WATER REUSE AT HIGHWAY REST AREAS: EVALUATION PHASE

by

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

Virginia Highway & Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Highways & Transportation and the University of Virginia)

In Cooperation with the U. S. Department of Transportation
Federal Highway Administration

Charlottesville, Virginia

December 1977
VHTRC 78-R22

1258

ABSTRACT

The limited availability of water and stringent wastewater effluent standards at rest areas led to the development of a water recycle-reuse system to treat flush water from water closets.

Flush fluid for rest area water closets accounts for 95% to 97% of the rest area water requirements. For a flush fluid to be acceptable it must have no objectionable odors, no objectional color, no substantial foaming, and no apparent suspended solids, and it must be low in bacterial count and chemically and biologically stable.

Prior research with a bench-scale system confirmed the application of extended aeration biological treatment followed by granular media filtration as a water recycle-reuse concept. This prior work led to the installation of a full-scale field system at a rest area to develop data for implementation of the recycle concept. The treatment system at an existing rest area was modified to provide a closed loop return of water to and from the water closets. A water balance was achieved by wasting an amount of recycle water equal to the water input from sewered potable water.

Data from the field recycle-reuse system were obtained during its operation from November 15, 1976, to August 31, 1977. During this time start-up was evaluated and equilibrium was achieved and evaluated at 95% recycle. The biological system and filtration system provided flush water of a quality that met standards set for flush water and was accepted by the users.

Operation of the closed loop extended aeration and granular filter system for flush water recycle and reuse was similar to the conventional operation of these processes. The influence of nitrogen accounted for the most significant operating difference. Ammonia nitrogen transformation to nitrite and nitrate nitrogen resulted in an operating pH of 5.5 to 6.0 and, as a result, incomplete nitrification occurred. Nitrogen buildup in the form of ammonia, nitrite, and nitrate was experienced but the concentrations did not cause a reduction in the organic biological oxidation efficiency. The biological system functioned under conditions suitable for the utilization of organics by fungi. The biological solids were threadlike; however, they readily separated through gravity settling.

The quality of the water in the recycle-reuse system varied between winter and summer operation, but it remained acceptable as a flush fluid. The variability in quality can be attributed

mainly to nitrogen. Nitrogen in the recycled water greatly influences biochemical oxygen demand results and renders this test useless as a measure of organic stability.

Storage requirements for recycle flush water are dictated by the resident time of the users in the building that houses the water closets, the resident time of users in the parking facility, and the physical layout of the water closet facility. Average daily and maximum daily water use based on resident times and gallons (litres) per user establishes storage, biological treatment, and filter requirements. Instantaneous peak flow establishes pipe sizes and integration of system requirements for storage and use sets pump requirements.

ACKNOWLEDGEMENTS

The following members of the Advisory Task Group for the water recycle-reuse project are acknowledged for their suggestions and guidance:

N. J. Castellanos, Federal Highway Administration

R. B. Chewning, Virginia State Water Control Board

R. A. Cline, Virginia Department of Highways and Transportation

R. E. Conner, Virginia Department of Health

R. L. Fink, Virginia Department of Highways and Transportation

A. B. Sadler, Austin Brockenbrough and Associates

Many persons in the Virginia Department of Highways and Transportation's Environmental Quality Division, Staunton District Office, and Lexington Residency deserve special thanks for their devoted labors.

The support and assistance of many persons in the Virginia Highway and Transportation Research Council that made this project possible are sincerely appreciated. The economic analysis by Gary R. Allen is gratefully acknowledged. John W. Reynolds provided invaluable assistance during this study and in the preparation of this report. His assistance with the analytical work, workshops, and data accumulation contributed immensely to the successful completion of the project. For his efforts I am most appreciative and deeply indebted.

The research reported here was financed from highway planning and research funds administered by the Federal Highway Administration of the U. S. Department of Transportation. Austin Brockenbrough and Associates, consulting design engineers for the prototype recycle and reuse system, supplied ideas and recommendations which were pertinent to the research project.

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INTRODUCTION

Development of Water Recycle-Reuse Concept

Rest areas in the Commonwealth of Virginia have experienced problems with both water supply and wastewater disposal. Water supply problems have occurred when existing or proposed water supplies have proved inadequate. To supply an adequate amount of fresh water to these facilities would require a substantial expense and would mean either trucking in water, increasing existing well capacities, or laying miles of water line. Wastewater disposal problems have occurred as a result of stringent standards placed on wastewater effluents at highway rest areas by governmental agencies. In some cases, tertiary treatment may be required to meet these standards.

