WATER REUSE AT HIGHWAY REST AREAS: FOLLOW-UP OF IMPLEMENTATION

by

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(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

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ABSTRACT

A water recycle-reuse system researched and developed by the Virginia Highway and Transportation Research Council for treating water closet flush water was constructed at an existing rest area. An existing 10,000 gpd (37,800 lpd) biological wastewater treatment system and rest area piping system were modified to accommodate water reuse. The recycle-reuse system consisted of biological treatment (extended aeration) followed by gravity sedimentation and granular filtration. It was designed for 95% water reuse with 5% make-up from sewered potable uses such as wash basins.

The field system became operative on November 15, 1976, and on August 31, 1977, an evaluation study was concluded. Based on results of the evaluation phase the water recycle-reuse design became an accepted alternative for resolving water supply and water pollution problems at Virginia highway rest areas.

From September 1, 1977, through August 31, 1978, an implementation follow-up study was made. During this period reuse of flush water varied between 92.0% and 96.7%. Potable uses that were sewered amounted to less than 5%, resulting in recycle in excess of 95% without the use of makeup water. Recycled flush water was stable and was acceptable to the rest area user at all observed recycle levels.

Operation of the biological and physical treatment units followed conventional guidelines. The biological system functioned satisfactorily at a low pH of from 5.5 to 6.5 and low alkalinity. The low pH and alkalinity resulted in complete nitrification and high ammonia nitrogen and nitrite nitrogen concentrations. Although high equilibrium nitrogen concentrations occurred, they were not detrimental to the process. Biological solids were filamentous but were satisfactorily separated from the flush water by gravity sedimentation. The system satisfactorily responded to seasonal variations in waste characteristics and water reuse imposed by the users as well as seasonal climatic variations. Operation and maintenance requirements at the rest area site did not significantly increase as a result of the recycle-reuse system.

Results from this study confirmed the conclusions of the evaluation study phase. The recycle-reuse system proved to be an acceptable and economical means of resolving water supply and water pollution problems at rest areas.

ACKNOWLEDGEMENTS

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INTRODUCTION

Previous Developments

As a result of experiences with water and wastewater problems in the Commonwealth of Virginia, the Virginia Highway and Transportation Research Council sponsored the research and development of a water recycle-reuse system for flushing water closets at highway rest areas. Based on the developed concept an existing wastewater disposal system at a rest area on Interstate 81 (milepost 200) near Fairfield, Virginia, was modified to incorporate water reuse. The system became operative on November 15, 1976, and was evaluated from start-up until equilibrium was assured on August 31, 1977. The results of this initial evaluation phase, as well as the results of the research and development work, have been published.[1,2,3] The report by Parker[3] provides a thorough description of the recycle-reuse concept, the field system design, and operation details that should be incorporated into future installations. The work reported here is an extension of the evaluation phase. The purpose of continuing the field evaluation was to provide a follow-up study of the implementation covering the seasonal traffic experienced during a full year's operation while the system was under the operational supervision of field personnel.

Water-Recycle-Reuse System

Plumbing at an existing rest area that employed biological wastewater treatment (extended aeration) designed to treat 10,000 gpd (37,800 lpd) was modified to separate potable water use from water closet flush water use. A granular pressure sand filter with pre- and postfiltration storage tanks and a hydropneumatic tank was installed in a closed loop to filter effluent from the biological system and to return water to the water closets as the flush fluid. Filter backwash water was collected in a separate storage tank and returned to the influent of the biological treatment system during off-peak use of the rest area. A blue food dye was added to the recycled water to assure public awareness and aesthetic conditions.

The filter was 6.0 ft (1.83 m) in diameter and was operated at a filtration rate of 2.3 gpm/ft^2 (94 lpm/m^2). Filter cleaning rates were 30 gpm/ft^2 (1,220 lpm/m^2) for backwash. Water closet flush water passed through biological treatment and rapid sand filtration in a closed loop system with provisions for the addition of wasted potable water from other rest area uses and the release of an equivalent amount of water to a pond where evaporation occurred. Potable water needs were served by a well through a separate pipe network.

A flow diagram of the water recycle-reuse system installed at the rest area is shown in Figure 1. Complete details of the unit processes and unit operations employed and an evaluation of the installation design can be found elsewhere.[3]

Previous Results: Evaluation Phase

The detail evaluation of start-up and implementation of the recycle-reuse system can be found in the report by Parker.[3] The summary and conclusions from that report are presented here.

The Research Council identified the water quality and quantity needs at rest areas and used a bench-scale, extended aeration biological treatment unit followed by granular media filtration to evaluate the recycle and reuse of water to flush water closets. Data from the bench-scale were used to design and construct a field recycle and reuse demonstration facility at an operating rest area.

Operation of the field demonstration system from November 15, 1976, to August 31, 1977, allowed the system to reach water balance equilibrium conditions and provide an acceptable flush water at a 95% reuse level. As water balance equilibrium was attained and during equilibrium the physical, chemical and biological quality of the water was acceptable for its intended use. The recycled water did not have any detectable characteristic odor or objectionable odor and as a result of the dye had a turquoise color at equilibrium flow conditions.

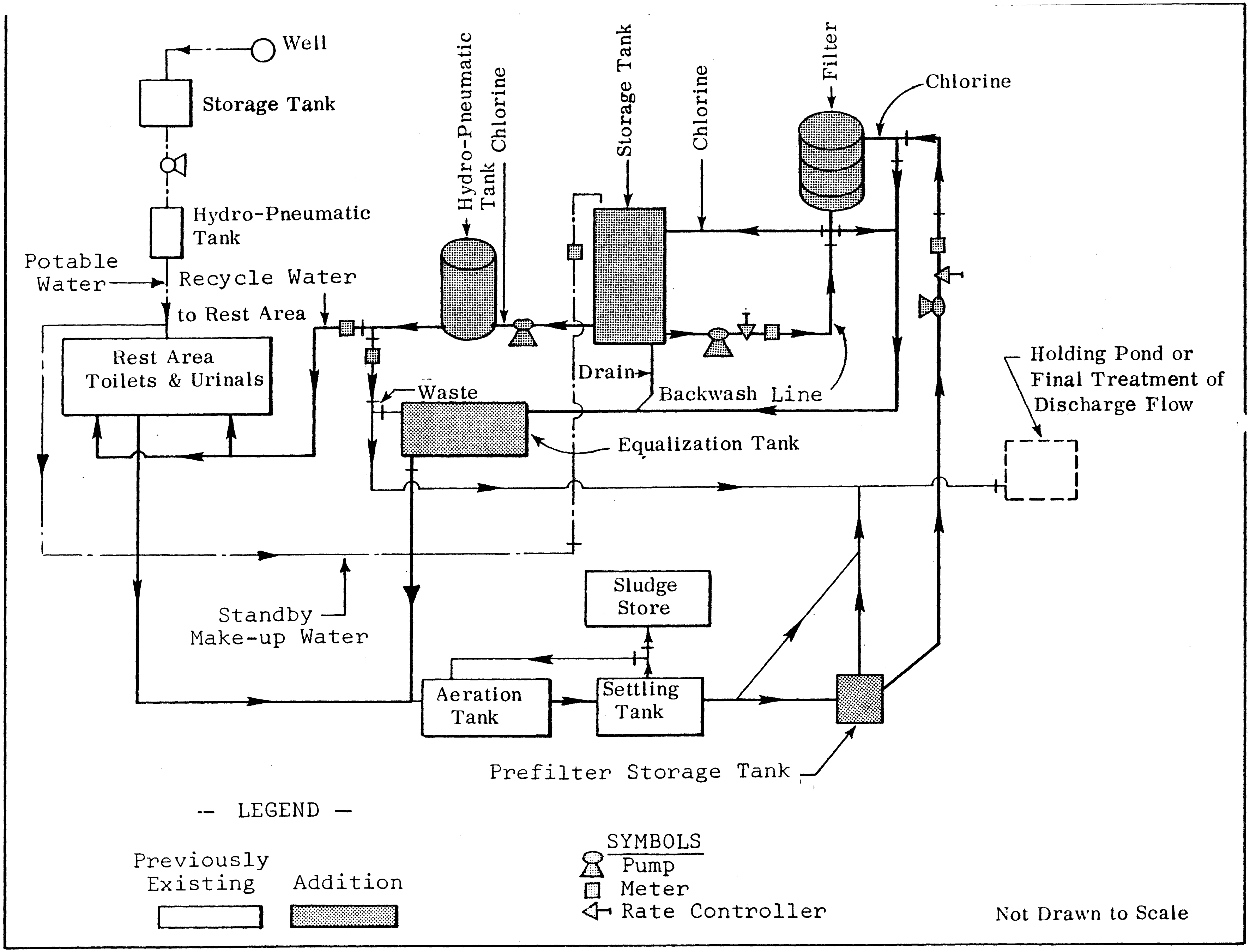

Figure 1. Schematic flow diagram for treatment system modified for water reuse.

At 95% recycle the water was used on the average of 20 times and the amount of water sewered from potable water use and human excretion was approximately equal to the 5% of the daily flow wasted to a holding lagoon. The potable water sewered from nontoilet uses provided a daily nonrecycled quantity to the recycle system that assured a water quality equilibrium condition that was not detrimental to the biological treatment system. At the water equilibrium condition the nonrecycled water input to the recycle system and water wastage from the system were equal. Water wastage from the recycle system occurred by evaporation from the extended aeration units and the surface of holding tanks and through an overflow to a terminal holding pond. During the period March 13, 1977, to August 31, 1977, 880,000 gal (3.3×10^6 l) of water were recycled and reused in the closed loop system. Although water overflow from the closed loop system to the terminal holding pond occurred, there was no net accumulation of wasted water and, as a result, a zero effluent discharge.

Excess biological solids from the extended aeration unit were wasted during the period of study; however, the frequency of wastage and the handling of the wasted biological solids were the same as practiced at the rest area prior to the installation of the recycle and reuse system.

Results from the evaluation phase indicated water reuse at rest areas is more economical than a mineral oil flush system and can be considered as a viable alternative for solving water and wastewater problems at highway rest areas. The results provided the fundamental details necessary for the design and operation of a water recycle and reuse system to flush water closets and for the implementation of water reuse at rest areas on a site-specific basis.

