking" problems in Areas #1 and #4. Area #1 was bulking because an attempt was made to rapidly build up solids while Area #4 was bulking because excessive solids had accumulated due to inaccurate flow meters on the waste sludge stream.

The effluent quality toward the end of the project (excluding the peaks in late February) was definitely on an improving trend. The only other period of corresponding quality was experienced during the first part of November 1969.

The effluent quality depicted in Figure 2 represents a composite of all of the areas and, therefore, the performance of the individual areas is not reflected directly. Areas #1 and #4 generally had the poorest quality effluents, while areas #2 and #3 gave the most consistent high quality effluents. The reasons for this may have been undetected differences in loading, the effects of different operational modes or undetected difficulties with flow meters.

Also shown in Figure 2 is the loading to the secondary process in pounds of BOD_5 per day. The dotted line represents the design average day loading (166,350 lbs. BOD_5 per day) which was exceeded on various days of all weeks during the project. The average loading for the entire period of study was 161,560 pounds BOD_5 per day. However, two aeration basins were not in service as activated sludge basins but rather as grease removal units. Thus, the aeration capacity to handle the design load was reduced.

The BOD_5 load was high during the month of October because of the effects of runoff from early snows that had occurred in the Denver area. There is no apparent explanation for the higher loadings in the middle of January and especially the peak load on January 15, 1970.

Another trend that is not as apparent is the relationship between loading and effluent quality.

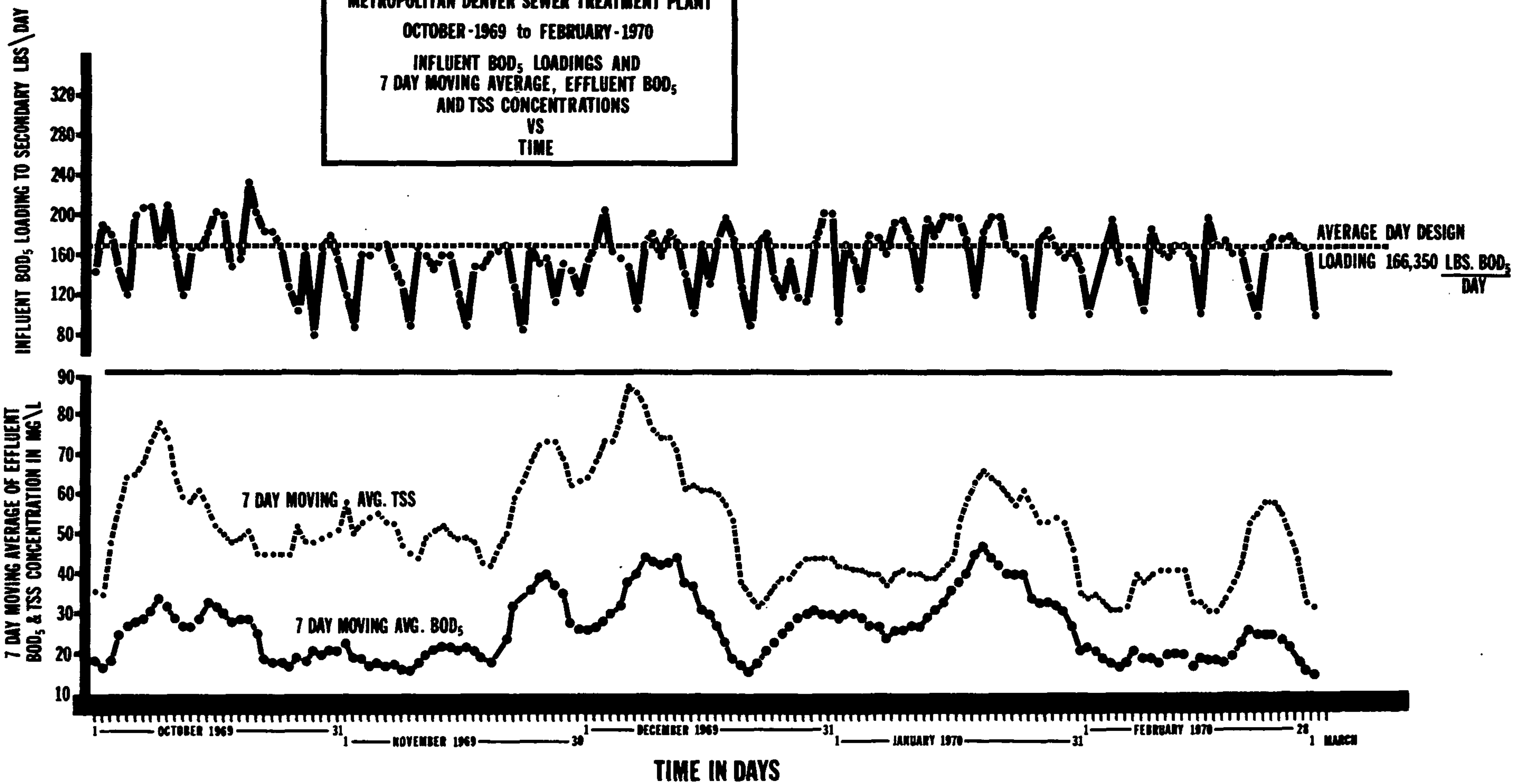


FIGURE 2

FEDERAL ASSISTANCE PROJECT
METROPOLITAN DENVER SEWER TREATMENT PLANT

OCTOBER-1969 to FEBRUARY-1970

INFLUENT BOD_5 LOADINGS AND
7 DAY MOVING AVERAGE, EFFLUENT BOD_5
AND TSS CONCENTRATIONS
VS
TIME

The low loading in December is reflected by a consistent high quality effluent during the first one-half of the month. The consistent steady loading during the last half of January and the month of February is reflected by consistently improving effluent BOD_5 and TSS concentrations. The higher loadings in October and in January demonstrate the adverse effect of decreasing effluent quality.

Figure 3 illustrates the percentage reduction (weekly average) of BOD_5 and TSS achieved by the Metro Denver plant. The percentage removal of BOD_5 is a better indicator than effluent BOD_5 concentrations of the benefits of process control. This fact is shown by the gradual increase in percentage removal throughout the project. The percentage removal of TSS declined during the initial phase of the project and then increased rapidly in December to a somewhat stable percentage reduction during the final phases of the project.

The increasing trend in percentage BOD_5 reduction in conjunction with the fluctuating effluent BOD_5 concentrations can be explained by the variations in the incoming BOD_5 load. An increasing BOD_5 load was accompanied by increased effluent concentrations and thus a relatively constant relationship as far as percentage removal.

The average reduction of BOD_5 for the entire period was 85% and for TSS it was 60%. These are reductions by the secondary treatment portion of the plant only and do not include the reductions of BOD_5 and TSS that were achieved by primary treatment. Therefore, the reduction of BOD_5 for the primary and secondary processes averaged greater than for the secondary treatment process only and adequately met the 80% minimum reduction of BOD_5 required by Colorado's Water Quality Standards.

C. Data Analysis - Procedures and Results

Large volumes of data were obtained from the numerous control tests that were conducted and the various monitoring or performance determinations that were made. These data were analyzed daily to determine trends which were indicative of process performance and from these various trends process control decisions were made. (i.e. increase or decrease return sludge flow, increase or decrease wasting flow rate, etc.) Metro Denver plant personnel were trained in analyzing the data and deriving the various trend relationships. Training was also provided in interpreting the various trend curves so that control adjustments could be made.

A large number of relationships were established to determine the best parameter or combination of parameters to use for controlling the activated sludge process. At the conclusion of the project many of these relationships were abandoned and only those that appeared most beneficial were recommended for continual use.

A summary of the more pertinent analyses performed are presented below.

The relationship between the settled sludge volume (settleometer readings) and time was plotted to indicate the trends in settleability of the sludge. Also established was the trend outlining the