As a result of these problems, the Virginia Highway and Transportation Research Council researched and developed a design to be used in the reuse of water at rest areas for flushing water closets. The design, which was a culmination of five years of research and development, was incorporated into the modification of an existing wastewater treatment system at a rest area on I-81 near Fairfield, Virginia, south of Staunton.

The concept of water reuse was initiated from conferences between personnel of the Environmental Quality Division of the Virginia Department of Highways and Transportation and environmental engineering consultants. These conferences, which took place in mid-1970, were followed by an investigation of water use and wastewater effluents at rest areas in Virginia.(1) It was concluded from this investigation that removal of suspended solids from extended aeration or aerated lagoon effluent would produce a water of a quality suitable for flushing toilets. It was projected that 90% to 95% of the water used at rest areas goes to flush water closets and that 10 to 20 recycles would be required to reach an equilibrium with the input of 5% to 10% sewered potable water from hand wash basins and other miscellaneous uses.

Since no information was available to support satisfactory operation of a biological treatment system where water was recycled through the system 10 to 20 times, the research and development of a recycle-reuse concept was evaluated by a bench-scale model that used a synthetic wastewater comparable in characteristics to waste inputs at rest areas.(2)

The bench-scale research and development program proved the concept to be extremely satisfactory, and sufficient research and development information was provided to allow a decision to be made as to the commitment to water reuse prior to letting the construction contract for a full-scale field facility at Fairfield.

In November 1976 construction of a recycle addition to the existing extended aeration biological treatment unit at the Fairfield rest area was completed and operation began November 15, 1976. Figure 1 is a schematic of the system used at the rest area.

Flush Fluid Requirements for Recycle-Reuse

The basic requirements for a flushing fluid are that it have no objectionable odor, no objectionable color, no foaming, and no suspended solids, and that it be chemically and biologically stable and have a low bacterial count. Extended aeration or aerated lagoons followed by filtration are capable of producing water meeting these requirements. Currently, the reuse of flushing fluid appears to be limited either to a water recycle system or a mineral oil recycle system.

In water recycle and reuse for flushing water closets it is necessary to identify the amount needed for potable water and the amount that can be of a lower quality. A recycle and reuse system for flushing water closets must take into consideration the water wasted from lavatories and drinking fountains. This water is considered a new water input to the recycle system and is a factor in the control of the amount of water that must be wasted from a water recycle system.

During this research the amount of water from this source has been found to vary from 2% to 9% of the total water use, with the average being 5.8%. Water from fountains and lavatories enters the system as a water input and becomes part of the recycled flushing water. The mineral oil system requires either evaporation of the fountain and lavatory wastewater or a separate treatment system for this water. In either recycle