The conclusions from the evaluation during implementation research were as follows:(3)

1. Effluent from the biological extended aeration treatment of rest area wastewater can be filtered by a granular pressure filter to produce water that can be recycled and reused a multiple number of times for toilet flushing. Water treated, recycled, and reused at least 20 times does not produce a readily detectable or objectionable odor. Recycled water dyed with a blue food coloring imparts a turquoise color to the water that is not objectionable in appearance. No special cleaning

of toilet bowls is required as a result of water recycle and reuse, and the recycled water meets all the criteria established for a fluid to be acceptable as a toilet flushing fluid.

2. Water inputs into the recycle system resulted from potable water use wastage plus liquid human wastes. The wasted potable water came from wash basins, water fountains, and custodial services and amounted to 5.8% of the total water used at the rest area. The water balance was approximately 95% recycle.

3. To obtain zero discharge, a water volume equal to the potable water input and liquid human excrement must be disposed of. During the period of operation excess water from the system went to a holding lagoon. Evaporative losses from the various tanks, aeration, and the lagoon resulted in no net water accumulations in the holding lagoon. In geographical areas with warm climates, zero discharge can be accomplished by designing the system to take advantage of solar evaporation.

4. Biological oxidation of organics was not hindered by the quality of the recycled water. The biological treatment system produced a water that was low in biodegradable organics and that was free of repugnant or disagreeable odors.

5. Extended aeration biological treatment employed to treat recycled and reused water will function at conditions not normally experienced when these systems are used to treat domestic wastewater. The biological transformation of ammonia nitrogen to nitrate nitrogen will not be complete. Ammonia, nitrite, and nitrate nitrogen will accumulate in the system, but not at levels that will be toxic to the hetertrophic organisms that oxidize the organics. The biological population in the summer will shift to those that can adapt to a low pH of 5.5 to 6.5 and low alkalinity of about 50 mg/l. Winter operation will result in a biological population that can tolerate a higher pH of 7.0 to 8.3 and a higher alkalinity of 100 to 500 mg/l. The heterotrophes present in the summer will consist of a large population of filamentous fungi.

6. Wastage of biological solids in the treatment of recycled water does not significantly increase over the wastage experienced with non-recycled treatment of rest area wastewater. The current practice of using MLSS settleability as an operational test to determine the need for the wastage of biological solids can be continued. Wastage should be accomplished to maintain an MLSS concentration of 3,500 mg/l to 4,500 mg/l in the aeration unit. These concentrations can be maintained by wastage when the settleable MLSS is above 600 to 800 ml in a litre graduated cylinder after 30 minutes of settling.

7. The use of the BOD test to determine biodegradable organics in a recycle-reuse system that employes biological extended aeration will not provide meaningful results. Due to the ammonia nitrogen present, the oxygen utilization in the test will be significantly influenced by its conversion to nitrate nitrogen in the test procedure. Five-day BOD values can be expected to be high and erratic.

8. Manpower requirements for the operation of the rest area are not significantly impacted by the use of a biological extended aeration and pressure filtration water recycle-reuse system.

9. Water use characteristics of a rest area significantly affect the unit sizes of a recycle system and the construction cost. Water use requirements should be carefully analyzed to assure optimum sizing of storage tanks, the hydropneumatic tank, the filter, and pumps. A clear distinction should be made between the instantaneous flow requirements placed on the piping system and the lower average flow requirements that establish the sizing of other components in the system. Overestimates in flows and excessive use of factors of safety in sizing will significantly impact capital costs.

10. Water recycle-reuse is an economical alternative to the use of a mineral oil system.

In addition to the preceding summary and conclusions taken from the start-up evaluation, the following pertinent details found in the report should be noted.

1. Since the facility was considered experimental by state regulatory agencies, the installed equipment (basins, tanks, pumps, and filter) was over-designed and plumbing and appurtenances were included that would not otherwise have been incorporated in the design; e.g., a 3 ft to 4 ft (0.91 m to 1.22 m) diameter filter would have been sufficient, storage tanks would have been smaller, and "future" use valves would have been eliminated.

2. The filter system was operated in the automatic backwash mode based on head loss but, due to filter overdesign, it could go for 3 to 6 weeks without backwash. (This is contrary to good filtration practice where backwashing every 3 to 4 days or a minimum once weekly is recommended.)

3. No filter aid was required and the blue food coloring dye persisted for 30 to 90 days; hence, the two chemical feeders installed served no useful purpose.

4. Ammonia nitrogen losses occurred due to elevation of flush water pH upon use and agitation in the sewer between the water closet facility and the biological wastewater treatment facility. This loss resulted in a nitrogen balance that was not detrimental to the biological process.

5. In geographical areas where severe freezing may occur it would be desirable to have the biological system and storage basins housed in the ground with access within the filter or operations building.

6. The flow scheme proposed for modification of existing extended aeration (biological treatment) systems was as shown in Figure 2.

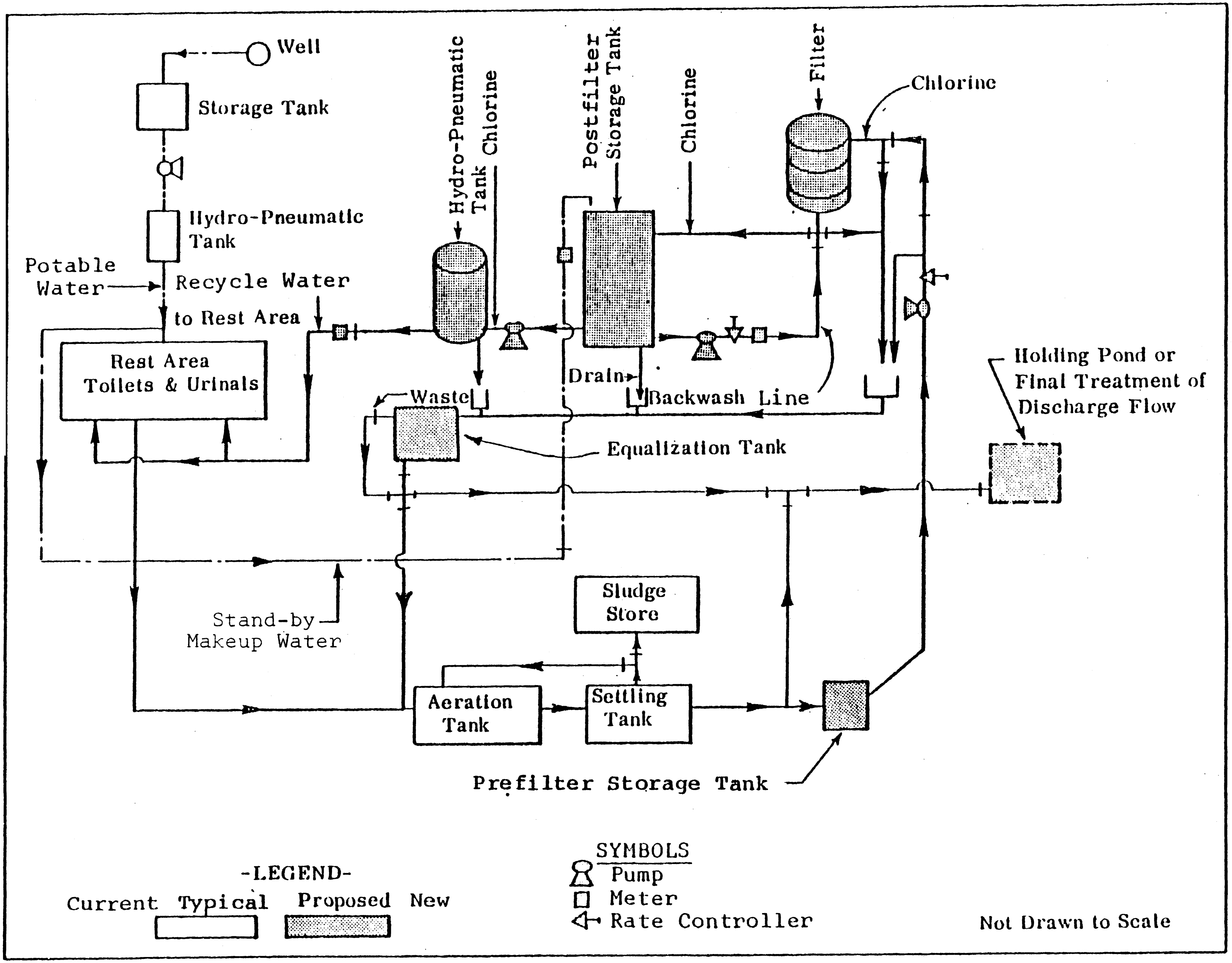

Figure 2 Schematic flow diagram for recycle and reuse of

RESULTS OF IMPLEMENTATION FOLLOW-UP

The follow-up on the implementation of the system was initiated immediately following the start-up evaluation phase in September 1977. During start-up water reuse was reported as a percentage of the total rest area use (including sewered and unsewered potable usages) and varied between 91.3% and 96.0% with an average value of 94.1%. On August 31, 1977, the ratio of water recycled to the initial water in the system was 20.53 and analytical data indicated the system was at water reuse equilibrium.

The day-to-day operation of the recycle-reuse system for the follow-up study was the responsibility of the rest area custodian. On a weekly basis the facility was visited by personnel from the Virginia Department of Highways and Transportation (Staunton District) and/or personnel from the Research Council. Decisions concerning the addition of dye, sludge wastage, filter backwash, and water balance were the cooperative effort of personnel from the District Office and the Research Council. No special conditions were necessary or imposed upon the operation of the system.

The only chemical added to the system was blue food coloring dye, FD&C Blue No. 1 (Brilliant Blue). This was added by hand as a solution on an as-needed basis. Decisions to add dye were based on the appearance of the recycle water in the water closets. Less than 5 lb (2.3 kg) were used during the 12-month follow-up study.

During the follow-up study, construction was completed for a third water closet facility at the rest area. This addition was made so that two facilities (one for men and one for women) could be open while the third was being cleaned. In addition, all wash basin water faucets were changed to a water-saving (time release) fixture. Between December 1 and December 15, 1977, two of the water closet facilities with water-saving fixtures were open to the public. Conversion of the third was completed January 20, 1978.