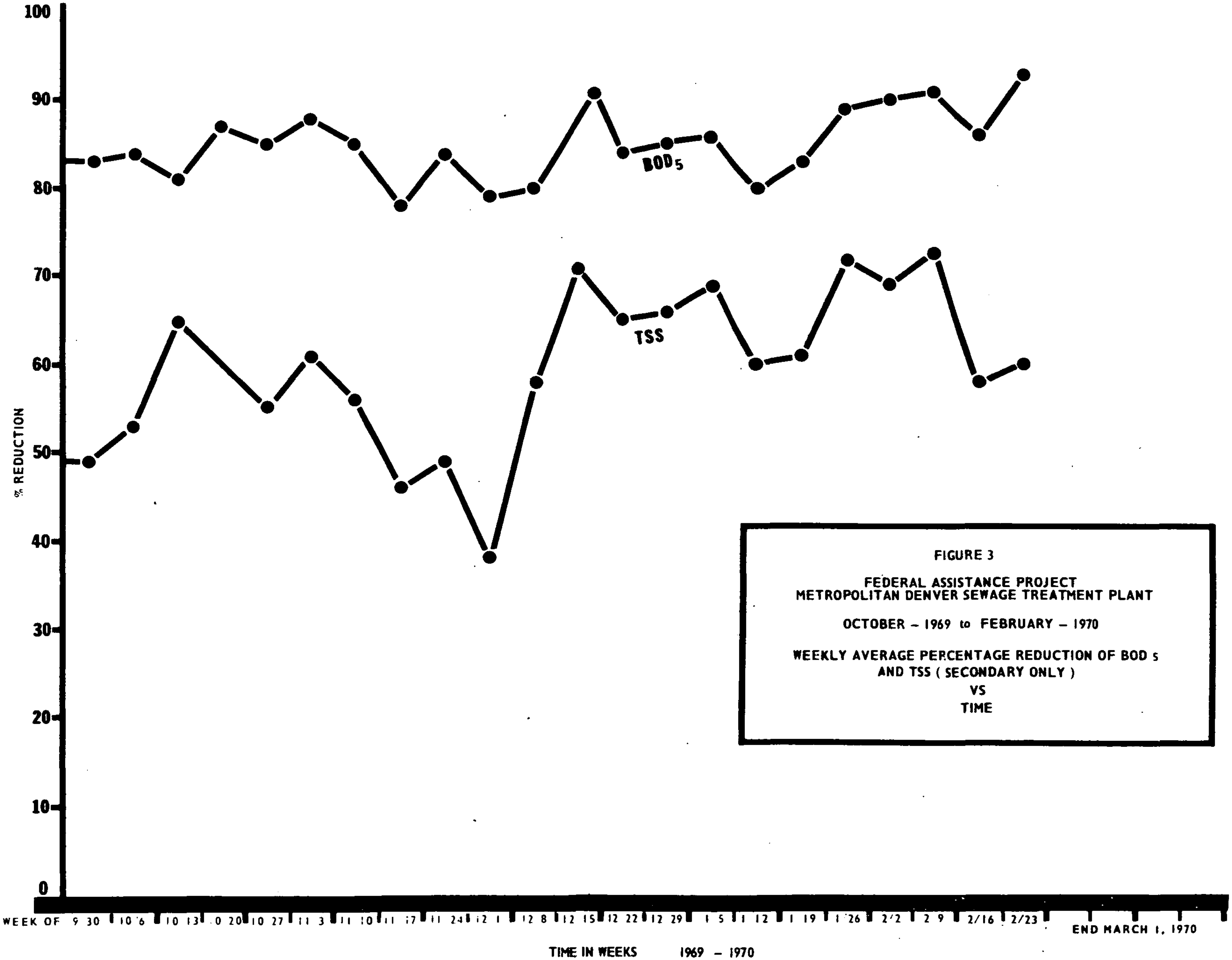


FIGURE 3

FEDERAL ASSISTANCE PROJECT
METROPOLITAN DENVER SEWAGE TREATMENT PLANT

OCTOBER - 1969 to FEBRUARY - 1970

WEEKLY AVERAGE PERCENTAGE REDUCTION OF BOD 5
AND TSS (SECONDARY ONLY)
VS
TIME

ability of the sludge to concentrate or dewater. Many of the relationships were based on data from the daily control test values. Sludge blanket depths were determined as many as twelve times per twenty-four hour period as well as aeration tank concentrations, return sludge concentrations and flow measurements. These values were averaged on a daily basis and such parameters as sludge age, total sludge mass in the system, clarifier overflow rates, sludge detention time in the clarifier, mass of sludge returned per gallon of sewage, etc. were calculated. Additional trends developed were effluent quality versus time as described by BOD_5 and TSS concentrations.

All of the above-outlined analyses, as well as others, were conducted on each of the areas.

D. Control of Areas - Procedures and Results

Prior to this project, Metro Denver plant personnel were operating the secondary treatment facilities as one large unit. All four areas were using a two aeration basin, three clarifier combination and were step loading the sewage to the aeration basins. Sewage could be introduced at four gates along the aeration basin: Gate A at the head end of the tank, Gate B approximately one-fourth of the length from the head of the basin, Gate C approximately one-half the length from the head of the basin and Gate D approximately two-thirds of the length of the tank from the head of the basin. Metro Denver personnel were loading one-half of the sewage at Gate B and one-half at Gate C. Return sludge was introduced at Gate A.

A short summary of the major operational changes made in each area will be described below. The majority of the operational changes were made to determine the operational mode which would allow maximum removal of TSS and BOD_5 and would improve the sludge characteristics to facilitate sludge handling.

1. Area #1 was operated using two aeration basins and three clarifiers throughout the project, except for a short time (one week) when one of the final clarifiers was inoperable. Only two aeration basins were used since the third aeration basin was required to remove the excessive grease received at the plant. This area was operated using step loading (one-half flow at Gate B and one-half at Gate C) from the start of the project until January 5, 1970, when loading was converted to introducing all the flow at the head of each aeration basin (Gate A). This loading procedure was used until the end of the project. All the return activated sludge was introduced at Gate A.
2. Area #2 was operated in a manner similar to Area #1. However, Area #2 was converted to loading all sewage at Gate A on December 12, 1969. Performance in Area #2 was generally superior to that of Area #1 throughout the project. Although the meters didn't indicate a difference, it appeared as though Area #2 was receiving less flow than Area #1. It was attempted to equalize the flow to all of the areas throughout the project. However, this was

difficult to achieve because of the plant's hydraulics and, therefore, equal splitting of the flow to each of the four areas was not successful.

3. Area #3 was converted to a three aeration basin, three clarifier basin operation within a week after the project started. All sewage was loaded into the aeration basins at Gate A, as well as return sludge. Area #3 provided the best overall performance during the project, as measured by effluent BOD_5 and TSS concentrations.

4. Area #4 was converted to a three aeration basin, three clarifier basin operation within a week after the project started. However, a variety of methods of introducing loads was tried on Area #4. Initially all return sludge was introduced at Gate A and the loading of one-half the sewage flow to Gate B and Gate C was maintained. However, this was changed to loading all the sewage at Gate D on November 12, 1969. (Contact stabilization) This loading was maintained until December 12, 1969 when all sewage was introduced at Gate A. Area #4, at times, showed excellent reductions but the area was generally sporadic in its performance because of difficulties in retaining the sludge in the final clarifiers.

The major operational changes above were affected by a variety of operational problems. Unreliable meter readings on the waste sludge flow, uneven flow distribution to the various areas, mechanical failure of three clarifiers during the project, and a continual problem with solids "flushing" out of the final clarifiers are but a few of the operational problems that added to the complexity of the project.

E. Control of Sludge Characteristics - Procedures and Results

The two major problems encountered at Metro Denver were the "flushing" of solids that occurred out of the final clarifiers and the sludge processing and handling problem. Since the initial emphasis was to work in the secondary treatment portion of the plant, improving removal efficiencies and effluent quality became primary considerations in operating the facility. However, a high quality effluent representing increased removals of BOD_5 and TSS also is associated with increased sludge production, which served to magnify the sludge processing and handling problems. To compensate for the increased sludge production accompanying the increased treatment efficiencies an attempt was made to develop a sludge that would concentrate or dewater better than previous sludges. The end result would be a lesser volume but increased mass of sludge being removed from the system.

At Metro Denver, the waste activated sludge is further concentrated by the use of chemical coagulants in air flotation units. Therefore, it was also attempted to develop a sludge more amenable to chemical coagulation.

Figure 4 illustrates the concentration of sludge wasted from the secondary treatment process. No data on the waste sludge total suspended solids concentration are available for the early phases of the project. Consequently, no comparison is made of the overall changes in waste sludge concentrations for the entire project period. The trends developed for the period of record are shown in Figure 4. A decrease in waste sludge concentration was initially noted paralleling the operational difficulties encountered with Areas #1, #2 and #4 in December (See IV-D above). Later in the project (January and February) the waste sludge concentration increased steadily to a weekly average of approximately 7,000 mg/l, representing a substantial increase over the low weekly average of 4,500 mg/l experienced during the last week of December. Figure 4 indicates that one of the goals in controlling sludge characteristics, that of increased waste sludge concentration, was achieved. However, the benefits derived from increasing the waste sludge concentration were partially overshadowed by the increased sludge production resulting from increased removal efficiencies of BOD_5.

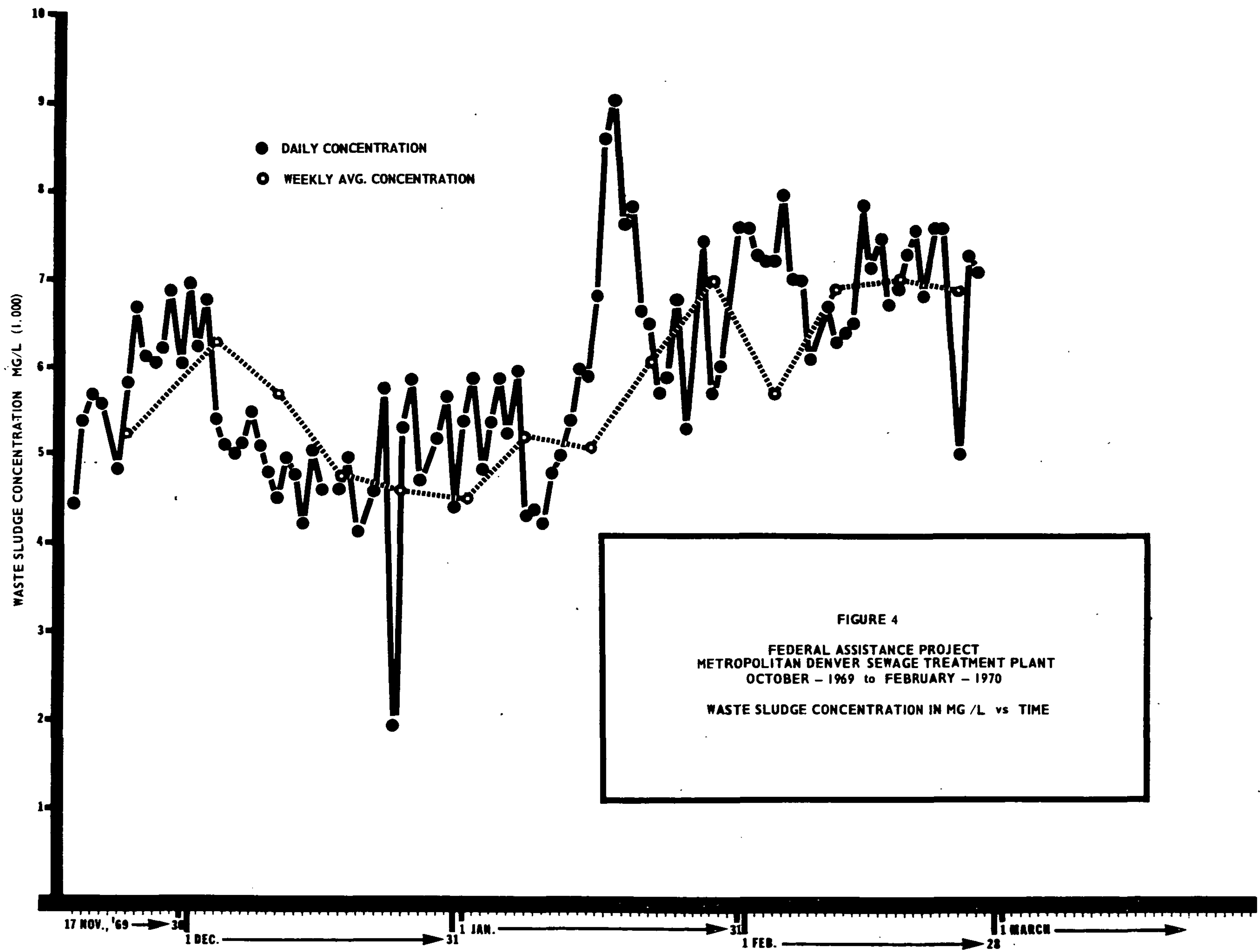


FIGURE 4

FEDERAL ASSISTANCE PROJECT
METROPOLITAN DENVER SEWAGE TREATMENT PLANT
OCTOBER – 1969 to FEBRUARY – 1970

WASTE SLUDGE CONCENTRATION IN MG /L vs TIME

V. DATA ANALYSIS

The objective of the assistance project was to operate the activated sludge process so that the waste sludge characteristics could be controlled, thereby alleviating at least a portion of the sludge handling problems. While trying to achieve this goal a large amount of data were collected. At the conclusion of the project portions of these data were analyzed to further evaluate the major problems encountered at the Metro Denver plant, namely the sludge handling problem associated with sludge produced in the activated sludge process and the problem of solids loss from the final clarifiers.