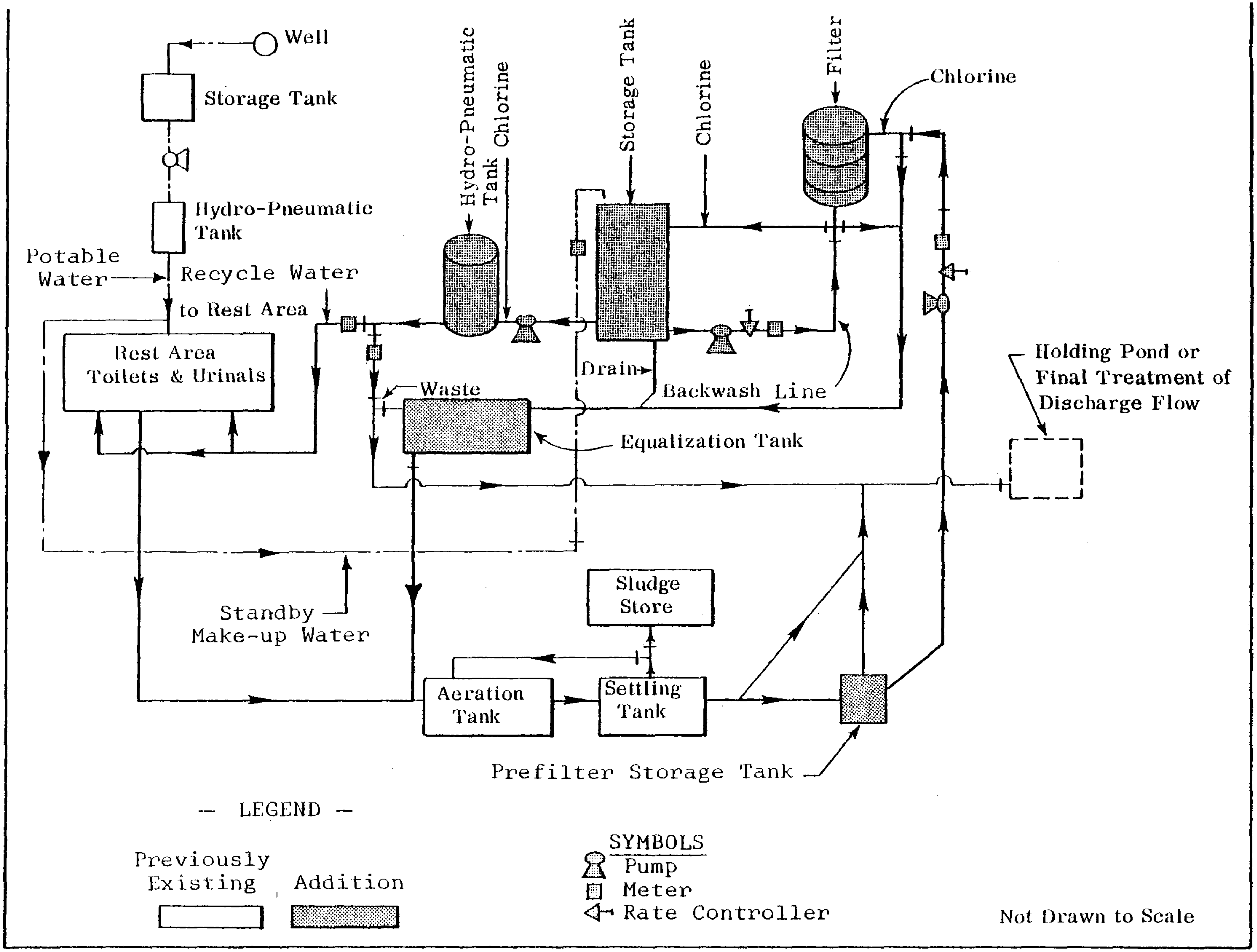

Figure 1. Schematic flow diagram for modifying typical extended aeration system.

system, water from fountains and lavatories must be potable water and must be handled in the total treatment scheme. In a recycled water system, this volume of water can be used to maintain an equilibrium dissolved solids concentration in the recycled water by wasting an equal volume of recycle water. It is apparent that with either water reuse or mineral oil recycle a volume of water equal to that produced from fountains and lavatories must be disposed of.

Approximately 95% of the water usage at highway rest areas is for flushing toilets, and extended aeration followed by sand filtration is capable of producing a water of sufficient quality for this use. Advantages of this system would be greatly reduced potable water requirements and a reduced volume of wastewater discharged to streams, or possibly no discharge to streams. The cost effectiveness of this type of system is expected to be maximized when the system is added to rest areas which already employ extended aeration or aerated lagoons. The water recycle and reuse concept presented here can be added directly to rest areas already equipped with extended aeration biological treatment.

A substantial number of rest areas now in existence and proposed are in locations where water and wastewater problems are now known to exist. Water reuse offers a technologically feasible alternative to other systems that may be used at rest areas with water or wastewater problems.

Recycle-Reuse Water Quality Changes

Water used in the recycle-reuse system originally is potable water. Once it enters the system it is treated to produce an acceptable toilet flush water and becomes recycled, treated, and reused to the fullest extent practicable. The characteristics of the recycled water change from summer to winter due to cold weather affecting the biological treatment, low usage of the rest area, and decreased evaporation. The most significant changes are those associated with the ammonia concentration and nitrification. Since cold weather retards nitrification, ammonia can be expected to increase during the winter months and result in an increase in both the alkalinity and pH of the water.

Since there are no provisions for accepting wastes from tanks of travel or camping trailers at the Fairfield rest area, the untreated wastewater is characterized by the materials and substances flushed in the toilets. For the most part, these consist of urine, human feces, and paper. This means that although rest area wastewater resembles municipal wastewater, the two are unlike in that the former has a high concentration of urine and the latter contains a variety of substances used in households that find their way into the municipal system. The urine concentration is the most significant difference from an operational viewpoint. It is responsible for the ammonia nitrogen concentration in rest area wastewater being much higher than that in municipal wastewater. This factor is significant and influences some of the treatment control parameters.