As construction of the additional water closet came to a close it was apparent that in the evaluation start-up phase potable water use was significantly affected by landscape watering and other unsewered outside potable water uses such as drinking fountains. (Water metered at the rest area was total potable use and as a result sewered and unsewered uses at the rest area were inseparable. Hence, potable use by the rest area user that was sewered and entered the recycle-reuse system as a new water addition was not measureable.) Since the percentage water recycle calculated in the start-up evaluation phase was based on all potable use at the rest area being sewered, the actual recycle percentage during the evaluation phase was greater than the average 94.1% reported. This trend can be seen from Table 1, where in October (all construction essentially complete and no landscape watering) the percent water reuse as a percentage of total rest area potable water use rose to 96.5%. Due to the underestimate of unsewered potable water uses at the rest area, it was clearly evident that water reuse in the recycle-reuse system was exceeding 95% and that with the addition of water-saving fixtures the reuse percentage would be further increased.

To evaluate the impact of unsewered potable water use the period of October through March was taken as minimal unsewered usage such as landscape use, fountain use, and other outside faucet use. Based on all potable water uses being sewered during this period, the average percent reuse was 96.7%. Reuse at the 96.7% level amounts to an average water reuse in excess of 30 times, compared to an average reuse of 20 times at 95% reuse. It is obvious that a small increase in percent reuse drastically increases the average number of times a water volume is reused. Flush water and potable water use are presented in Tables 1 and 2, respectively. Table 1 shows the percent water reuse based on metered potable water at the rest area (includes all potable water usages). These results show a clear differential between water uses during October through March and those during the months of September, July, and August when substantial unsewered potable use can be expected.

Upon recognition of the underestimated percentage recycle and based on data that supported acceptable flush water quality at 95% reuse, addition of small amounts of potable makeup water to the recycle loop was necessary for maintaining 95% reuse. This addition was initiated April 17, 1978, and continued through August 31, 1978. An evaluation of water reuse for the study period on a monthly basis is presented in Table 3. Recycle-reuse values presented in columns 4 and 5 are the actual values experienced during the study. (Due to unmetered water uses for various purposes in April 1978, recycle percentages are not presented for that month.) During the implementation follow-up 1.76 million gal. (6.65×10^6 l) of flush water were treated and returned for flushing at an overall recycle of 95.3%. Water was added on a weekly basis but not according to an established formula; hence, a significant variation in makeup occurred.

Flush Water Use

Date	Accumulated volume used, gallons	Average daily flow, gpd	Maximum daily flow, gpd	Minimum daily flow, gpd	Average percent recycle based on total potable water use[a]
1977					
9-07	917,795	5,026	8,240	3,850	93.1
9-14	940,935	3,306	4,300	2,330	94.9
9-28	990,085	3,511	5,680	1,750	94.8
10-19	1,065,145	3,574	6,400	2,070	96.5
11-02	1,124,745	4,257	7,730	1,570	96.6
11-16	1,177,465	3,766	6,750	2,020	96.8
11-30	1,242,995	4,681	11,070	2,430	97.5
12-07	1,260,345	2,479	3,590	1,280	95.0
12-19	1,290,805	2,538	3,930	1,380	95.9
1978					
1-04	1,368,055	4,828	8,270	1,990	96.2
1-25	1,404,725	1,746	2,900	520	96.8
2-08	1,430,895	2,181	4,670	850	97.9
3-15	1,519,135	2,521	6,870	120	NA
3-29	1,569,955	4,235	9,420	1,590	96.1
4-12	1,631,080	4,702	10,170	2,410	95.7
4-26	1,696,550	4,676	7,646	2,040	95.4
5-10	1,769,865	5,237	7,930	2,710	95.9
5-25	1,855,125	6,090	9,680	2,580	96.2
5-31	1,907,655	7,504	16,350	3,990	95.6
6-07	1,949,795	6,020	8,030	3,350	94.8
6-14	1,995,755	6,566	12,170	3,740	96.1
6-21	2,044,735	6,997	13,020	4,970	93.8
6-29	2,107,815	7,885	11,020	4,920	94.9
7-05	2,188,125	13,385	17,630	8,220	95.7
7-12	2,256,515	9,770	14,320	5,750	95.0
7-19	2,316,945	8,633	11,475	5,180	96.2
7-26	2,375,550	8,372	12,390	5,525	93.9
8-02	2,438,385	8,976	13,015	6,640	94.5
8-09	2,500,215	8,833	13,470	4,960	95.0
8-16	2,558,865	8,379	11,030	5,120	95.4
8-30	2,673,955	8,221	12,570	3,700	92.8

Note: 1 gallon = 3.785 litres.
(a) Includes all sewered and unsewered potable water uses.

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Table 2

Potable Water Use

Date	Accumulated volume used, gallons	Average daily flow, gpd	Maximum daily flow, gpd	Minimu daily flow gpd
1977				
9-07	56,183	371	496	263
9-14	57,405	175	226	132
9-28	60,079	191	442	101
10-19	62,825	131	186	83
11-02	64,891	148	294	72
11-16	66,623	124	194	57
11-30	68,299	120	218	61
12-07(a)	69,210	130	269	60
12-19(a)	70,407	109	255	51
1978				
1-04	73,487	193	338	118
1-25	75,517	97	269	31
2-08	76,944	102	202	45
3-15	---	---	---	---
3-29	79,380	174	438	18
4-12	82,123	211	362	117
4-26(b)	85,275	225	555	111
5-10	88,346	219	310	97
5-25	91,753	243	391	131
5-31	94,187	348	722	196
6-07	96,463	325	692	99
6-14	98,300	262	353	147
6-21	101,563	486	847	213
6-29	104,963	425	494	260
7-05	108,536	595	849	428
7-12	112,138	515	715	309
7-19	114,513	339	546	233
7-26	118,341	547	959	247
8-02	121,967	518	876	334
8-09	125,199	462	667	316
8-16	128,040	406	518	305
8-30	136,936	635	1,600	194

Note: Potable water use includes both sewered and unsewered usages due to user and custodial services. Water fountains, outside faucets, and landscape water facilities are included.

1 gallon = 3.785 litres.

(a) Low water use wash basin fixtures installed.

(b) Periodic fresh water addition initiated to maintain 90% 95% water reuse.

Table 3

Monthly Recycle-Reuse

Date	Potable makeup water added, gallons	Recycle based on actual potable sewered water,[a] percent	Recycle based on total potable RA use,[b] percent	Recycle-reuse based on actual potable water entering recycle system,[c]	
				percent	avg. number of times reused
September 1977	0	96.7	94.8	96.7	30.3
October 1977 — March 1978	0	96.7	96.7	96.7	30.3
May 1978	5,680	96.7	95.9	94.2	17.2
June 1978	10,230	96.7	94.9	92.1	12.7
July 1978	4,850	96.7	95.2	95.0	20.0
August 1978	1,240	96.7	94.1	96.3	27.0

(a) Based on all potable rest area water use sewered to recycle loop during fall and winter.

(b) Based on all potable metered water at rest area (sewered and unsewered usages) with no makeup water added.

(c) Based on actual potable sewered water and makeup added to recycle loop. This is actual recycle-reuse experienced during the implementation follow-up study.

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Inadvertent additions in June resulted in less than 95% recycle. August additions were less than required for 95% recycle due to repairs to the holding pond; hence, the percentage reuse exceeded 95%. The results of changes in water reuse are clearly reflected in the analytical results.

Water in the recycle-reuse system was sampled after flushing (prior to treatment, called raw wastewater), after biological treatment and sedimentation, and just prior to reuse as a flush fluid (from the pneumatic tank). All analyses were made in accordance with Standard Methods for the Examination of Water and Wastewater.[4] Results from analyses of these sampling points are presented in Tables A-1, A-2, and A-3 in the Appendix. Data for recycled water just prior to reuse as a flush fluid are shown in Figures 3 through 10. These data are presented as a function of sampling date. Since conductivity, fixed solids, and chlorides are least influenced by biological oxidation, sedimentation, and filtration, these parameters best indicate changes as a result of new water inputs to the recycle-reuse system. A drop in these values during the later part of January 1978 was the result of meltwater from ice and snow entering the sewer between the rest area and the biological treatment unit. The further decline in April through July resulted from the addition of makeup water. The increase experienced in the month of August resulted from the increase in water reuse as a result of only a small amount of makeup water being added to the system.

Analytical results from analyses of the biological treatment unit are documented in Table 4. The biomass responded to changes in flushed waste characteristics without failure. Fungi were in predominance, but under suitable conditions nitrifying bacteria resulted and produced significant nitrificatior Due to the low pH and alkalinity, nitrification was not complete and was limited to nitrites. Water inputs were reflected in mixed liquor suspended solids (MLSS) and pH.

DISCUSSION OF RESULTS

Biological Treatment Performance

The performance of the biological treatment system was comparable to its performance during the start-up evaluation phase. The system proved to be durable and effective in the biological oxidation of biodegradable organics and thus