Certain portions of the data obtained during the project were selected so that smaller and more workable portions could be investigated. It was decided to evaluate only Areas #2 and #3, since these two areas covered most of the operational modes investigated and demonstrated the best response to operational controls. Area #2 was operated with both step loading and conventional loading and with two aeration basins in combination with the three clarifiers. Area #3 was operated with three aeration basins in combination with the three final clarifiers. Both Areas #2 and #3 gave the most consistently good quality effluents and responded favorably to operational controls.

A. Analysis of Sludge Production

The sludge handling problems at the Metro Denver plant were affected by the amount of sludge produced in the secondary unit. To evaluate the sludge production per pound of BOD_5 removed, an application of the kinetic model which has been used and frequently outlined in the literature to describe biological treatment systems was used. Papers by Lawrence and McCarty (2), Jenkins and Garrison (3), Pearson (4) and McKinney (5) are a few that have discussed and presented the kinetic model. The assumptions made in relating the data collected during the project to the analysis made using the kinetic model are outlined in a sample calculation presented in Appendix C.

Since the kinetic model has been well documented in the literature, the following equations will be used without a formal presentation of their theoretical basis.

Basic Kinetic Equations

$$q = \frac{F(S_0 - S_1)}{X_1 V} = \text{Substrate removal rate} \qquad \text{Equation 1}$$

$$\mu - K_d = \frac{FX_2 + WX_r}{VX_1} \qquad \text{Equation 2}$$

$$\mu = Yq = \text{Specific Growth Rate} \qquad \text{Equation 3}$$

$$\theta_c = \frac{VX_1}{FX_2 + WX_r} = \text{Mean cell residence time} \qquad \text{Equation 4}$$

$$1/\theta_c = Yq - K_d = \frac{FX_2 + WX_r}{VX_1} = \text{Net growth rate} \qquad \text{Equation 5}$$

WHERE:

q = substrate removal rate, pounds of substrate removed per pounds of cells in the system per day

S_0 = influent substrate concentration

S_1 = effluent substrate concentration

F = influent flow rate

X_1 = MLSS or MLVSS concentration

V = volume of aeration plus secondary sedimentation basins

μ = specific growth rate, pounds of cells produced per pounds of cells in the system per day

Y = yield coefficient, pounds of cells produced per pounds of substrate removed

K_d = endogenous decay coefficient, pounds of cells lost per pounds of cells in system per day

X_2 = effluent TSS or VSS concentration

W = waste sludge flow

X_r = return sludge and waste sludge TSS or VSS concentration

θ_c = mean cell residence time (sludge age), days = pounds of cells in system per pounds of cells lost from system per day

To derive a kinetic description of a particular waste source requires the development of a series of steady state conditions. In other words, the rate of change of substrate removal with time is assumed to be zero. Although steady state is never achieved in a large dynamic activated sludge plant such as Metro Denver's, certain periods of operation approach this condition. For Areas #2 and #3 time periods were selected based on uniformity of aeration basin solids concentration and of sludge settling and concentration characteristics. The uniformity of these characteristics best described a period of "steady state." Table 1 summarizes briefly the periods selected and the average of selected parameters for each period.

The reciprocal of the mean cell residence time (θ_c) is the net growth rate. Equation 5, above, outlines the relationship between the net growth rate ($1/\theta_c$) and the substrate removal rate q. These values are related by the yield coefficient (Y) and the endogenous respiration coefficient (K_d). For normal domestic wastes, values for Y and K_d have been determined. Heukelekian, Oxford and Manganelli (6) have presented values of Y = 0.5 milligrams volatile suspended solids produced per milligram of waste (BOD_5) removed and values of K_d = -0.055 as being representative, while Middlebrooks and Garland (7) have presented values of Y = 0.67 milligrams volatile suspended solids

TABLE 1

FEDERAL ASSISTANCE PROJECT
METROPOLITAN DENVER SEWAGE TREATMENT PLANT
OCTOBER 1969 - FEBRUARY 1970

A Summary Of Various Parameters Associated
With The Selected "Steady State" Periods

Parameter-Average For Period	AREA #2		AREA #3			
	1/5/70 to 1/11/70	1/29/70 to 2/12/70	12/15/69 to 1/5/70	1/10/70 to 1/13/70	1/20/70 to 1/25/70	2/9/70 to 2/16/70
Influent Flow - MGD	25.62	27.78	29.64	29.85	26.30	29.47
Return Sludge Flow - MGD	13.85	11.50	14.41	11.77	23.00	13.01
Waste Sludge Flow - MGD	.611	.262	.593	.490	.458	.445
Aeration Tank Concentration (ATC) % Volume Concentration by Centrifuge	2.96	4.46	3.71	1.36	5.44	3.92
Return Sludge Concentration (RSC) % Volume Concentration by Centrifuge	8.27	14.89	12.00	4.61	13.19	14.05
Ratio TSS/ATC *	706	585	616	817	482	684
Ratio VSS/TSS *	0.804	0.811	0.840	0.846	0.793	0.782
Influent (To Secondary) BOD_5 Concentration - mg/l	197	197	188	194	199	207
Effluent BOD_5 Concentration - mg/l	45	24	21	36	37	13
Effluent TSS Concentration - mg/l	68	36	40	44	79	26

* The relationship between % volume concentration by centrifuge and TSS and VSS was established by comparing results conducted on grab samples - normally daily grab samples.

produced per milligram of waste (BOD_5) removed and values of K_d = -0.048.

The value of Y (slope) and K_d (intercept) can be graphically determined by determining the value of θ_c (Equation 4) and q (Equation 1) and plotting $1/\theta_c$ versus q. Values of the removal rate (q) and the mean cell residence time (θ_c) were calculated using the Metro Denver data for the selected "steady state" periods. (See Appendix C for example calculations) These data are presented in Table 2. Values derived for θ_c indicate a relatively low cell residence time. Normal residence times for conventional activated sludge are five to fifteen days, with a mean of ten days [See Jenkins (3)]. When considering θ_c and normal values obtained for Y and q during the period, K_d values were not within the recognized range (i.e. -.05, -.06), which could reflect a lack of aeration capacity, complete mixing, etc.

The values of q_{BOD_5} and $1/\theta_c$ determined from the project data have been plotted in Figure 5. Also plotted is the line representing the relationship between $1/\theta_c$ and q for a typical domestic sewage using an average of the values presented in the literature (6) (7). (Y = 0.60 K_d = -0.052) The majority of the points determined using the Metro Denver data are located above the line drawn for a typical domestic sewage. This indicates that the characteristics of the waste received at the Metro Denver plant are such that they may deviate to a degree from that expected of a typical domestic waste. Again, whether waste characteristic, dissolved oxygen maintenance, deviation from complete mixing, etc. were responsible for the variation cannot be definitely determined. An attempt to determine the degree of this deviation is also illustrated on Figure 5. It is recognized that the plotted points demonstrate a considerable amount of scatter, however, a line was drawn through the centroid of these points to estimate a yield coefficient (Y). The intercept (K_d) of the estimated line was assumed to be zero to minimize any increase in slope. Since K_d must be negative, a value of K_d other than zero will produce a line of a greater slope if the line is constructed through the centroid. It is stressed that this line is only an attempt to estimate a yield factor for the Metro Denver waste, although the scatter of the points may not warrant its location on the graph or even its construction. The estimated line has a slope slightly greater than that normally expected. However, the variation between the two slopes is not great enough to warrant a conclusion that the sludge production at Metro Denver is greater than that of typical domestic sewage.

Figure 5 also shows that those points representing values from Area #2 are generally lower or closer to the "typical" line than those of Area #3. The reason for this fact is not apparent. However, Area #2 was using only two aeration basins while Area #3 was using three.

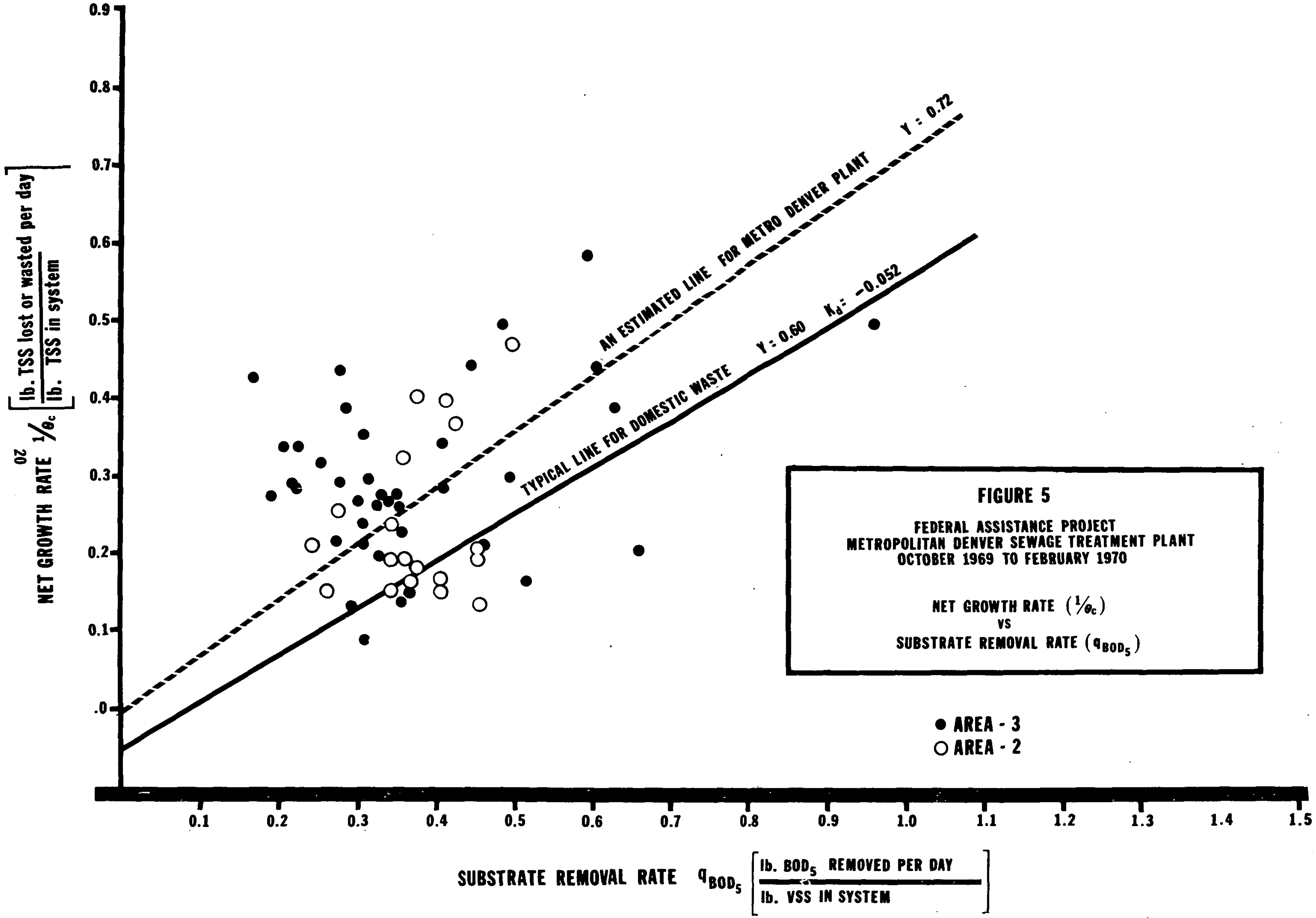
The average influent BOD_5 to the secondary process was 161,560 pounds BOD_5 per day for the entire project. The average effluent BOD_5 load for the same period was 23,700 pounds BOD_5 per day. This represents a daily average reduction of 137,900 pounds of BOD_5, or about 86 percent removal. If the yield coefficient (Y) for typical domestic sewage is applied (Y = 0.60), the amount of excess