Since the characteristics of the wastewater reflect the water used in flushing as well as the material flushed in the toilet by the traveler and the substances used in custodial services, the characteristics of the recycled water used to flush the toilets will change until the recycle system reaches a state of equilibrium. This change in water characteristics with each recycle results from the fact that the biological system and filtration system do not remove all the substances entering the water with each recycle. While biodegradable organics, suspended solids, and bacteria will be removed from the flushed water by the treatment system, other substances will increase with each recycle either in a modified form or in the form in which they are introduced until equilibrium is reached.

OPERATING PRINCIPLES OF TREATMENT SYSTEM FOR WATER RECYCLE-REUSE

Extended Aeration Biological Treatment Process

The use of extended aeration biological treatment of wastewater at rest areas in the Commonwealth of Virginia is common practice. This use has stemmed from the fact that this treatment system is relatively easy to operate, does not require continuous monitoring, has a high detention time which dampens out peak flows, and is capable of producing an effluent low in biochemical oxygen demand (BOD) and suspended solids. In addition, the system provides nitrification, i.e., it converts ammonia nitrogen to the non-oxygen demanding form of nitrate nitrogen.

The extended aeration biological process consists of an aeration basin, settling basin, source for aeration, and pumps to transfer the settled solids either back to the aeration unit or to a sludge storage basin.

Normally, prior to the wastewater entering the aeration basin it passes through a comminuter that shreds large solids. Then it flows into the aeration basin, where the biological activity that decomposes the organics takes place. This basin contains suspended material that is primarily microorganisms growing on the organic material in the incoming wastewater. These suspended microbial solids are the biomass needed to break down the organic material and substances flushed into the toilets. High concentrations of biological solids must be maintained in the aeration basin to assure that a sufficiently active biomass is present to use up the biologically degradable organics and to assure good gravity separation in the settling basin. The suspended biological solids, or biomass, in the aeration basin are commonly referred to as "mixed liquor suspended solids" (MLSS). After the wastewater has had sufficient contact with these MLSS in the aeration basin, normally 24 hours, the wastewater containing the solids flows into the settling basin. In the settling basin the MLSS settle out and are pumped from the bottom of the basin back to the aeration basin. Treated wastewater leaving the settling basin overflows a baffled weir at the top of the basin. The return of the MLSS to the aeration basin keeps the incoming wastewater in contact with the concentration of microorganisms necessary for removing the biologically degradable organics; i.e., it assures that sufficient MLSS are maintained in the aeration basin for proper functioning of the system. Since the biomass grows on organics in the flushed wastewater and MLSS are returned to the aeration basin, there will be a gradual increase in concentration of the MLSS. As a result, it is periodically necessary to decrease the MLSS in the aeration basin. This reduction is accomplished by wasting solids which have been allowed to accumulate in the settling basin into a sludge storage basin.

Treatment by the biological activity in the aeration basin followed by settling is responsible for the improvement in water quality that takes place. The major changes are in biodegradable organics (measured as BOD), pH, alkalinity, suspended solids and nitrogen. The nitrogen change is very sensitive to environmental conditions in the aeration unit, especially dissolved oxygen, pH, alkalinity, and temperature. In addition to being sensitive to dissolved oxygen, pH and alkalinity, when converted from ammonia to nitrate the nitrogen has a profound effect on these three parameters.

Filtration Process and Hydro-pneumatic System

The practice of water treatment by filtration is very common and well established. Its use to make wastewater meet stringent water quality standards has become extensive during recent years. There are many types of filtration processes and many kinds of media. The most commonly used media are sand, anthracite, and nonhydrous aluminum silicate.

Rapid filtration in a pressurized vessel is used to the greatest extent in small systems where continuous monitoring is not required, space is limited, and protection of the filter media may be desirable. It is particularly useful where limited space is available and it is impractical to provide enough head for gravity filtration.

The primary objective of filtration is the removal of suspended solids; however, it is generally considered that improvement in water quality is obtained by some biological activity.

Rapid filters are called such because of the rate of application of water to the surface of the filter. A high application rate is possible due to a design which permits the filter to be automatically cleaned periodically by reversing the flow of water. Since the reversal of flow through the filter media results in the smaller and lighter particles coming to the top of the surface and the entire filter media arranging itself with the particles becoming larger and heavier with increasing depth, this design is also referred to as a stratified filter. (The stratified arrangement is assured due to the design and placement of the media in the filter.)