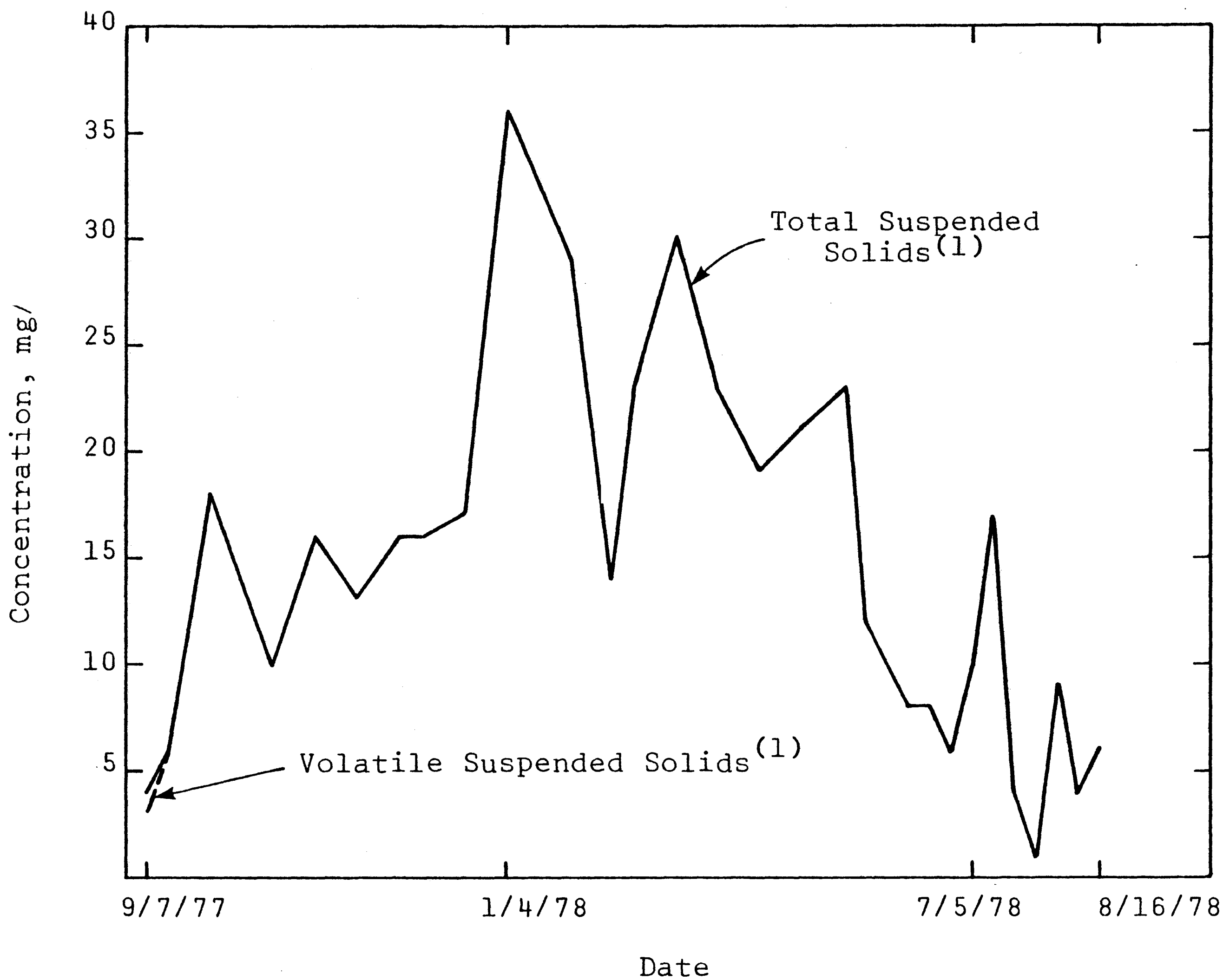

Figure 3. Flush water suspended solids.

(1) Volatile suspended solids ≅ total suspended solids.

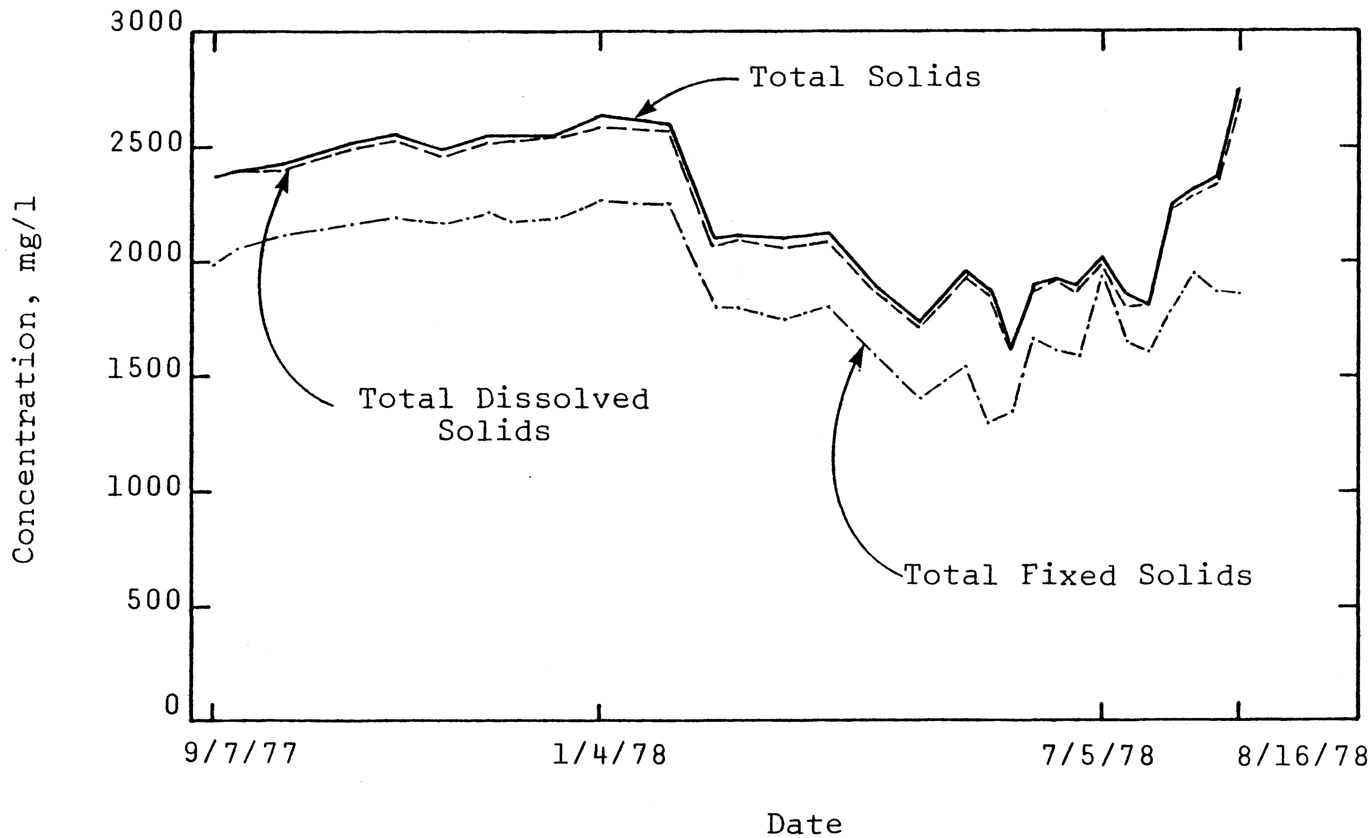

Figure 4. Flush water total solids.

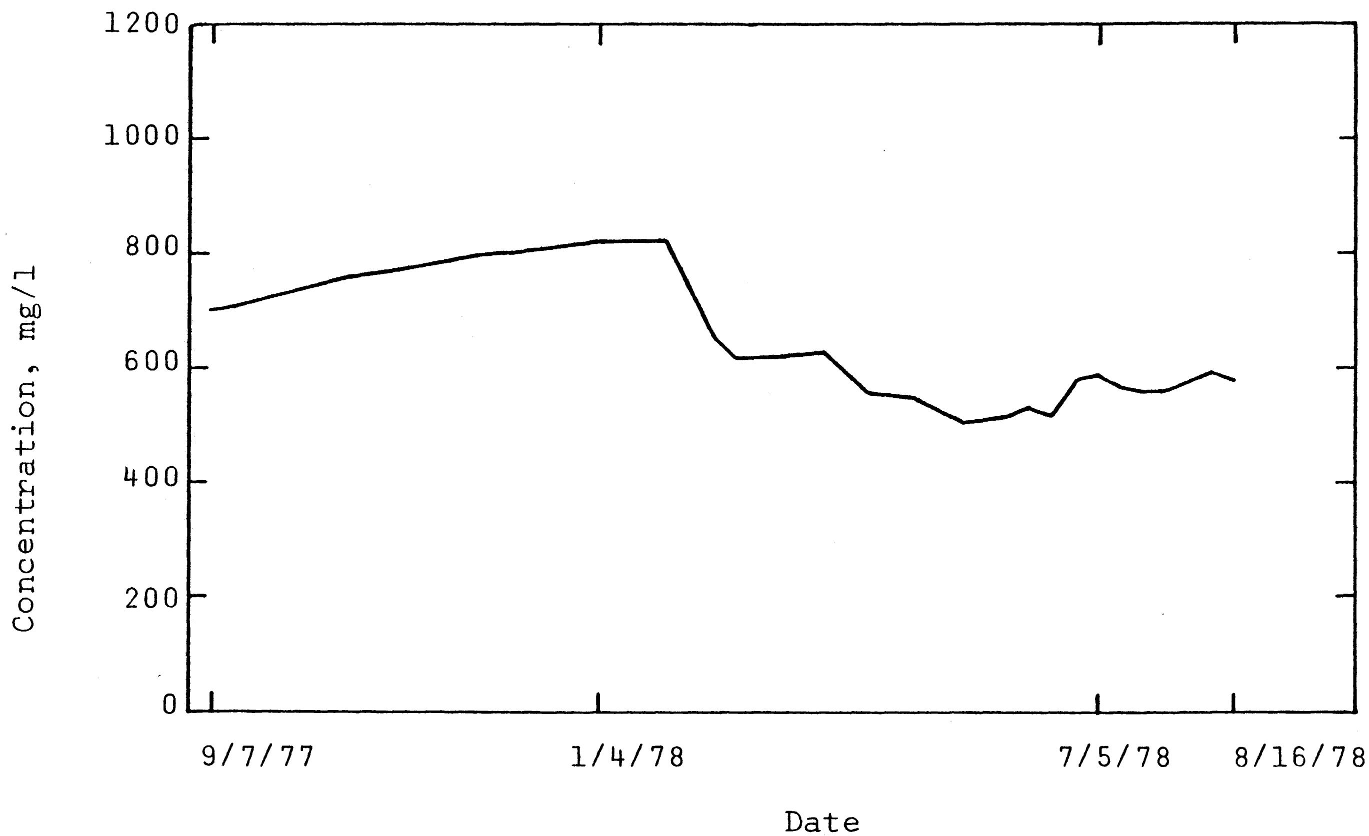

Figure 5. Flush water chlorides.