TABLE 2

FEDERAL ASSISTANCE PROJECT
METROPOLITAN DENVER SEWAGE TREATMENT PLANT
OCTOBER 1969 - FEBRUARY 1970

Calculated Values of θ_c and q_{BOD_5}
Selected Periods of Operation
Areas #2 and #3

AREA #2					AREA #3				
Day	Date	q_{BOD_5} lb/lb	θ_c Days	$1/\theta_c$ Days-1	Day	Date	q_{BOD_5} lb/lb	θ_c Days	$1/\theta_c$ Days-1
Mon	1/05/70	0.412	2.533	0.395	Mon	12/15/69	0.592	1.72	0.581
Tues	1/06/70	0.495	2.160	0.463	Tues	12/16/69	0.483	2.03	0.493
Wed	1/07/70	0.373	2.510	0.400	Wed	12/17/69	0.606	2.29	0.437
Thurs	1/08/70	0.344	4.263	0.235	Thurs	12/18/69	0.629	2.59	0.386
Fri	1/09/70	0.424	2.736	0.365	Fri	12/19/69	0.492	3.38	0.296
Sat	1/10/70	0.352	3.128	0.320	Sat	12/20/69	0.299	3.78	0.265
Sun	1/11/70	0.275	3.947	0.253	Sun	12/21/69	0.217	3.50	0.286
					Mon	12/22/69	0.408	2.94	0.340
Thurs	1/29/70	0.365	6.514	0.154	Tues	12/23/69	0.407	3.53	0.283
Fri	1/30/70	0.404	6.250	0.160	Wed	12/24/69	0.323	3.84	0.260
Sat	1/31/70	0.341	6.714	0.149	Thurs	12/25/69	0.271	4.75	0.211
Sun	2/01/70	0.259	6.750	0.148	Fri	12/26/69	0.351	3.88	0.258
Mon	2/02/70	0.402	6.706	0.149	Sat	12/27/69	0.276	3.44	0.290
Tues	2/03/70	0.457	7.586	0.132	Sun	12/28/69	0.220	3.51	0.285
Wed	2/04/70	0.449	5.409	0.185	Mon	12/29/69	0.304	11.42	0.088
Thurs	2/05/70	0.360	5.261	0.190	Tues	12/30/69	0.252	3.17	0.315
Fri	2/06/70	0.343	5.311	0.188	Wed	12/31/69	0.285	2.59	0.387
Sat	2/07/70	0.351	5.273	0.190	Thurs	1/01/70	0.187	3.66	0.273
Sun	2/08/70	0.242	4.818	0.208	Fri	1/02/70	0.312	3.40	0.294
Mon	2/09/70	0.454	4.952	0.202	Sat	1/03/70	0.276	2.31	0.433
Tues	2/10/70	0.377	5.561	0.180	Sun	1/04/70	0.305	2.84	0.352
Wed	2/11/70	0.372	6.053	0.165	Mon	1/05/70	0.443	2.27	0.441
					Sat	1/10/70	0.956	2.02	0.495
					Sun	1/11/70	0.658	4.94	0.202
					Mon	1/12/70	0.902	5.62	0.178
					Tues	1/13/70	0.512	6.22	0.161
					Tues	1/20/70	0.366	6.66	0.150
					Wed	1/21/70	0.325	5.09	0.196
					Thurs	1/22/70	0.207	2.98	0.336
					Fri	1/23/70	0.290	7.55	0.132
					Sat	1/24/70	0.224	2.97	0.338
					Sun	1/25/70	0.166	2.36	0.424
					Mon	2/09/70	0.348	2.70	0.370
					Tues	2/10/70	0.330	3.68	0.272
					Wed	2/11/70	0.339	3.75	0.267
					Thurs	2/12/70	0.354	4.38	0.228
					Fri	2/13/70	0.307	4.75	0.211
					Sat	2/14/70	0.354	4.29	0.233
					Sun	2/15/70	0.302	4.24	0.236
					Mon	2/16/70	0.458	4.88	0.205


NET GROWTH RATE $1/\theta_c^{20}$ [lb. TSS lost or wasted per day / lb. TSS in system]
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
SUBSTRATE REMOVAL RATE q_{BOD_5} [lb. BOD_5 REMOVED PER DAY / lb. VSS IN SYSTEM]
AN ESTIMATED LINE FOR METRO DENVER PLANT
Y : 0.72
TYPICAL LINE FOR DOMESTIC WASTE
Y : 0.60
K_d: −0.052
FIGURE 5
FEDERAL ASSISTANCE PROJECT
METROPOLITAN DENVER SEWAGE TREATMENT PLANT
OCTOBER 1969 TO FEBRUARY 1970
NET GROWTH RATE ($1/\theta_c$)
VS
SUBSTRATE REMOVAL RATE (q_{BOD_5})
● AREA - 3
○ AREA - 2

sludge produced in the secondary would have been 82,800 pounds per day. To maintain a specific cell residence time (sludge age), this amount of sludge should have been wasted. If the estimated yield coefficient Y = 0.72 (See Figure 5) is used, 99,300 pounds per day would have been produced and would have had to be wasted. These values are daily average values and do not represent the peaks in loading and sludge production that occur. Both values are less than the 131,000 pounds per day which was the design basis for the Metro Plant secondary sludge handling facilities. Although this design loading was not exceeded on an average basis, problems did occur with the sludge handling facilities (i.e. concentrators and incinerators).

B. Analysis of Secondary Clarifiers

Eckenfelder and O'Connor (8) have stated that the size of secondary clarifiers in biological systems is related to three design factors. These factors are: (1) The permissible retention of the settled sludge in the basin as dictated by its biological properties, (2) The area required for clarification over the operating mixed liquor suspended solids range, and (3) The area and volume requirements to produce by thickening an underflow of a desired concentration.

At Metro Denver sludge retention in the final clarifiers should be minimized; possibly to one hour or less. The value of the sludge detention time, SDT, in the final clarifiers was determined during the project on a daily average basis and normally was easily controlled by adjusting the return sludge pumping rates. This fact implies that the volume of the clarifiers and the return sludge pumping capacity was generally satisfactory to allow rapid removal of the sludge.

The clarification and thickening capacities for a secondary clarifier can be estimated from batch settling tests. A great number of batch settling tests were conducted during the project, and these results were used to evaluate the clarification and thickening capacities of the Metro Denver plant.

The limitation of this type of analysis is in the determination of a representative batch settling test. The previously selected "steady state" periods for Areas #2 and #3 were selected for analysis. These periods were initially selected based on uniformity of sludge settling and sludge concentration characteristics, as well as uniformity of solids concentration. In addition, these periods were generally the best periods of control and operation and therefore were representative of sludge settling characteristics that were experienced during the project.

During most of the project four batch settling tests were conducted on a daily basis at 5:00 A.M., 9:00 A.M., 1:00 P.M. and 9:00 P.M. Values for settled sludge volume for each hourly test were averaged for the various "steady state" periods. These values are presented in Table 3. Table 1 gives the associated average parameters and average flow values for these same periods. The period January 10, 1970 to January 13, 1970 for Area #3 was omitted from this analysis because of the low mixed liquor solids concentration and resulting rapid settling.

TABLE 3

FEDERAL ASSISTANCE PROJECT
METROPOLITAN DENVER SEWAGE TREATMENT PLANT
OCTOBER 1969 - FEBRUARY 1970

Average Settled Sludge Volumes For
"Steady State" Periods

Area and "Steady State" Period	Settling Time (Min)	Average Settled Sludge Volumes for "Steady State" Period - cc/l			
		5:00 A.M.	9:00 A.M.	1:00 P.M.	9:00 P.M.
#2	5	496	523	424	517
	10	346	383	286	332
January 5, 1970	20	261	279	211	246
to	30	224	239	179	213
January 11, 1970	60	171	184	144	161
#2	5	666	737	453	617
	10	489	545	332	452
January 29, 1970	20	403	433	261	362
to	30	343	376	228	320
February 12, 1970	60	276	301	184	249
#3	5	805	855	650	677
	10	660	725	521	523
December 15, 1969	20	510	585	408	401
to	30	431	495	347	348
January 5, 1970	60	320	360	260	265
#3	5	922	953	903	936
	10	870	914	752	829
January 20, 1970	20	742	828	582	598
to	30	642	717	482	489
January 25, 1970	60	480	542	367	381
#3	5	541	604	470	539
	10	413	476	368	421
February 9, 1970	20	334	382	294	337
to	30	294	335	259	308
February 16, 1970	60	238	264	207	237

The clarification capacity required in a clarifier can be estimated from the initial rate at which the solids liquid interface subsides as outlined by Eckenfelder (8), Rich (9) and Smith and Loveless (10). The zone settling rate (V_s) can be calculated by determining the slope of the initial straight line portion of the sludge settling curve. This settling rate can then be expressed as the equivalent surface overflow rate since solids will be lost in the plant effluent if the settling rate is exceeded by the clarifier overflow rate.

$$O_r = V_s \times 7.5 \text{ gallons per cubic foot} \times 24 \text{ hours per day}$$
$$= V_s \times 180$$
Equation 6

WHERE:

O_r = Equivalent Surface Overflow Rate (gal/sq ft/day)

V_s = Zone Settling Rate (ft/hr)

Curves were drawn from each set of average settled sludge volume values for the selected periods. The slope of the initial straight line portion of the curve was determined and thus the zone settling rate (V_s) was established. An example determination of V_s is shown in Figure 6. The values of the zone settling rates (V_s), as well as the associated equivalent overflow rates (O_r), are shown in Table 4.