Generally, during the filtration cycle, the flow rate is between 2 and 4 gpm/ft^2 (80 and 160 lpm/m^2), and during the backwash cleaning cycle the rate is 7 to 15 gpm/ft^2 (285 to 610 lpm/m^2). In the filtration mode the pressure filter is flooded and the flow is regulated to the filter to provide the desired filtration rate. Eventually, the suspended solids collected on the filter will cause a drop in pressure across the filter and a reduction in the filtration rate. When this occurs, it is necessary to clean the collected solids from the filter and then resume filtration. The cleaning of the filter can be performed either automatically or manually. Automatic cleaning can be initiated in two ways: (1) preset a pressure differential switch that measures the pressure at the top of the filter and at the bottom of the filter so that a specified differential between the pressures at the two locations will start the cleaning cycle, or (2) set a timer-switch system so that at preselected times the filter will go through the cleaning cycle. Normally, the automated system is designed so that once the cleaning cycle is initiated it will automatically go through all the cycles necessary for cleaning and restoring the system to the filtration cycle. In the manual operation of the cleaning cycle each step can be maintained as long as desired, but in the automatic modes each step is preselected by setting a timer.

When the cleaning cycle is initiated the prefiltered water line is closed and then the surface wash line opens. The surface wash scours the surface of the filter media and breaks up deposits into small particles and loosens the fine surface media. After the surface wash cuts off, the backwash step initiates. In the backwash step water enters through the bottom of the filter with an upward velocity great enough to "lift" or "expand" the upper layers of the filter media, causing these materials to rub together. (These expanded upper layers resemble quicksand conditions.) The upward flow is regulated so that it is great enough to lift the upper layers and allow collected suspended material to flow up and out with the water but not great enough to flush out the filter media. The water from both the surface wash and the backwash flows to a drain where it is sewered. Following the cutoff of the backwash, the prefiltered water line opens to permit filtration again. To assure that the filtered water does not contain suspended solids as a result of the disturbance of the filter bed during the backwash step, the first water that is filtered is sewered. After a small quantity of water is sewered, the drain valve closes and the system returns to the production of filtered water ready for its intended use.

Filtered water, or processed water, may be stored in a holding tank to provide a supply during fluctuating demands and to serve as the source of filter cleaning water during the surface wash and backwash steps.

Hydro-pneumatic tanks are used in water systems with or without filtration to supply water to the user in an acceptable pressure range. In order to do this a tank is pressurized with air at the desired high pressure when it is filled to a maximum water level, about 1/2 of its total volume. The maximum operating pressure will be determined by the pressurization at the selected high water level and minimum pressure is dictated by the minimum allowable pressure needed to operate the water system. In order to prevent air from entering the water lines, some minimum water level must be maintained in the pressure tank.

Usually, additional air is needed only infrequently after the tank is pressurized at maximum pressure and high water level. If air losses occur, a portable air compressor can be brought to the site to restore maximum pressure. The pump that supplies water to the hydro-pneumatic tank may be regulated by a pressure switch and a float switch. As water is used and the water level drops, the float switch goes to the on position, but an override by the low pressure switch will not allow the pump to cut on and add water to the tank until the low pressure switch goes to the on position. Once both the float switch and the low pressure switch are on, the pump adds water until it is cut off at the high water level (also, maximum pressure) by the float switch. The low pressure switch automatically goes to off when the float switch cuts off. If an air compressor is available at the site, a system of pressure switches can be installed to automatically check the pressure at the high water level at the end of each pump cycle, and if the desired maximum pressure is not attained the compressor activates to add air and bring the pressure up to the desired value.

Fairfield Recycle-Reuse System

The system used in this research was biological treatment by extended aeration followed by rapid filtration using a granular nonhydrous aluminum silicate media. Wastewater from the rest area was treated by the 10,000 gpd (37,800 lpd) extended aeration system and released to a small stream prior to the installation of the filtration system. Modification for water recycle-reuse involved pumping the biologically treated effluent through a newly constructed filter and then back to the water closets as the flush fluid. The filter was 6.0 feet (1.83 metres) 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 (1221 lpm/m^2) for surface wash and 8.5 gpm/ft^2 (346 lpm/m^2) for backwash. Water closet flush water was posted through biological treatment and rapid 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 different piping system.

For additional information on the system installed at the Fairfield rest area, refer to Appendix A.

ANALYSES AND PROCEDURES

The evaluation of the acceptability of the recycle-reuse system focused on the ability of the biological treatment system to perform with recycled water; the acceptability of filtration as the sole method of polishing the biological treatment system effluent before recycle and reuse; the changes in the physical, chemical, and biological characteristics of the water that have a bearing on the acceptability of the recycled water as a flush fluid; system characteristics that would lead to design improvements; and characteristic parameters that indicate system performance. The evaluation thus required an accumulation of performance data for the installed system over an extended period of time.