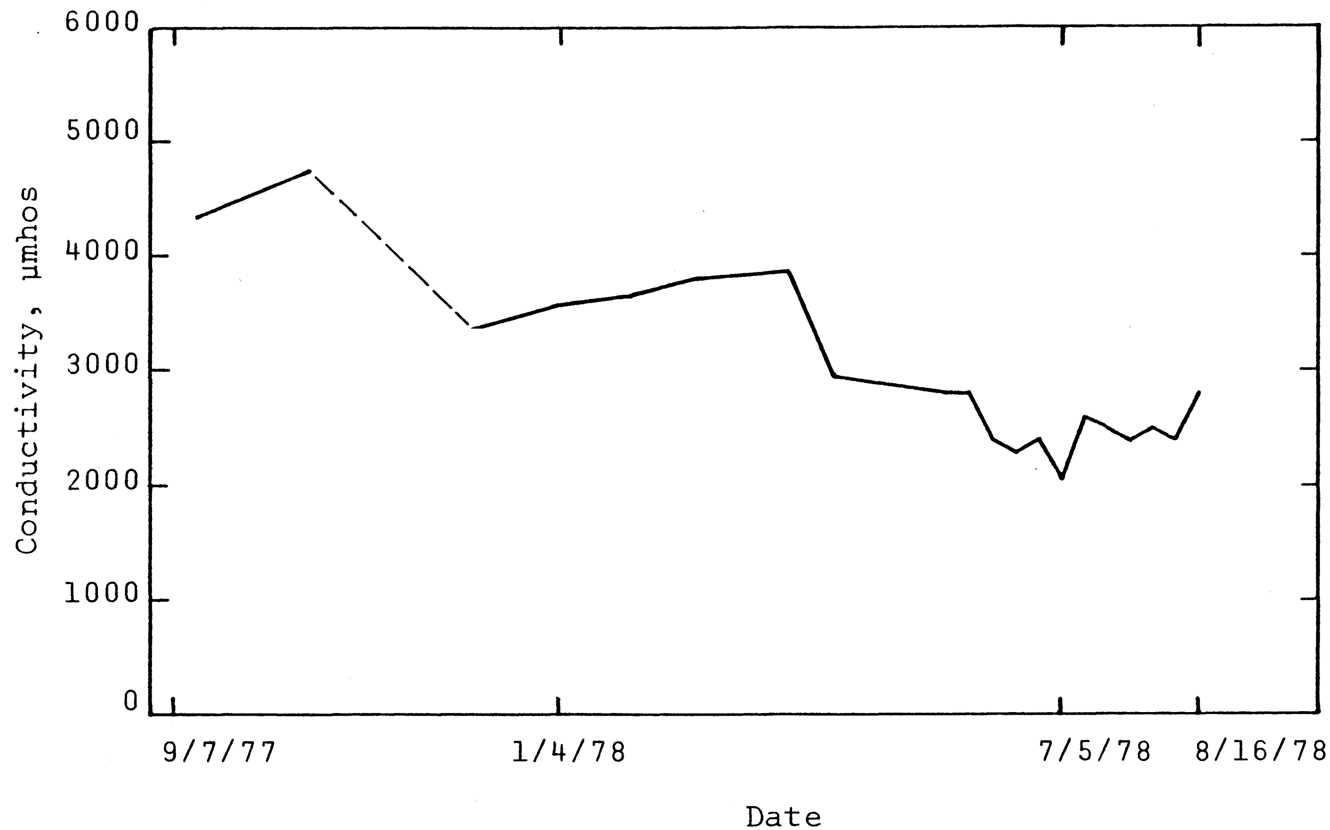

Figure 6. Flush water conductivity.

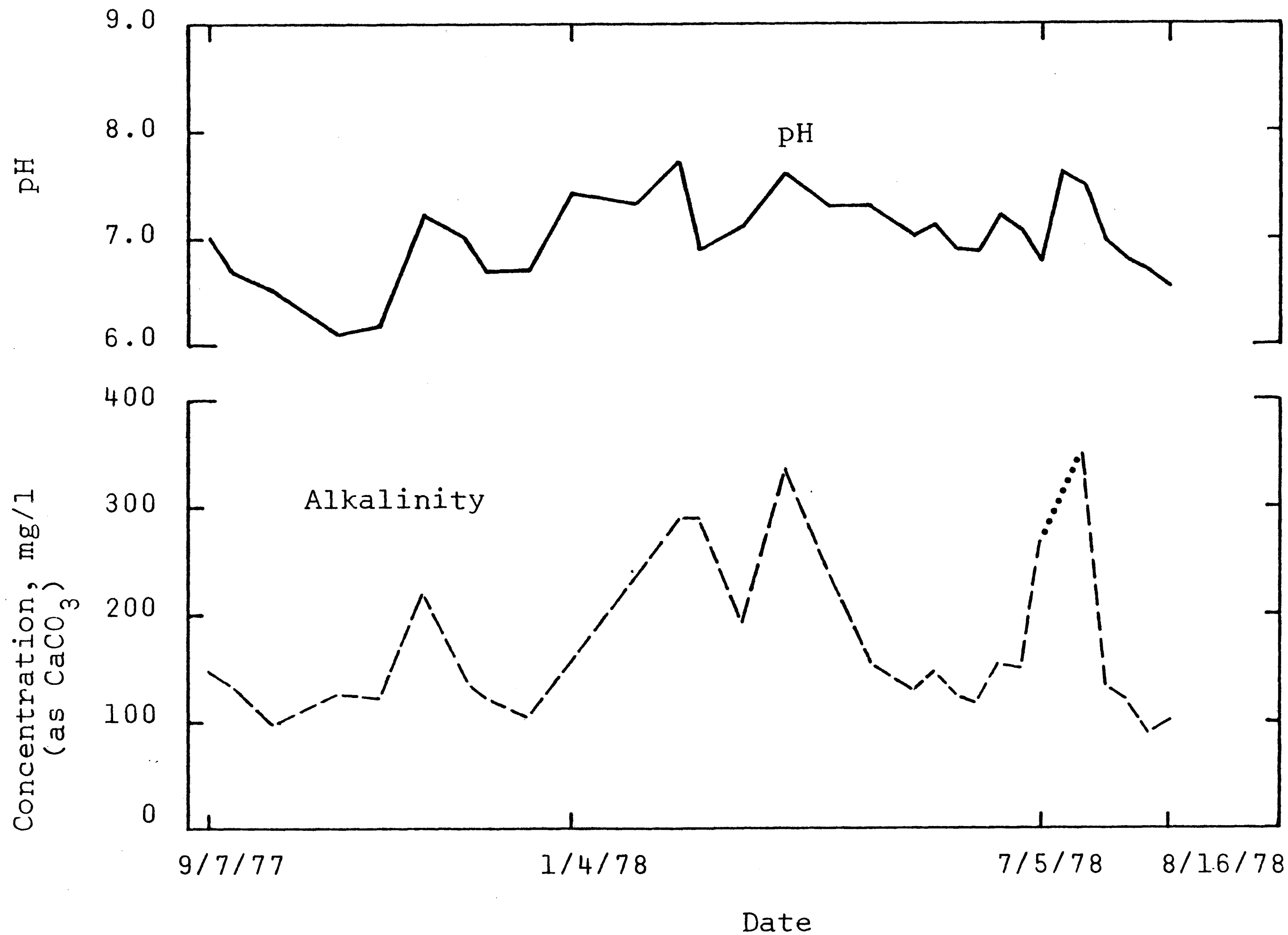

Figure 7. Flush water pH and alkalinity.

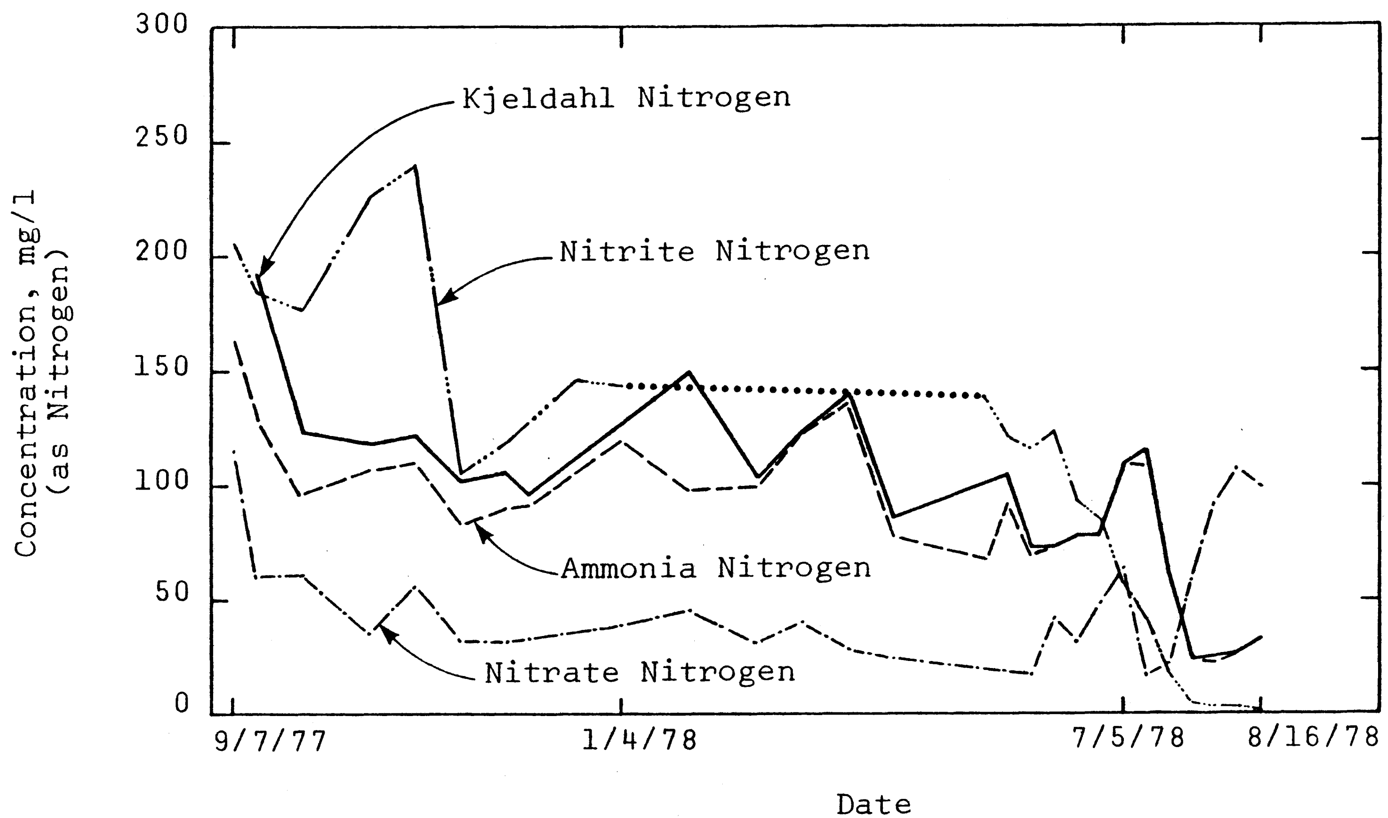

Figure 8. Flush water nitrogen.