The zone settling rate (V_s) varied throughout the "average" day for the selected periods. This is to be expected since the zone settling rate is a function of the initial MLSS concentration and of the loading rate, i.e. pounds of BOD per pounds of MLSS. [Smith and Loveless (10)]. Flow variations throughout the day caused the MLSS and the loading rates to fluctuate, causing the observed variations in the values of V_s. No attempt was made to distinguish between the portion of the change in V_s due to changing load and that due to change of initial MLSS concentration or in response to any possible variances in growth rates. In addition, as mentioned earlier, cell residence time seldom exceeded five to six days. Associated effects on settleability were also not separable.

It is shown in Table 4 that the maximum zone settling rate normally occurred at the 1:00 P.M. test. However, it was observed that this was also the time of the day when most of the solids flushing occurred. Table 4 shows the calculated overflow rates based on the daily average flow for each area during the periods. Each area at Metro Denver had three 130 foot diameter secondary clarifiers which gave a total surface overflow area of 39,900 square feet. Generally the 1:00 P.M. equivalent surface overflow rates exceeded the average clarifier overflow rates for the periods investigated. However, this is based on maximum zone settling rates compared with average clarifier overflow rates. If the maximum flow is assumed to occur at 1:00 P.M. and the design ratio of $\frac{\text{maximum hourly rate}}{\text{average day rate}} = 2$ [See Henningson, Durham and Richardson (11)] is applied to the clarifier overflow rates, then in every case the equivalent surface overflow rate derived from V_s values at

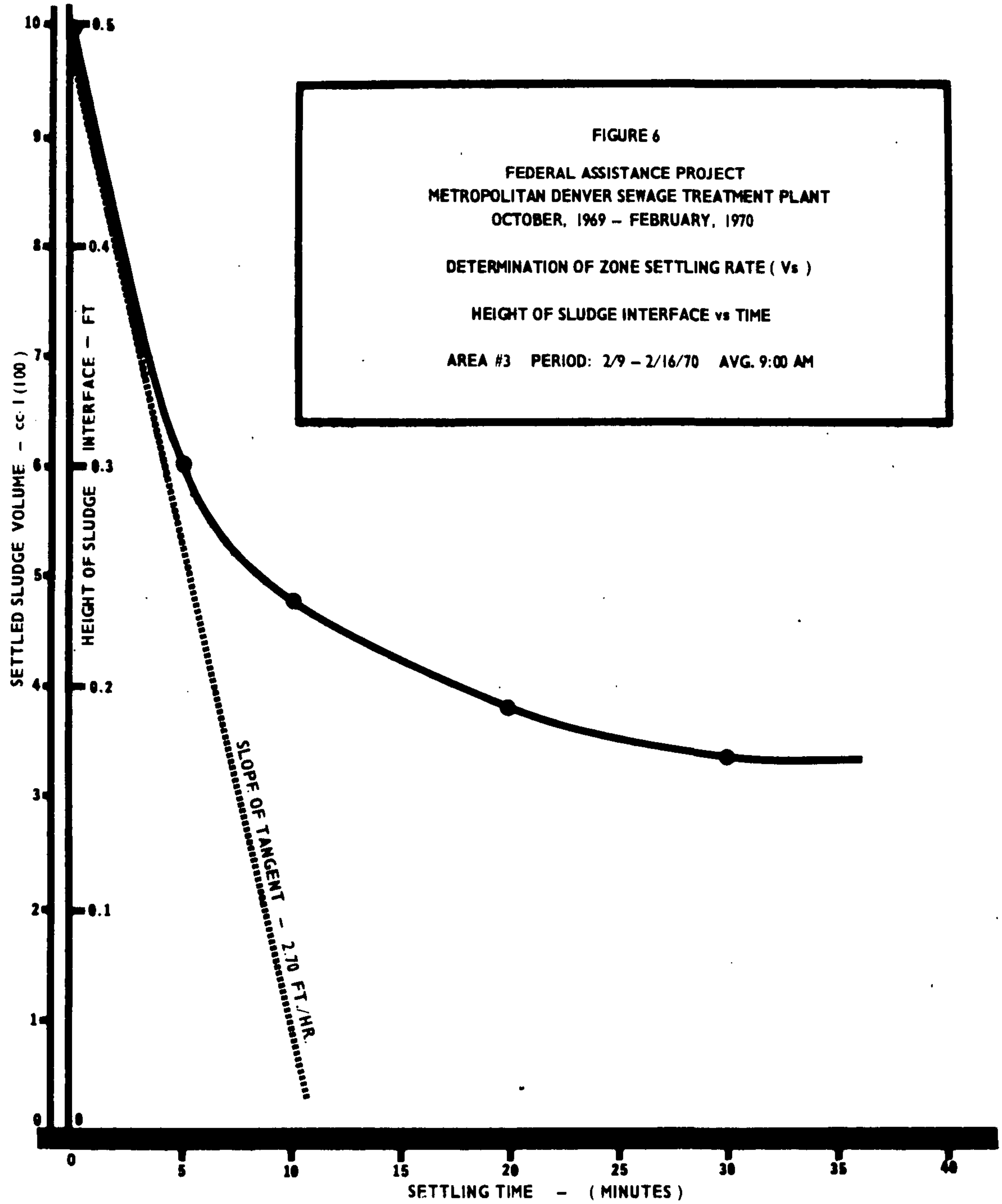


FIGURE 6
FEDERAL ASSISTANCE PROJECT
METROPOLITAN DENVER SEWAGE TREATMENT PLANT
OCTOBER, 1969 – FEBRUARY, 1970
DETERMINATION OF ZONE SETTLING RATE (Vs)
HEIGHT OF SLUDGE INTERFACE vs TIME
AREA #3 PERIOD: 2/9 – 2/16/70 AVG. 9:00 AM
SETTLED SLUDGE VOLUME – cc·l (100)
HEIGHT OF SLUDGE INTERFACE – FT
SLOPE OF TANGENT – 2.70 FT./HR.
SETTLING TIME – (MINUTES)
0
5
10
15
20
25
30
35
40
0.5
0.4
0.3
0.2
0.1
10
9
8
7
6
5
4
3
2
1

TABLE 4

FEDERAL ASSISTANCE PROJECT
METROPOLITAN DENVER SEWAGE TREATMENT PLANT
OCTOBER 1969 - FEBRUARY 1970

Zone Settling Rates (V_s) And Equivalent Surface Overflow Rates (O_r) For "Steady State" Periods

Area and "Steady State" Period	Zone Settling Rates (V_s) - ft/hr and Equivalent Surface Overflow Rates (O_r) - gpsfd for "Steady State" Periods *				Daily Average Overflow Rate For "Period"
	5:00 A.M.	9:00 A.M.	1:00 P.M.	9:00 P.M.	gpsfd
#2	3.43	6.80	3.30	3.83	644
January 5, 1970 to January 11, 1970	620	595	1,225	690	
#2	1.72	1.45	4.93	3.03	698
January 29, 1970 to February 12, 1970	310	262	890	546	
#3	1.13	0.88	2.72	2.53	744
December 15, 1969 to January 5, 1970	204	159	490	456	
#3	<1	<1	<1	<1	660
January 20, 1970 to January 25, 1970	<180	<180	<180	<180	
#3	3.00	2.70	6.00	3.24	740
February 9, 1970 to February 16, 1970	544	488	1,080	585	

* V_s values are given on top and O_r values on bottom.

1:00 P.M. is exceeded by the clarifier overflow rate and flushing of solids could be expected to occur. Additionally, a portion of this flushing may be attributable to the normal high return sludge pumping rates that were utilized in the operational controls.

This problem was further aggravated by locating the effluent weirs for the 130 foot diameter clarifiers at the outer edge of the clarifiers. This allowed localized high upflow velocities to occur in the final clarifiers. These localized high velocity currents could have been avoided if weir placement had been such that more of the surface area in the final clarifiers was developed to provide a more uniform upflow velocity. However, even if the additional weirs were located to develop more of the surface area of the final clarifiers, the data shown in Table 4 indicates that problems with flushing of solids still could occur.

Therefore, either more surface area must be provided or the settling characteristics must be altered such that the zone settling rate is increased (i.e. a faster settling sludge). The zone settling rate is dependent upon the initial MLSS concentration and the loading rate (which directly affect the sludge flocculation characteristics). [See Eckenfelder (8) and Smith and Loveless (10)] These factors are dependent upon the influent flow rate, which is highly variable and therefore makes a positive control of the zone settling rate difficult to achieve. For ease of operation it appears that more effective surface area, which is better developed by weir placement, is required at Metro Denver to provide adequate clarification capacity.

The thickening capacity required in a final clarifier can also be estimated from a batch settling test (8) (9). The average 1:00 P.M. settling test (See Table 3) was selected for analysis since this time was assumed to coincide with normal daily peak flows which are approximated by twice the average daily flow (11). The most rapid 1:00 P.M. zone settling rate (See Table 4) was selected to determine a desired thickening capacity since the value determined would represent a minimum thickening area required. (i.e. any settling rate with a lesser value would require more thickening area.) The peak zone settling rate for Area #2 at 1:00 P.M. was 4.93 feet per hour and for Area #3 it was 6.00 feet per hour. (See Table 4)

Rich (9) outlines an equation for determining the thickening area required:

$$A = \frac{qT_u}{Z'_o} \qquad \text{Equation 7}$$

WHERE:

A = cross section required to obtain a layer of a desired concentration -- ft^2

q = flow rate of the mixed liquor entering the final clarifier -- ft^3/sec.

Z'_0 = initial height of the interface in the settling column - feet (The settleometers used at Metro Denver for the batch settling tests had a 0.5 feet depth.)