Samples were taken on a weekly basis of the flushed water (raw wastewater), aeration basin mixed liquor, settling basin effluent, prefiltered water, postfiltered water, and recycled water prior to reuse. These samples were analyzed for those parameters presented in Table 1. Exceptions to this sampling schedule were that (1) biological analyses, ultimate BOD, and hardness were monitored on a less frequent basis, and (2) aeration basin mixed liquor was analyzed only for those parameters that reflect the characteristics of the biomass.

FAIRFIELD USER CHARACTERISTICS

A traffic and use survey of the Fairfield rest area was undertaken to determine user relationships to main line traffic and water use. A summary of these data are presented in Table 2. These data indicate that the user characteristics of the Fairfield rest area are compatible with results obtained for other Virginia rest areas and rest areas located in other states.[2]

The resident time of vehicles at the rest area, persons per vehicle, users per vehicle, resident time of users in the toilet facility, and water use relationships are essential to the design of a facility that is to adequately serve the public. These relationships will obviously vary with location of the rest area and the physical layout of the parking facilities and toilet facilities. Although they are important in establishing water and wastewater needs for any rest area, they are especially so where an adequate supply of flush water is to be economically provided by a recycle-reuse system.

Figures 2 and 3 are bar diagrams for resident times for users of the toilet facility and for vehicles at the rest area. Based on these data and a toilet layout such as at the Fairfield rest area, the flush fluid requirements at design capacity are (1) an average daily flow of 16 gpm (60 lpm); (2) a maximum daily flow of 20 gpm (75 lpm), and (3) a peak hour flow of 27 gpm (100 lpm). For detailed information on the use of these data in design considerations see Appendix B.

Table 1

Analyses Performed and Procedures

	Analysis	Procedure[a]
1.	Biological	
	Fecal Coliform	SM, p. 937
	Total Coliform	SM, p. 928
	Fecal Strep	SM, p. 944
2.	Chemical	
	Biochemical Oxygen Demand, 5 day (BOD)	SM, p. 543
	Biochemical Oxygen Demand, ultimate (BOD)	SM, p. 543
	Chemical Oxygen Demand (COD)	SM, p. 550
	Total Kjeldhal Nitrogen (TKN)	SM, p. 437
	Organic Nitrogen	SM, p. 437
	Ammonia	EPA, p. 165
	Nitrite	Orion Electrode
	Nitrate	SM, p. 422
	Total Phosphorus	SM, p. 479
	Hydrogen Ion Activity (pH)	SM, p. 424
	Alkalinity	SM, p. 278
	Chlorides	SM, p. 306
	Conductivity	SM, p. 71
	Oxygen Uptake Rate	SM, p. 127
	Dissolved Oxygen	SM, p. 450
3.	Physical	
	Color	Observation
	Odor	Observation
	Total Dissolved Solids (TDS)	SM, p. 93
	Total Volatile Solids (TVS)	SM, p. 95
	Total Fixed Solids (TFS)	SM, p. 91
	Settleable Solids	SM, p. 95
	Suspended Solids (SS)	SM, p. 94
	Volatile Suspended Solids (VSS)	SM, p. 95
	Mixed Liquor Suspended Solids (MLSS)	SM, p. 127
	Mixed Liquor Volatile Suspended Solids (MLVSS)	SM, p. 127
	Sludge Volume Index (SVI)	Calculated

(a) SM — Standard Methods for the Examination of Water and Wastewater, 14th edition.

EPA — Methods for Chemical Analysis of Water and Wastes, Environmental Protection Agency, 1974.

Orior Electrode[5] — Instruction Manual, Nitrite Ion Electrode, Model 95-46, Orion Research, Inc., 1976.

Table 2

Rest Area Use Survey

Percentages of Main Line Vehicles Entering Rest Area	
Cars	11.3
Tractor trailers	8.3
All vehicles	10.8
Resident Time of Vehicles at Rest Area, Minutes	
Cars	8.14
Tractor trailers	6.47
Recreational vehicles	9.50
All vehicles	7.94
Vehicle Occupancy, Average Persons Per Vehicle	
Male	1.13
Female	.92
All users	2.05
Toilet Facility Users as Percentage of Persons Stopping	
Male	73.3
Female	80.7
All users	76.6
Resident Time of Users in Toilet Facility, Minutes	
Men	2.40
Women	2.77
All users	2.57
Toilet Flush Water Use, Gallons (Litres)	
Per flush	3.35 (12.7)
Per toilet user	3.96 (15.0)
Potable Water Use, Gallons (Litres)	
Per toilet user	0.21 (0.8)