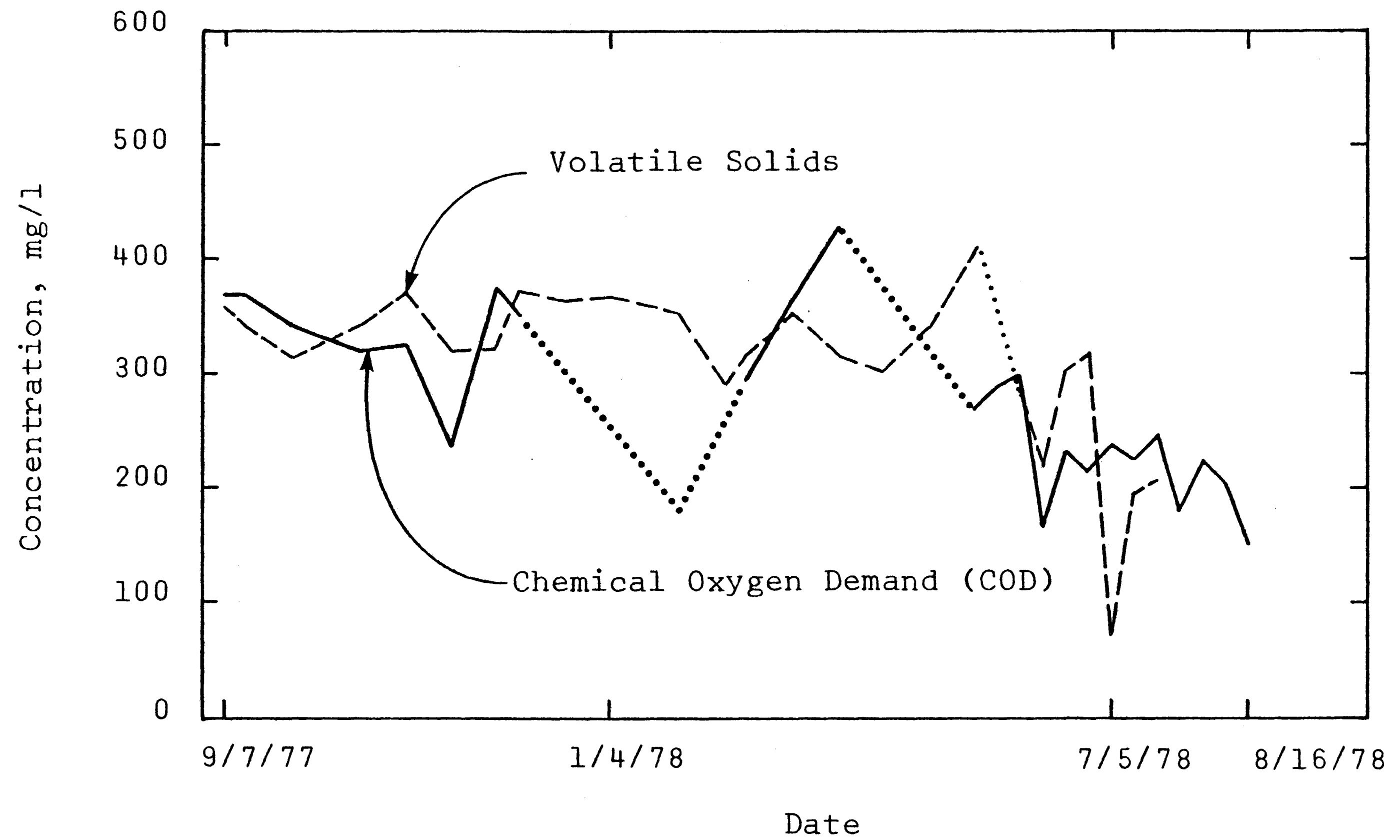

Figure 9. Flush water COD and volatile solids.

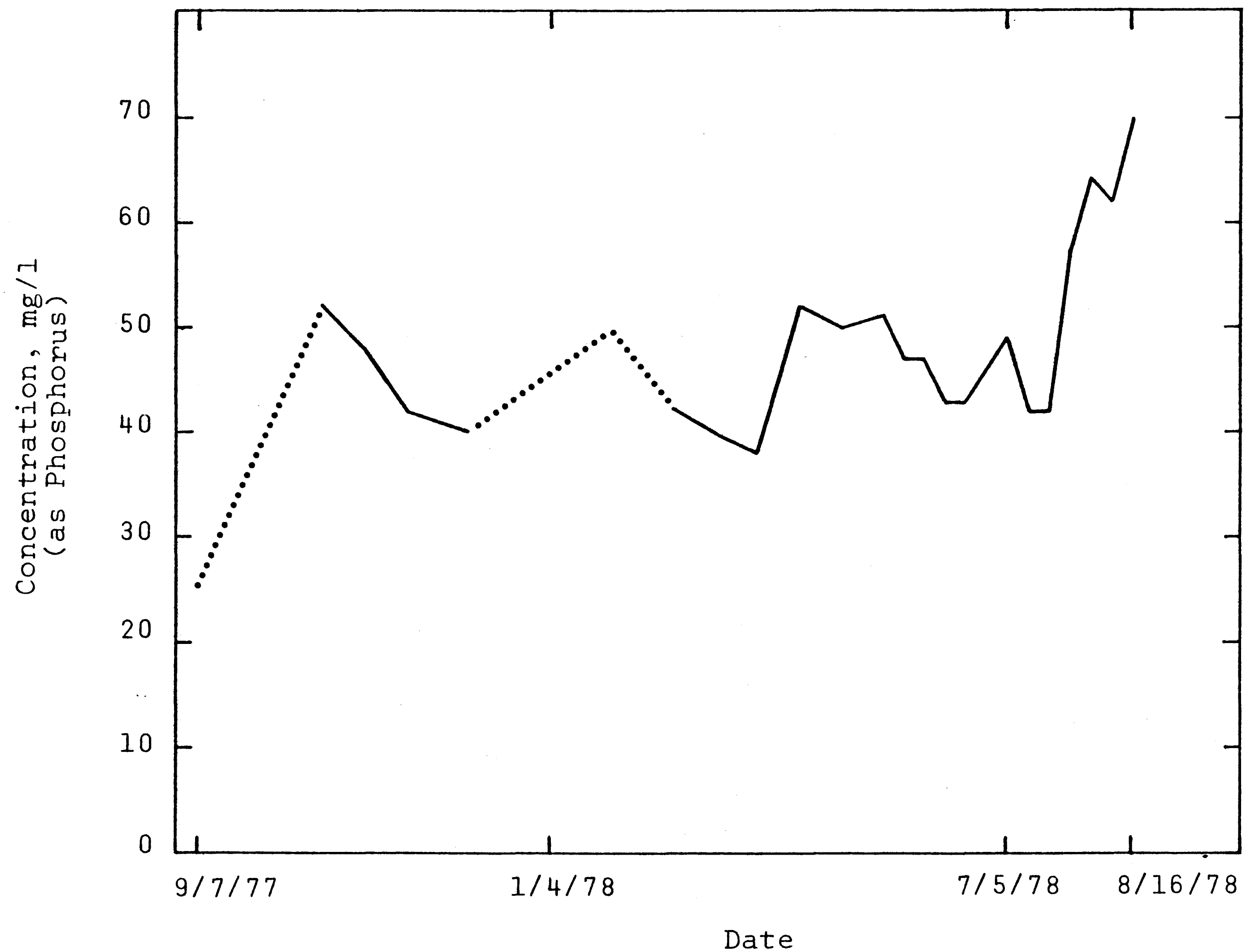

Figure 10. Flush water phosphorus.

Table 4

Aeration Basin Analyses

Date	Oxygen Uptake, mg/l/hr	MLSS, mg/l	MLVSS, mg/l	Settling,[a] ml	SVI[b]	Temp., Deg. C	DO, mg/l	pH	Alkalinity (as $CaCO_3$), mg/l
1977									
9-07	10.2	4,268	4,052	750	176	25	4.3	5.9	71
9-14	7.6	5,132	4,912	850	166	23	5.2	5.7	58
9-28	7.2	4,312	4,084	700	162	19	6.5	5.6	42
10-19	4.4	3,756	3,620	800	213	12	6.8	5.3	33
11-02	6.4	4,212	4,044	780	185	15	6.0	5.2	21
11-16	6.0	2,576	2,440	580	225	12	9.2	5.9	38
11-30	6.0	---	---	720	---	8	9.8	5.6	38
12-07	5.3	3,368	3,236	650	193	7	9.8	5.5	33
12-19	---	3,416	3,280	650	---	--	---	6.6	96
1978									
1-04	5.2	3,576	3,396	780	218	4	---	7.3	267
1-25	3.6	2,796	2,660	600	215	2	---	7.2	192
2-08	---	3,724	3,468	500	134	4	---	7.9	592
3-15	6.0	4,884	4,668	---	---	6	8.5	6.9	248
3-29	9.6	4,956	4,663	800	161	10	9.8	7.2	256
4-12	---	3,924	3,680	650	167	15	8.5	6.9	171
4-26	8.0	2,570	2,437	200	78	9	8.5	6.3	70
5-10	8.0	2,320	2,180	200	86	14	7.0	6.6	96
5-25	9.2	3,000	2,850	300	100	19	5.0	6.3	67
5-31	8.0	3,496	3,324	350	100	20	5.1	6.0	58
6-07	7.6	3,196	3,036	320	100	19	5.3	6.0	54
6-14	10.8	3,692	3,512	530	144	18	2.9	6.1	54
6-21	14.0	2,996	2,864	380	127	22	4.7	6.1	59
6-29	16.2	3,180	3,044	390	123	23	5.0	5.9	46
7-05	22.4	3,088	2,908	360	117	21	1.8	7.0	354
7-12	28.4	2,120	1,816	220	104	21	0.4	7.3	563
7-19	26.4	2,304	2,080	250	109	22	1.2	6.3	79
7-26	20.0	2,477	2,205	280	113	23	0.8	5.7	25
8-02	18.8	2,768	2,428	300	108	23	1.1	5.5	17
8-09	26.4	2,352	2,132	290	123	23	0.7	5.7	37
8-16	22.0	2,252	2,024	260	115	24	2.3	5.6	25
8-30	15.6	---	---	280	---	24	3.1	---	---

(a) Sludge volume occupied in a litre graduated cylinder after 30 minutes settling.

(b) Sludge Volume Index.

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provided an odor-free and chemically stable flush water. Both nitrogen and phosphorus concentrations were adequate for biological growth. Nitrogen concentrations were high, however, they did not prove to be toxic to the biomass. All changes in the biological unit were in responses to changes in the pH, alkalinity, temperature, and water input.