T_u = settling time required to attain a desired underflow concentration - sec. [This value is obtained from a graphical analysis of a sludge settling curve as outlined by Eckenfelder (8) and Rich (9).]

To complete the analysis of thickening capacity a desired underflow concentration must be selected. At Metro Denver the design values for underflow concentration expected ranged between 5,000 to 15,000 mg/l. Therefore, a desired underflow concentration of 10,000 mg/l was selected.

The settling time (T_u) required to obtain a 10,000 mg/l underflow concentration for Area #2 for the selected period January 29 to February 12, 1970 (V_s = 4.93) was determined by a graphical analysis of the sludge settling curve. This value was used with the average flow for the period to determine by Equation 7 the area required for thickening. For average flows 42,500 ft^2 would be required for thickening while for peak flows 85,450 ft^2 would be required. A similar analysis conducted on Area #3 for the selected period (February 9 to February 16, 1970) showed required areas of 114,000 ft^2 and 57,000 ft^2 at peak and average flow rates respectively.

The available surface area in Areas #2 and #3 is 39,900 ft^2. This is not adequate to provide the thickening area required to achieve a 10,000 mg/l underflow concentration with the type of sludge obtained during the project. The above analysis also indicates the implications of limited thickening capacity on sludge handling problems. Without sufficient thickening capacity a more dilute waste sludge flow concentration is realized. The effect of the dilute concentrations is shown by the relative differences in total sludge volumes to waste 100,000 lbs. of solids as summarized in Table 5.

The preceding materials were developed to compare actual performance results with the batch settling data. Most importantly, Rich (9) describes the numerous departures of actual sedimentation basin performance from that of ideal basins. "The net effect of all the factors that contribute toward reducing the efficiency of sedimentation in an actual basin is to decrease the clarification rate and to increase the detention time over that derived from a batch analysis. For the sedimentation of flocculent particles from dilute suspensions the overflow rate generally will be decreased by a factor of 1.25 to 1.75 and the detention time will be increased by a factor of 1.50 to 2.00. In scaling-up thickening operations, a factor of 1.0 to 2.0 is applied to the area required for clarification (hindered settling) and a factor of 1.0 to 1.5 to that required for thickening."

Results of the Metro Denver settleability testing should be judged in this light and with the reported values of loading, residence times, etc. obtained during the period.

TABLE 5

FEDERAL ASSISTANCE PROJECT
METROPOLITAN DENVER SEWAGE TREATMENT PLANT
OCTOBER 1969 - FEBRUARY 1970

Waste Sludge Flow Required To Remove
An Equivalent Amount Of Solids With
Varying Underflow Concentrations

Underflow Concentrations -- mg/l	5,000	10,000	15,000
Waste Volume to Remove 100,000 Lbs. of Solids - Gal.	2,400,000	1,200,000	800,000

VI. SUMMARY AND CONCLUSIONS

One of the objectives of the project was to instigate additional process control testing for the secondary treatment (activated sludge) portion of the Metro Denver plant. Plant personnel were trained to conduct process control tests on a routine basis, to evaluate and graph various selected parameters, and to interpret these data so that adequate daily operational changes could be made. The full beneficial effect of these process controls was not realized because of various problems encountered with plant operation, as outlined below:

1. Adjustment of flow to each aeration basin was difficult because each basin was fed by a gate opening from a common channel. Balancing the hydraulic effects of ten gates to achieve equal flow to each of the four areas required a great deal of attention. After the gates were adjusted, determination of actual flow to each aeration basin was questionable because of occurrences of unreliable instrument readings.
2. Two of the twelve aeration basins provided in the secondary portion of the plant were used as grease flotation units to remove grease from the influent waste stream and were thus unavailable for use as a portion of the activated sludge process. This becomes important since the average loading to the secondary during this investigation was 161,560 pounds of BOD_5 per day, which is approaching the design loading of 166,350 pounds of BOD_5 per day.
3. The rate of wasting sludge was difficult to control on a continuous basis because the meters and control instruments frequently gave erroneous readings. Several times it was discovered that actual flow and meter readings differed by as much as 100 percent. This definitely effected the ability to establish a process balance.
4. No reserve capacity was available for final clarification. When a clarifier broke down (three clarifiers broke down during the project) solids were carried over in the plant effluent, the effluent quality was degraded, and the process balance in the affected area was impaired.

Other difficulties encountered were the sludge production in the secondary treatment process and the flushing of solids from the final clarifiers into the effluent.

The initial emphasis in dealing with the problems at Metro was to control the secondary treatment portion of the plant. Therefore, removal efficiencies and effluent quality became important considerations in operating the facility. Unfortunately, a high quality effluent representing increased removals of BOD_5 and TSS is associated with increased sludge production, which served to antagonize the sludge processing and handling problem. To compensate for the increased sludge production that accompanied the slightly increased removals achieved during the project and to relieve the existing sludge problem, an attempt was made to develop a sludge that would concentrate or dewater better than previously. This would have allowed a lesser volume of a more dense sludge to be wasted. Average concentrations of 6,900 to 7,000 mg/l were obtained in the waste sludge flow toward the end of the project. However, the benefits derived from increasing the waste sludge concentration were not realized because of the increased removal efficiencies and the resulting increase in the amount of sludge produced.

Although slightly greater BOD and suspended solids removal efficiencies were realized through operational controls, little was accomplished to alleviate the sludge handling problems at the plant. It is hoped that the increased removal efficiencies will be maintained and the sludge handling procedures modified to alleviate these difficulties. An investigation of the sludge production characteristics at the Metro plant to compare them with presently available sludge handling facilities was made.

A kinetic model was applied to the collected data to determine the microbiological character of the waste stream. At Metro Denver the results of this analysis indicate that the characteristics of the waste received at the Metro Denver plant do not deviate significantly from those expected from a typical domestic waste. An attempt was made to determine the amount of sludge production and to compare these results with the sludge handling capacities at the plant. The results indicate that the design sludge handling capacity (131,000 pounds per day of secondary sludge) could be exceeded during peak loading periods. It is important when sludge handling procedures or facilities are modified at Metro Denver that the sludge production during peak loading periods be considered in the design criteria.

The second major operating difficulty evaluated was the flushing of solids that occurred from the final clarifiers. Representative zone settling rates were determined for the sludge at Metro Denver based on the numerous batch settling test data obtained. From this analysis it was determined that the clarification capacity of the final clarifiers at the Metro Denver plant was not adequate for the selected periods of investigation. The type of sludge developed proved to have a zone settling rate (V_s) that was too slow to be held in the final clarifiers. A portion of the flushing problem was also attributed to the large diameter (130 feet) final clarifiers which had effluent weirs located at or near the outer periphery. This weir placement allowed excessive velocity currents to develop further aggravating the solids "flushing" problem. This problem can be alleviated by a different weir placement arrangement that allows a more uniform use of the surface area on the final clarifiers. (i.e. another launder of weirs located nearer the center of the tank.)

It was also determined that the thickening area requirements of the final clarifiers were not adequate to obtain a 10,000 mg/l underflow concentration with the type of sludge developed during the project.

Two alternatives can be used to change the effects of the slow zone settling rates of the sludge.

The first is to increase the clarifier surface area to reduce overflow rates to less than the settling velocity established by the zone settling rate. This would provide additional thickening area at the same time. The second approach would be to increase the zone settling rate of the sludge at the Metro Denver plant. The zone settling rate is a function of the MLSS concentration and the loading rate. Because of the constantly changing load (flow) and its effect on the MLSS concentration, it is a continuous problem to maintain a proper process balance and achieve a desired zone settling rate.

VII. RECOMMENDATIONS

The following recommendations are made:

1. It is recommended that control testing established during the Federal Assistance Project be continued.
2. An effort should be made at the Metro Denver plant to assure the accuracy of all metered values in order to adequately use control testing procedures.
3. It is recommended that Metro Denver be considered for demonstrating various comparisons. Because of the unique arrangement of facilities at the Metro plant, four areas with an identical influent waste are available for evaluation. This arrangement is ideal for conducting comparisons of various types of equipment (i.e. provide various types of aeration equipment, evaluate effects of different skimmer arrangements on final clarifiers, evaluate different weir placement patterns on final clarifiers, etc.).
4. The Metro Denver plant should be operated to achieve the maximum possible reduction of waste pollutants. To operate and achieve these high removal efficiencies, modifications to the sludge handling procedures or facilities must be made. Any modification of the Metro Denver sludge handling facilities should take into account the sludge production characteristics at the Metro Denver plant which are apparently similar to those of typical domestic sewage and the clarification-thickening capacity requirements of the secondary clarifiers.
5. Properly located additional weirs are recommended on the secondary clarifiers to develop a more uniform distribution of flow over the surface area provided in the relatively large diameter final clarifiers. Surface skimmers are also recommended.
6. Additional clarifier surface area with proper weir placement is recommended or the sludge settling characteristics must be altered by operational control in order to assure that solids will not be flushed into the final effluent. Additionally, increased area would appear to improve sludge thickening, thereby reducing waste sludge volumes. More reliable control would also be obtained by increased clarifier surface area.

VIII. APPENDICES

Appendix A - A Resolution: "Concerning the Federal Government's Responsibilities in Constructing and Operating Sewage Disposal Facilities."