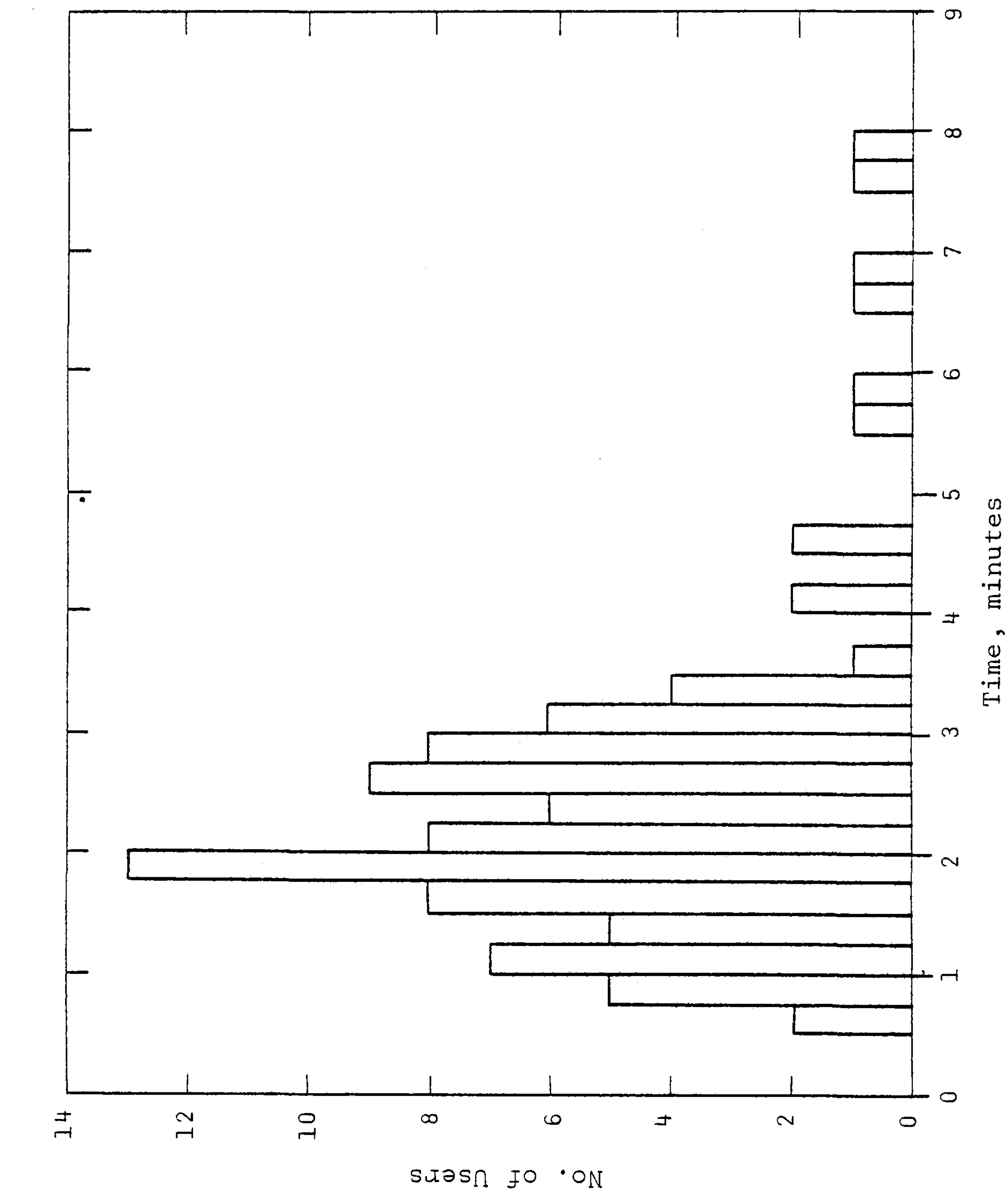

Figure 2. Resident time of toiler facility user.