Oxygen uptake by the biomass responded to expected changes in temperature and nitrification. The range of values experienced were typical of start-up values experienced in the evaluation phase with the exception of July and August 1978. In July a substantial transient increase in the alkalinity of the raw wastewater was experienced. With the high alkalinity and the accompanying increase in pH, significant nitrification occurred. This resulted in an increase in the oxygen uptake and a lowering of dissolved oxygen in the aeration basin, a significant lowering of ammonia nitrogen and nitrite nitrogen, and an increase in nitrate nitrogen. Although an increase in nitrification was observed in the evaluation phase during late summer, it was not to the extent experienced in July and August during this study. Since the trend for the latter part of August was a decrease in nitrification, the changes in nitrification appeared to be solely a response to increases in the pH and alkalinity.

The lowering of the MLSS was a response to sludge wastage and the use of makeup water in an attempt to maintain 95% recycle. The most significant change coincided with the addition of makeup water and the increase in nitrification in July. Although low MLSS values were experienced (and effective) during late summer, the system operated with a MLSS between 3,000 and 5,000 mg/l and a settleability (30 minute settling in a litre graduated cylinder) of 200 to 800 ml during most of the study.

The biomass under aeration was mostly filamentous, but separation of the MLSS from the liquid fraction was good and the carryover of suspended solids from the settling basin was not sufficient to be detrimental to the performance of the granular filter. The physical appearance of the MLSS and the ability to separate the solids from the liquid phase indicated that average water reuse of about 20 times was acceptable and sustained reuse of up to 30 times may cause deterioration in the separation of suspended solids and, ultimately, the quality of the recycle flush water.

The alkalinity and pH in the biological unit followed the same pattern established in the evaluation phase. Extreme changes in the alkalinity were the result of the inputs from the raw wastewater. Variations in alkalinities observed were extreme, 17 to 563 mg/l; however, the operating range was almost solely between 20 and 100 mg/l. The values of pH ranged from 5.1 to 7.9. High pH values were transient, and most often the system maintained a pH between 5.5 and 6.5. The quality of the flush water remained acceptable through all the observed variations in the alkalinity and pH.

Data from the biological unit indicate that a biological system (extended aeration) used to treat recycled water closet flush water at 95% recycle can be routinely monitored by settleable solids, MLSS, pH, alkalinity, temperature, and dissolved oxygen, and that the operation of the system does not differ significantly from the operation of a system treating non-recycled water. Nitrogen and biological oxygen demand will exhibit the greatest difference. Nitrogen will remain in the system primarily as ammonia nitrogen and nitrite nitrogen. Only when highly alkaline wastes are sewered (enter the recycle loop) will significant increases in nitrate nitrogen be detected. Concentrations of ammonia nitrogen, nitrite nitrogen, and nitrate nitrogen in the aeration basin as high as 150, 240, and 125 mg/l, respectively, were not detrimental to biological degradation. If significant agitation of the flushed raw wastewater between the flush and the treatment system is provided, an equilibrium concentration of ammonia nitrogen can be expected, except when transient high alkalinities occur. The introduction of waste by the rest area user raises the pH and results in ammonia stripping, provided some form of agitation is applied. At this site, flow in the sewer between the rest area and the biological unit provided sufficient agitation for maintaining nontoxic equilibrium nitrogen concentrations. As a result of the high ammonia nitrogen and nitrite nitrogen maintained in the system, BOD values were of no real significance as a measure of biodegradable organics.

As was the case in the evaluation study, the blue food coloring added to the system was not degraded; hence, the addition of dye was required only periodically and then in small amounts.

Foaming during this study was insignificant and, as a result, no chemical additives were required for control.

Filter Performance

Suspended solids concentrations imposed upon the filter were variable; however, they were usually maintained between 20 and 60 mg/l. Suspended solids in the flush water were generally less than 20 mg/l. Only during the period of freezing and extremely cold weather was a high suspended solids value, 41 mg/l, detected in the flush water.

The performance of the filter was significantly affected by the frequency of backwashing. The filter system was operated in a pressure differential (across the filter bed) backwash mode until May 1978. Because it was overdesigned the filter could operate in this mode without backwash for sustained periods, 4 weeks or more, unless backwashed manually. (Manual backwash while in the pressure differential mode was occasionally performed as a check on the system.) Since good standard practice is to backwash filters at least once weekly, in May 1978 the operating mode was changed to an automatic weekly backwash mode. After the system was set on an automatic weekly backwash mode, except for one analysis, flush water suspended solids did not exceed 12 mg/l. These data indicate that limiting the suspended solids in flush water requires careful attention to the design and operation of the filter. Oversizing the filter may not improve its performance; on the contrary, it may hinder the performance. Ideally, for the highest seasonal rest area use, the system should be designed on the basis of a backwash every 2 to 3 days. Hence, in designing recycle-reuse facilities particular attention must be given to filter size, filter media selection, and storage basin design. An evaluation of the design at this study site can be found in the start-up evaluation phase report.(3)

Quality of Recycled Flush Water

During this study the recycled water appearance and the chemical stability of the water remained acceptable as a flush fluid; no odors were detected and rest area users readily accepted the recycled water.

Only minor water quality differences were detected between this study phase and the evaluation phase. Differences in values for suspended solid (SS) between the two study phases were insignificant. Average suspended solids were approximately 15 mg/l for both study phases, with the lowest suspended solids occurring in this work when the filter was backwashed a minimum of once weekly. (Suspended solids were almost consistently less than 12 mg/l during this period.) Total solids (TS), total dissolved solids (TDS), and total fixed solids (TFS) showed little differences between equilibrium values established in the evaluation phase and those for this study, except where meltwater from ice and snow entered the system and the water adjustment in April 1978 to maintain 95% recycle. The TS values dropped to between 1,700 and 2,000 mg/l when water addition was sufficient to establish recycle ratios of 95% or less. In August, when the recycle level rose to 96.3%, the TS values returned to previous levels of approximately 2,400 mg/l. Chlorides rose slightly during the period in which 96.7% recycle was maintained. The pattern established by the chlorides was similar to the solids data. Chloride concentrations varied between 550 and 600 mg/l. Conductivity patterns basically followed the same trends as the TFS and chlorides; changes in chemical oxygen demand (COD) and total volatile solids (TVS) followed similar trends. Values for COD and TVS during the evaluation phase and this study were within approximately the same range until makeup water was added to maintain 95% (or less) recycle. The COD and TVS were lowered from the 300 to 400 mg/l range to the 200 to 300 mg/l range during the period in which adjustment of the recycle was implemented.

As previously stated, results for alkalinity and pH and nitrogen concentrations were very much related. (The interdependence of these parameters for microbial aquatic systems is well recognized and is a consideration in the design of biological treatment systems.) In the evaluation phase, equilibrium alkalinity and pH for the flush fluid was higher than for the biological unit. This was also true for this study. Alkalinity and pH values in both phases were within the same limits (100 to 150 mg/l and 6.5 to 7.5, respectively), except when transient high alkalinities occurred in the flushed wastes, and caused a shift in flush water alkalinity to the 200 to 300 mg/l range. Although some difference in nitrogen concentrations between the two study phases was observed, as would be expected, the greatest difference was observed when the alkalinity and pH values increased. During the start-up evaluation equilibrium values of approximately 160 mg/l for total Kjeldahl nitrogen (TKN) and ammonia nitrogen (NH_3-N), 180 to 220 mg/l for nitrite nitrogen (NO_2-N), and 75 mg/l for nitrate nitrogen (NO_3-N) were indicated. Prior to the nitrification experienced in July and August 1978, the range for these values were 100 to 150 mg/l, 70 to 140 mg/l, 100 to 180 mg/l, and 25 to 60 mg/l for TKN, NH_3-N, NO_2-N, and NO_3-N, respectively. Due to the range of conditions (seasonal use, water input balance, temperature, pH, alkalinity, and other waste characteristics) the system was exposed to during the follow-up study, variations in the nitrogen values experienced represent likely operative characteristics. The nitrification response to increase alkalinity and pH during July and August, when the TKN and NH_3-N were lowered to about 25 mg/l, the NO_2-N decreased to less than 5 mg/l, and the NO_3-N increased to the 70 to 110 mg/l range, is also a likely operating response. The lowering of the NH_3-N during late summer also appears to be related to an increase in NH_3-N losses in the sewer system as a result of an increase in temperature and flushed waste pH. (It should be noted that if the NH_3-N exhibited an inhibitory effect on nitrification, increased losses of NH_3-N could result in increased nitrification. This is not an unlikely condition since the total nitrogen decreased during the nitrification experienced in July and August.)

The phosphorus content of the flush water showed an increase between the evaluation phase and the implementation follow-up phase (from a range of 20 to 40 mg/l to a range of 40 to 50 mg/l) with a sharp increase in July and August to a range of 60 to 70 mg/l. During the evaluation phase the raw phosphorus was generally between 30 and 60 mg/l with an occasional value much greater; however, in this study phase, it was usually 30 mg/l or less with the exception of a rise to between 50 and 60 mg/l in late summer. A rising trend of raw wastewater phosphorus was as expected; however, variations in phosphorus concentrations to the extent exhibited was unaccountable Interference with the phosphorus analysis and/or a variation in the phosphorus in the MLSS (influenced by sludge wastage, MLSS concentration and chemical characteristics of the recycle water) are plausible explanations.

CONCLUSIONS

The conclusions from this study are as follows:

1. The conclusions established in "Water Reuse at Highway Rest Areas: Evaluation Phase"[3] were confirmed.

2. The recycle-reuse system — biological treatment followed by granular filtration — is capable of producing an acceptable flush water for water closets at 95% recycle (an average reuse of 20 times).

3. The recycle-reuse concept and design can be used at other rest areas on a site-specific basis. It has national application.

4. In certain geographical areas zero discharge may be attainable at 95% recycle and reuse of water closet flush water.

5. The water recycle-reuse system has application for facilities other than highway rest areas. The system can be used at facilities where a substantial amount of the water use is for flushing water closets.

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3. Parker, C. E., "Water Reuse at Highway Rest Areas: Evaluation Phase", Virginia Highway and Transportation Research Council, Charlottesville, Virginia, VHTRC 78-R22, December 1977.

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Raw Wastewater Characteristics

Concentration in mg/l.