Appendix B - References

Appendix C - Determination of Substrate Removal Rate (q) and Net Growth Rate ($1/\theta_c$)

APPENDIX A

A RESOLUTION ADOPTED BY METROPOLITAN
DENVER SEWAGE DISPOSAL DISTRICT NO. 1'S
BOARD OF DIRECTORS

ENTITLED

"Concerning the Federal Government's
Responsibilities in Constructing and
Operating Sewage Disposal Facilities"

July 11, 1969

A RESOLUTION

(CONCERNING THE FEDERAL GOVERNMENT'S RESPONSIBILITIES IN CONSTRUCTING AND OPERATING SEWAGE DISPOSAL FACILITIES)

WHEREAS, the federal government has enacted water pollution control legislation which makes it incumbent upon states to establish stream quality limits, or to be subjected to stream quality standards as dictated by the federal government itself, and

WHEREAS, the water pollution legislation adopted by the State of Colorado is not consistent but rather relates to stream classification, based upon an evaluation of each stream's individual characteristics, and

WHEREAS, the evaluation process for stream classification relates to a multitude of factors other than the consideration of protection to health and the abatement of nuisance, and

WHEREAS, sewage treatment to the extent of providing for the development of streams and adjacent properties into recreational areas does require an additional capital investment for treatment facilities, as well as substantially increasing operating and maintenance expenses thereof, and

WHEREAS, the arid and semi-arid regions of the western United States have additional burdens for capital investments and operational and maintenance expenses, due to the lack of dilution water to the same degree as do the other regions of the United States, and

WHEREAS, the high degree of sewage treatment required to effect water pollution control does generate additions to solid wastes to be disposed of in the form of sludge, and

WHEREAS, cities, counties and independent samitation districts in the Metropolitan Denver area recognized in the early 1960's their financial inability as separate political subdivisions to meet the strict standards being forced upon them by the national Congress and the State Legislature, and

WHEREAS, these independent political subdivisions banded together and created the Metropolitan Denver Sanitation District No. 1, prevailing upon the Colorado General Assembly to adopt Colorado Revised Statute 89-15-5 giving them authority so to do, and

WHEREAS, property owning electorate, demonstrating their concern over the pollution threat to the health and welfare of the total community, by a vote of 25,099 to 2,756, agreed to mortgage their property so that bonds in the amount of $32.5 million could be issued for the construction of a modern primary and secondary sewage treatment plant at the confluence of Clear and Sand Creeks with the Platte River, and

WHEREAS, this plant has been constructed following review and approval of engineering and construction plans by all required federal, state and regional agencies with these bond moneys, supplemented by some federal but no state funds, to take care of residential, commercial and industrial wastes with each participating political subdivision, by means of billings to users within their subdivisions, paying their proportionate shares of all operating costs, and

WHEREAS, this multi-million-dollar plant does bring effluent dumped into the Platte River up to water pollution control standards it does not dispose of the solid wastes resulting from such treatment for a variety of reasons not the least of which is the fact that our technology has developed a multitude of consumer goods, paper products, garbage disposal systems and detergents, handle human waste, and

WHEREAS, resident property owners of Metropolitan Denver recognized their responsibilities to take the initiative and act to abate practices which contributed to the pollution of Clear Creek, Bear Creek, Sand Creek and other watercourses that flowed into the Platte River as well as the Platte River itself, and

WHEREAS, residents and taxpayers of the various political subdivisions that are now participating in this metropolitan effort to eliminate a pollution problem are being taxed the maximum they can afford to pay for sewage disposal and do not have the financial capability to pay imminent additional operating and maintenance costs or to effect the engineering, design and capital construction necessary to increase the efficiency of this plant so as to halt continuing pollution of our environment;

NOW, THEREFORE, be it resolved, that the Board of Directors of the Metropolitan Denver Sanitation District No. 1 hereby does petition the Congress of the United States and the appropriate federal agencies to:

1. Conduct and finance extensive research to discover new techniques of handling the variety of waste products now being dumped into the sanitary sewers of America and being carried to traditional plants that do not have the capabilities of handling them.
2. Make available to this district a special team of scientists and engineers assembled from appropriate federal departments to serve as a task force to inspect the District's sewage disposal plant and make appropriate recommendations.
3. Appropriate sufficient funds so that these recommendations can be implemented, since the Federal government has set up the standards the District is required to meet.
4. Recognize that antipollution standards adopted by the Congress and enforced by federal and state as well as local government agencies are placing unprecedented and unbearable financial responsibilities on local governments and their constituents, thus making it mandatory that the Federal government assist local communities in meeting costs involved not only in constructing adequate sewage facilities but of operating them as well.

APPENDIX B

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APPENDIX C

DETERMINATION OF SUBSTRATE REMOVAL RATE (q) AND NET GROWTH RATE ($1/\theta_c$)

It is the purpose of this appendix to present a sample calculation of the determinations made of the substrate removal rate (q) and the net growth rate ($1/\theta_c$). Throughout the sample calculation the assumptions made in relating the data collected and analyzed during the assistance project to the analysis made using the kinetic model will be stated. Data obtained for Area #3 on December 15, 1969, will be used for the presentation of the sample calculation.

A. Determination of the Substrate Removal Rate (q)

$$q = \frac{F(S_0 - S_1)}{VX_1} \qquad \text{[See Jenkins (3)]}$$

1. Determination of $F(S_0 - S_1)$

WHERE:

S_0 = influent substrate concentration - For Metro Denver a BOD_5 value based on a composite sample was used to represent S_0 (12/15/69 for Area #3, S_0 = 198 mg/l).

S_1 = effluent substrate concentration - For Metro Denver a BOD_5 value based on a composite sample was used to represent S_1 (12/15/69 for Area #3, S_1 = 16 mg/l).

F = influent flow rate (12/15/69 for Area #3, F = 34.8 MGD) - This value was obtained from flow meters at the Metro Denver plant.

THEREFORE:

F = 34.8 MGD S_0 = 198 mg/l S_1 = 16 mg/l

34.8 (198-16) (8.33 lbs/gal) = 52,760 lbs. BOD_5 removed/day

2. Determination of VX_1

WHERE:

V = volume of aeration plus secondary sedimentation basins

X_1 = MLSS or MLVSS concentration

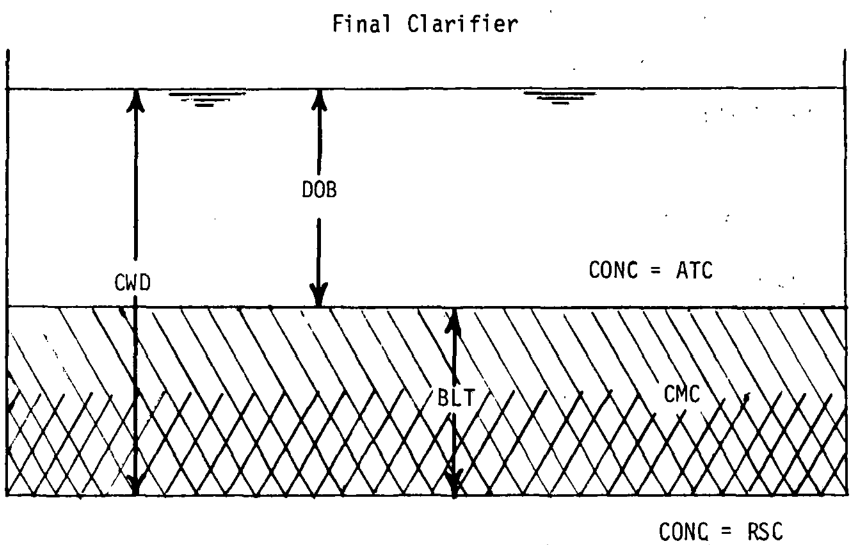
NOTE:

VX_1 is a number representing the total pounds of cells in the system. Normally in determining this value mixed liquor suspended solids concentrations by weight are used (X_1). Instead of MLSS concentrations, sludge concentrations were obtained on a percent volume basis by using the centrifuge. During most of the project, however, daily relationships between percent concentration of sludge by volume and concentration by weight were determined on the basis of a grab sample. These comparisons varied from 1% = 500 mg/l TSS to 1% = 1,000 mg/l TSS. However, during "steady state" conditions, the relationship between spin concentrations and mg/l remained fairly constant. Therefore, the average of the relationship between spin concentrations and mg/l for each "steady state" period selected was determined and used to convert the spin concentration to mg/l of total suspended solids. The relationship between total suspended solids (TSS) and volatile suspended solids (VSS) was also obtained from the analysis of daily grab samples. The average ratio of VSS/TSS for each "steady state" period was determined. For December 15, 1969, and the associated "steady state" period the average relationship between volume or spin concentrations and mg/l was 1% = 616 mg/l TSS for Area #3 and the average VSS/TSS ratio was 0.840. Another refinement was also used in obtaining VX_1, which will be outlined below.

APPROACH:

A value comparable to VX_1 called total sludge units (TSU) was determined using the Metro Denver data. Total sludge units are equivalent to the summation of the aerator sludge units (ASU) and the clarifier sludge units (CSU). A sludge unit is defined as one gallon of sludge at 100% concentration, based on sludge concentrations obtained by centrifuge testing. One of the differences between TSU and VX_1 lies in the fact that a modification is made in determining the clarifier sludge units.

a. <u>Determination of Clarifier Sludge Units (CSU)</u>



WHERE: [West's Symbols (12)]

CWD = clarifier water depth (mean depth if bottom is sloped) - At Metro Denver the mean depth was 11.7 feet.

DOB = depth of sludge blanket - At Metro Denver blanket depth determinations were made every two hours on each of the three clarifiers in the respective areas. These values were averaged on a daily basis to obtain DOB (12/15/69 for Area #3, DOB = 9.7 feet).

BLT = sludge blanket thickness - This value is equivalent to CWD - DOB (11.7 - 9.7 = 2.0 feet (BLT) for Area #3 on 12/15/69).

ATC = aeration tank concentration - This is the concentration of sludge by percent volume in the aeration basin. This value was obtained by centrifuging samples of the effluent from the aeration basins. A daily average of ATC values was obtained for use in calculations. (12/15/69 for Area #3, ATC = 2.75%)

RSC = return sludge concentration - This is the concentration of sludge by percent volume drawn off the bottom of the secondary clarifiers. This value was obtained by centrifuging samples taken from the return sludge wet well. A daily average of RSC values was obtained for use in calculations. (12/15/69 for Area #3, RSC = 11.25%)

CMC = clarifier mean sludge concentration - This value is obtained by the equation $\frac{ATC + RSC}{2}$. This equation assumes a sludge concentration at the top of the blanket equal to ATC and that at the bottom equal to RSC and a uniform distribution of concentration. ($\frac{2.75 + 11.25}{2}$ = 7.0% (CMC) for Area #3 on 12/15/69)

OTHER FACTORS:

CVG = clarifier volume in gallons per clarifier multiplied by the number of clarifiers in operation. At Metro Denver the volume of each clarifier was 1.165 million gallons and three clarifiers were in operation. (1.165 x 3 = 3.495 MG (CVG) for Area #3 on 12/15/69)

CSP = clarifier sludge percentage or the portion of the clarifier occupied by sludge which is determined by the ratio of $\frac{BLT}{CWD}$ ($\frac{2.0}{11.7}$ = 0.171 (CSP) for Area #3 on 12/15/69).

From the above the clarifier sludge units can be determined by the equation: CSU = CMC x CSP x CVG.

A modification was made in the equation for this analysis in that the CMC was multiplied by the factor representing the conversion between percent concentration by volume and mg/l (616 mg/l TSS = 1% for Area #3 for 12/15/69 and the related "steady state" period).

Therefore the modified clarifier sludge mass can be determined by CSU (modified) = CMC x 616 x CSP x CVG x 8.33 lbs/gal.

C = 7.0 x 616 x 0.171 x 3.495 x 8.33

= <u>21,550 lbs. of total suspended solids or sludge in clarifier</u>

b. <u>Determination of Aerator Sludge Units (ASU)</u>

ASU = AVG x ATC

WHERE:

AVG = aeration basin volume in gallons per aeration basin times the number of basins in service. At Metro Denver the volume of each aeration basin was 2.0 MG and three basins were in operation in Area #3 (2.0 x 3.0 = 6 MG (AVG) for Area #3 on 12/15/69).

ATC = 2.75% for Area #3 on 12/15/69 (See a. above).

From the above the aeration basin sludge units can be determined. However, the percentage sludge concentration by volume must again be converted to mg/l (616 mg/l TSS = 1% for Area #3 for 12/15/69 and the related "steady state" period).

Therefore the modified aeration basin sludge mass can be determined by:

ASU (modified) = AVG x ATC x 616 x 8.33 lbs/gal.

= 6 x 2.75 x 616 x 8.33

= 84,670 lbs. of total suspended solids or sludge in aeration basin

c. Determination of TSU

Using the modifications outlined above the value of TSU is assumed to be equivalent to the value VX_1.

THEREFORE:

TSU (modified) = VX_1 = ASU (modified) + CSU (modified)

= 21,550 (From a. above) + 84,670 (From b. above)

= 106,220 lbs. of total suspended solids or sludge in system

NOTE:

The value of TSU, as determined above, was obtained on a TSS basis. Normally in determining a substrate removal rate (q) a VSS basis is used. (VSS/TSS = 0.840 for Area #3 for 12/15/69 and the related "steady state" period)

THEREFORE:

TSU (modified) x VSS/TSS = VX_1 in lbs. of VSS

= 106,220 x 0.840

= 89,220 lbs. of volatile suspended solids in system

3. Example Determination of q

$$q = \frac{F(S_0 - S_1)}{VX_1}$$

For Area #3 on 12/15/69:

$F(S_0 - S_1)$ = 52,760 lbs. BOD_5 removed/day (1. above)

VX_1 = 89,220 lbs. of volatile suspended solids in system (2. above)

$$q = \frac{52,760}{89,220}$$

$$= 0.592 \frac{\text{lb. of } BOD_5 \text{ removed per day}}{\text{lb. of VSS in system}}$$

[q for conventional activated sludge normally has a value of 0.2 to 0.5, see Jenkins (3)]

B. Determination of the Net Growth Rate $1/\theta_c$

$$1/\theta_c = \frac{FX_2 + WX_r}{VX_1}$$ [See Jenkins (3)]

1. Determination of VX_1

VX_1 or its assumed equivalent was determined in Part A-2 above. This was determined for Area #3 for the date of 12/15/69.

VX_1 = 106,220 lbs. of total suspended solids in system (A-2 above)

NOTE:

In the determination of $1/\theta_c$ it is not necessary to convert from a TSS basis to a VSS basis since both the numerator ($FX_2 + WX_r$) and denominator (VX_1) in the calculation can be determined on a total suspended solids basis. Therefore, VX_1 on a total suspended solids basis is given above and WX_r and FX_2 will be calculated on a total suspended solids basis below.

2. Determination of WX_r

WX_r represents the mass of sludge wasted from the system per day.

WHERE:

W = waste sludge flow rate (12/15/69 for Area #3, W = 0.89 MGD) - This value was obtained from flow meters at the Metro Denver plant.

X_r = return sludge TSS or VSS concentration - This value was not determined at Metro Denver on mg/l basis but rather the return sludge concentration (RSC) was determined as a percent volume using the centrifuge. This value (RSC) can be related to X_r using the relationship established between mg/l and percent concentration by volume based on daily grab samples. (616 mg/l TSS = 1% for Area #3 and the related "steady state" period) For Area #3 the daily average RSC concentration on 12/15/69 was 11.25%.

X_r = 11.25 x 616 = 6,930 mg/l

THEREFORE:

WX_r = 0.89 x 6,930 x 8.33 lbs/gal. = 51,310 lbs. wasted per day

3. Determination of FX_2

FX_2 represents the cells lost from the system per day in the plant effluent.

WHERE:

X_2 = effluent TSS or VSS concentration - At Metro Denver the effluent TSS concentration was determined for each area based on the analysis of a composite sample (12/15/69 for Area #3 effluent TSS = 36 mg/l).

F = influent flow rate (F = 33.9 MGD for Area #3 on 12/15/69).

THEREFORE:

FX_2 = 33.9 x 36 x 8.33 lbs/gal.

= 10,180 lbs. of total suspended solids lost in the effluent per day

4. Example Determination of Net Growth Rate ($1/\theta_c$)

$$1/\theta_c = \frac{FX_2 + WX_r}{VX_1}$$

For Area #3 on 12/15/69:

FX_2 = 10,180 lbs/day (3. above)

WX_r = 51,310 lbs/day (2. above)

VX_1 = 106,220 lbs. (1. above)

THEREFORE:

$$1/\theta_c = \frac{10,180 + 51,310}{106,220}$$

$$= \frac{61,490}{106,220}$$

$$= 0.581 \ \frac{\text{lbs. TSS wasted or lost per day}}{\text{lbs. TSS in system}}$$

The reciprocal of $1/\theta_c$ is equal to θ_c or the mean cell residence time (sludge age). For Area #3 on December 15, 1969, θ_c = 1.72 days.

Similar calculations were made for the other days included in the selected "steady state" periods for Areas #2 and #3. The results of these analyses are presented in Table 2 in text.

APPENDIX C

SAMPLING PROCEDURES

SAMPLING PROCEDURES

Influent samples of the Denver Northside plant and the Denver Metro plant were collected upstream of the point of supernatant return every half hour. Denver Northside influent samples were collected using automatic samplers. All other samples were collected manually within the Metro plant area. All samples were flow composited, according to instantaneous flow readings obtained near the point of collection, and were iced during the entire 24-hour period. Field measurements of pH, temperature, and conductivity were made at selected stations. The composite samples were delivered to the NFIC-D laboratory and analyzed for BOD, total and suspended solids, volatile suspended solids, settleable solids, total organic carbon, chemical oxygen demand, nitrogen series, total phosphorus, and selected heavy metals.

Samples of the final effluent from the Denver Metro facility were analyzed for total and fecal coliforms. These bacteria samples were iced and delivered to the NFIC-D mobile bacterial laboratory for analyses. At the time of collection, field measurements and chlorine residual were measured.

APPENDIX D

DATA ON
METROPOLITAN DENVER SEWAGE DISPOSAL DISTRICT PLANT #1
AND
NORTH DENVER WASTEWATER TREATMENT PLANT

TABLE D-1

SUMMARY OF ORGANIC DATA ON METROPOLITAN DENVER AND NORTH DENVER WASTEWATER TREATMENT PLANTS
August 1-9, 1971

Station[a/]	Description	Flow mgd	BOD mg/l	Total Solids mg/l	Susp. Solids mg/l	Vol. Susp. Solids mg/l	Settl. Solids mg/l	COD mg/l	TOC mg/l
A	Clear Creek Raw Influent	17.3-21.2	140-250	930-1300	210-480	180-440	3.5-7.0	320-700	64-150
B	Packaging Corporation Effluent	0.4-0.6	280-480	1120-2130	220-480	150-400	19-100 (est)	890-1200	80-320
C	Sand Creek Raw Influent	9.5-11.0	140-290	890-1200	240-440	180-420	5-8	350-1560	66-190
D	Combined Raw Influent to Metro	27.2-32.6	190-250	1120-1640	300-620	160-540	5-9	480-870	66-360
E	Denver Northside Influent	76.7-92.5	180-430	920-1440	320-1240	240-1200	3.5-10	590-1800	84-340
F	Primary Effluent from Metro	27.2-32.6	120-160	980-1060	60-180	60-140	Trace-1	250-290	31-120
G	Denver Northside Primary Effluent	76.7-92.5	80-310	620-820	<20-300	<20-160	0.2-7	160-270	31-54
H	Influent to Secondary Units	103.9-124.0	75-210	780-890	50-140	40-130	0.1-0.5	200-270	33-80
I	Influent to Cl_2 Contact Chamber	103.9-124.0	25-95	690-790	20-240	<20-200	Trace-5	100-410	15-69
J	Final Effluent from Metro	103.9-124.0	10-100	660-830	30-240	30-240	Trace-7	80-790	18-70

a/ For location see Figures 2 and 3.

TABLE D-2

SUMMARY OF HEAVY METAL DATA ON METROPOLITAN DENVER AND NORTH DENVER WASTEWATER TREATMENT PLANTS
August 1-9, 1971

Station[a]	Description	Cadmium mg/l	Chromium mg/l	Copper mg/l	Lead mg/l	Zinc mg/l	Mercury μg/l
A	Clear Creek Raw Influent	<0.02-0.05	<0.02-0.07	0.05-0.10	0.05-0.20	0.17-0.21	<0.2-0.6
B	Packaging Corporation Effluent	<0.02-<0.02	0.03-0.37	0.07-0.26	0.29-2.3	0.26-6.1	<0.02-1.0
C	Sand Creek Raw Influent	<0.02-<0.02	0.09-0.43	0.13-0.58	0.06-0.14	0.13-0.43	0.02-1.2
E	Denver Northside Influent	<0.02-0.04	0.03-0.26	0.16-0.23	0.09-0.22	0.69-1.9	0.2-1.3
J	Final Effluent from Metro	<0.02-<0.02	0.03-0.11	0.04-0.24	0.03-0.10	0.06-0.49	0.2-1

a/ For location see Figures 2 and 3.

TABLE D-3

SUMMARY OF NUTRIENT DATA ON METROPOLITAN DENVER AND NORTH DENVER WASTEWATER TREATMENT PLANTS
August 1-9, 1971

Station[a]	Description	NH_3 as N mg/l	Total N as N mg/l	$NO_2 + NO_3$ as N mg/l	Total P mg/l
A	Clear Creek Raw Influent	16-21	23-31	0.02-0.07	9.6-13
B	Packaging Corporation Effluent	0.1-3.9	4.3-8	0.7-3.5	0.4-2.8
C	Sand Creek Raw Influent	17-22	25-37	0.01-0.61	11-14
E	Denver Northside Influent	12-20	21-29	0.01-0.23	7.5-12
J	Final Effluent from Metro	11-18	15-34	0.2-1.7	4.8-13

a/ For location see Figures 2 and 3.

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