Date	°C	pH	Cond. μmohs	Alk.	COD	TKN	NH_3-N	NO_3-N	NO_2-N	TS	TFS	TVS	TDS	SS	SVS	P	Cl^-
1977																	
9-07	24	8.4	--	663	533	--	309	27	75	2412	1935	477	1896	516	459	12	714
9-14	24	8.4	4530	621	988	280	196	33	79	2615	1995	620	2288	327	307	--	718
9-28	20	8.4	--	617	1537	238	179	39	87	3690	2286	1404	2236	1454	1178	--	--
10-19	14	7.9	4950	359	558	215	184	32	118	2544	2139	405	2370	174	158	38	781
11-02	16	7.9	--	409	683	185	155	45	123	2565	2123	442	2362	203	187	29	776
11-16	10	8.3	--	490	1074	192	140	26	50	2942	2179	763	2348	594	520	25	--
11-30	10	8.6	--	484	996	218	169	22	70	2603	2174	429	2459	144	134	--	801
12-07	8	8.5	3650	455	1109	213	152	26	128	2687	2217	470	2597	90	82	27	839
12-19	--	8.3	--	354	--	--	--	--	85	2944	2185	759	2512	432	392	--	819
1978																	
1-04	--	8.4	3750	525	--	--	173	90	71	3198	2236	962	2892	306	298	--	821
1-25	4	8.3	3720	509	301	236	123	40	--	2573	2200	373	2512	61	55	23	828
2-08	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
3-15	7	8.3	4200	433	1066	181	175	17	--	2626	1837	789	2116	510	670	17	649
3-29	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
4-12	15	8.4	4000	646	1028	220	180	27	--	2295	1804	491	2130	165	165	26	656
4-26	--	8.5	3000	533	--	153	138	10	--	1914	1516	398	1779	135	135	20	541
5-10	13	8.4	--	492	--	--	--	--	--	2004	1546	458	1866	138	138	32	560
5-25	17	8.1	--	345	893	--	133	--	102	2125	1623	502	2015	110	110	28	531
5-31	18	8.3	2900	542	337	173	153	--	63	1692	1190	502	1682	10	10	22	509
6-07	19	8.4	3200	538	712	185	165	11	63	2016	1321	695	1556	460	410	15	534
6-14	19	8.3	2700	475	220	160	154	29	87	2037	1641	396	1947	90	80	18	587
6-21	21	8.5	2600	579	1311	215	176	20	58	3019	1838	1181	2064	955	747	14	584
6-29	22	8.0	2700	413	625	175	157	35	63	2288	1637	651	1850	438	353	17	794
7-05	21	7.8	2700	654	402	217	210	42	25	2418	1720	698	1853	565	505	16	618
7-12	21	8.1	2900	854	506	225	188	7	3	2238	1843	395	2083	155	122	30	648
7-19	22	8.3	2700	638	881	158	132	12	11	2533	1844	689	2305	228	208	27	770
7-26	23	8.1	2700	429	351	100	95	52	9	2182	1747	435	2122	60	57	50	586
8-02	23	7.9	2900	383	429	115	91	69	0.6	2226	1689	537	2053	173	170	50	547
8-09	23	7.8	2700	350	342	89	82	84	0.7	2537	1870	667	2337	200	200	53	610
8-16	24	7.7	3100	388	202	129	100	70	0.6	2991	1951	1040	2841	150	140	60	581

APPENDIX A-2

Settling Basin Effluent Characteristics

Concentration in mg/l.

Date	°C	pH	Cond. μmohs	Alk.	COD	TKN	NH_3-N	NO_3-N	NO_2-N	TS	TFS	TVS	TDS	SS	SVS	P	Cl^-
1977																	
9-07	24	6.1	--	58	408	--	145	83	166	2392	2023	369	2377	15	15	30	718
9-14	22	5.7	4480	46	428	176	123	66	170	2480	2121	359	2455	25	25	--	713
9-28	19	5.8	--	46	384	111	101	58	157	2434	2092	342	2397	37	32	--	--
10-19	12	5.7	4850	67	366	123	106	30	195	2548	2183	365	2497	51	51	56	763
11-02	14	6.0	--	83	368	114	97	59	210	2577	2178	399	2538	39	39	40	780
11-16	10	5.5	--	25	280	97	74	50	78	2565	2189	376	2481	84	84	39	--
11-30	8	6.1	--	42	428	103	87	37	126	2700	2216	484	2491	209	197	--	788
12-07	6	5.6	3300	25	449	92	82	47	141	2607	2185	422	2537	70	70	35	804
12-19	--	6.7	--	96	--	--	--	--	138	2577	2166	411	2533	44	44	--	799
1978																	
1-04	4	7.3	3680	246	--	--	131	48	155	2677	2276	401	2555	122	95	--	830
1-25	2	7.2	3480	163	521	147	100	63	--	2603	2194	409	2463	140	115	50	810
2-08	1	7.8	--	517	--	--	--	--	--	2185	1849	336	2121	64	64	--	668
3-15	7	7.3	3750	246	374	104	91	40	--	2126	1754	372	2070	56	56	42	613
3-29	9	7.2	--	229	374	150	136	40	--	2167	1763	404	2078	89	85	40	622
4-12	15	6.8	3800	150	489	118	108	34	--	2157	1780	377	2098	59	59	38	620
4-26	9	6.1	2900	46	--	67	56	35	--	1950	1604	346	1896	54	54	52	554
5-10	14	6.4	--	58	--	--	--	--	--	2007	1615	392	1944	63	63	50	548
5-25	18	6.1	--	46	316	--	56	--	140	2014	1582	432	1958	56	56	51	509
5-31	21	6.1	2800	46	341	94	78	--	134	1723	1374	349	1666	57	57	47	504
6-07	20	6.0	2800	42	360	70	66	19	138	1608	1358	250	1574	34	34	47	516
6-14	18	5.9	2500	38	182	67	64	46	140	1959	1648	311	1919	40	40	43	533
6-21	22	6.0	2300	38	416	66	61	52	113	2150	1682	468	2002	148	147	43	521
6-29	23	5.8	2500	34	761	87	63	75	88	2180	1694	486	2172	28	28	46	581
7-05	21	6.7	2300	267	299	84	79	66	35	2088	1751	337	1972	116	116	49	383
7-12	21	7.4	2500	429	311	78	67	10	9.0	1883	1661	222	1859	24	24	42	561
7-19	22	6.4	2400	42	203	13	6	92	86	2171	1763	408	2147	24	24	42	575
7-26	23	5.5	2400	8	220	12	9	105	0.1	2303	1802	501	2274	29	29	57	554
8-02	24	5.4	2500	4	210	21	19	121	0.1	2389	1891	498	2356	33	33	64	583
8-09	24	5.5	2500	12	215	18	16	125	0.2	2511	2010	501	2490	21	21	62	587
8-16	25	5.1	3000	8	171	31	26	120	0.1	2443	2023	520	2511	32	27	70	573

APPENDIX A-3

Flush Water Characteristics

Concentration in mg/l.

Date	°C	pH	Cond. µmohs	Alk.	COD	TKN	NH_3-N	NO_3-N	NO_2-N	TS	TFS	TVS	TDS	SS	SVS	P	Cl^-
1977																	
9-07	25	7.0	--	146	368	--	163	115	206	2341	1983	358	2377	4	3	25	700
9-14	22	6.7	4350	133	369	192	130	62	184	2389	2050	339	2383	6	6	--	707
9-28	21	6.5	--	96	341	124	96	61	176	2418	2104	314	2400	18	14	--	--
10-19	12	6.1	4750	125	320	118	107	35	226	2507	2166	341	2497	10	10	52	759
11-02	14	6.2	--	121	327	122	110	57	240	2550	2180	370	2534	16	16	48	768
11-16	12	7.2	--	220	237	102	83	32	106	2480	2161	319	2467	13	13	42	--
11-30	7	7.0	--	138	373	106	90	32	119	2536	2215	321	2520	16	16	--	795
12-07	4	6.7	3350	121	351	96	91	33	128	2545	2175	370	2529	16	16	40	799
12-19	--	6.7	--	104	--	--	--	--	146	2550	2187	363	2533	17	17	--	808
1978																	
1-04	4	7.4	3580	155	--	--	120	39	143	2629	2264	365	2588	41	41	--	817
1-25	2	7.3	3630	233	180	148	98	46	--	2591	2239	352	2562	29	29	50	819
2-08	1	7.7	--	288	--	--	--	--	--	2098	1808	290	2084	14	14	--	654
3-15	12	6.9	3800	288	296	104	99	32	--	2111	1792	319	2088	23	23	42	617
3-29	10	7.1	--	192	362	123	115	41	--	2100	1748	352	2070	30	30	40	620
4-12	16	7.6	3850	334	421	140	137	29	--	2117	1800	317	2094	23	23	38	626
4-26	9	7.3	2950	242	--	87	78	25	--	1897	1595	302	1878	19	19	52	551
5-10	16	7.3	--	158	--	--	--	--	--	1737	1397	340	1716	21	21	50	543
5-25	21	7.0	--	129	269	--	68	--	139	1955	1547	408	1932	23	23	51	506
5-31	22	7.1	2800	146	288	104	92	--	121	1880	1292	588	1868	12	12	47	507
6-07	22	6.9	2800	125	300	73	72	18	116	1623	1332	291	1613	10	10	47	512
6-14	20	6.9	2400	117	167	73	73	42	123	1894	1669	225	1886	8	8	43	530
6-21	23	7.2	2300	154	232	--	78	32	93	1917	1616	301	1909	8	8	43	516
6-29	25	7.1	2400	150	214	79	70	48	85	1895	1579	316	1889	6	6	46	570
7-05	22	6.8	2100	263	236	109	83	64	58	2007	1933	74	1997	10	10	49	585
7-12	22	7.6	2600	617	226	115	109	17	41	1856	1663	193	1839	17	17	42	565
7-19	23	7.5	2500	346	245	62	23	22	20	1815	1609	206	1811	4	4	42	558
7-26	24	7.0	2400	133	179	25	24	71	5.0	2245	1786	459	2244	1	1	57	560
8-02	25	6.8	2500	121	222	25	23	92	2.5	2314	1942	372	2305	9	9	64	574
8-09	24	6.7	2400	87	207	27	27	108	2.3	2373	1875	498	2369	4	4	62	591
8-16	24	6.6	2800	100	153	33	26	101	1.3	2352	1856	496	2346	6	6	70	576