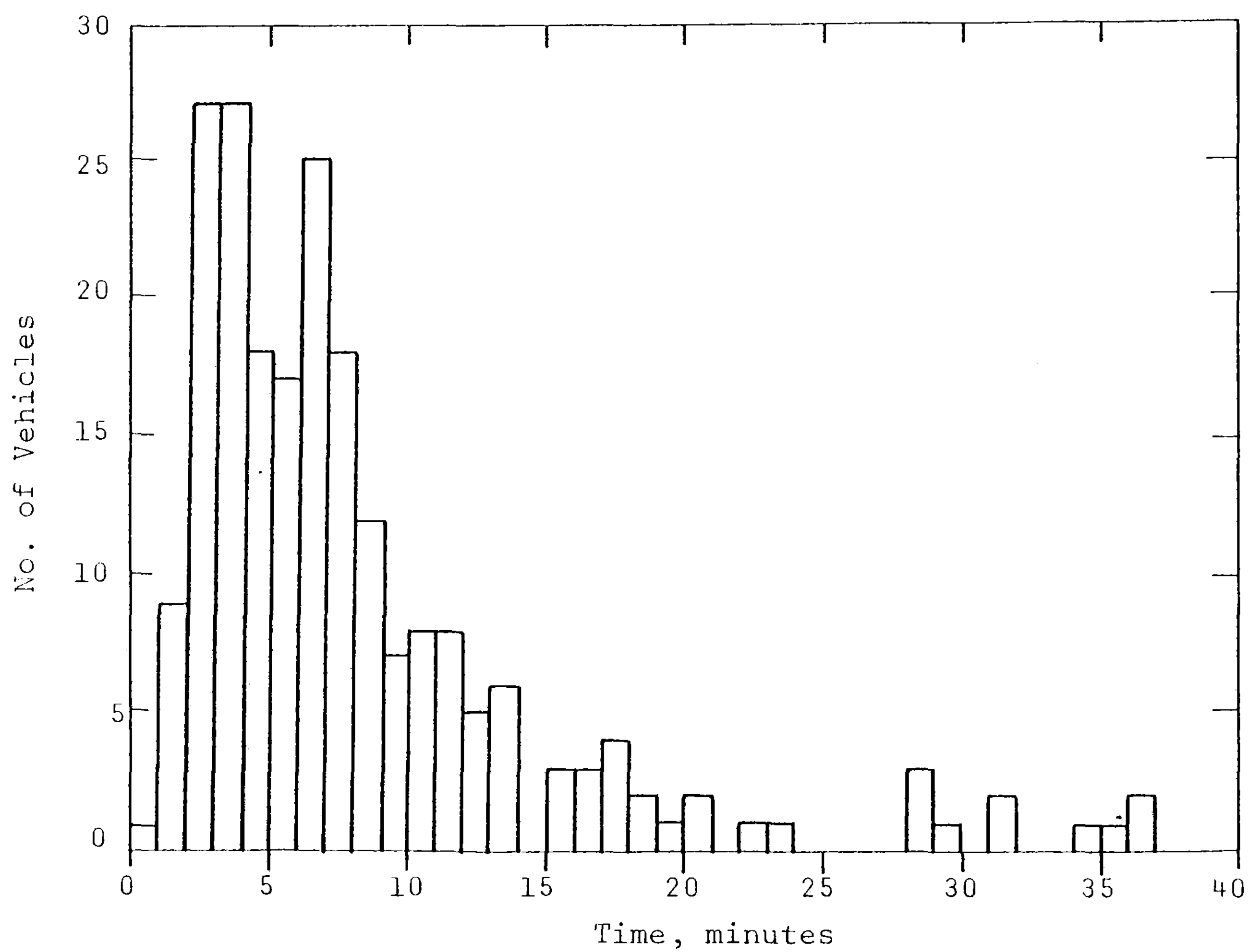

Figure 3. Resident time for vehicles at rest area.

RESULTS FROM OPERATION OF FIELD SYSTEM

Operation of the rest area facility with water recycle and reuse began November 15, 1976. The total volume of water in all units (aeration basin, settling basin, prefiltration tank, postfiltration tank and hydro-pneumatic tank) at start-up was 43,000 gallons (163,000 litres). Water volume at the maximum operating level in all basins and tanks was 50,000 gallons (190,000 litres). At start-up the postfiltration tank and the hydro-pneumatic tank were filled to their maximum operating level with potable water.

No special preparations were made with the biological treatment system. At the completion of construction the discharge from the hydro-pneumatic tank in the recycle system was connected to the water closets and the effluent from the settling basin was diverted to the prefiltration tank. Hence, the change in water characteristics in the biological system was gradual and dependent upon user demand. The system was operated until January 21, 1977, without difficulty. On that date the Fairfield rest area, like others in the state that employed biological treatment, was closed due to severe freezing. (The winter of 1976-77 was the most severe on record for this area. Unusually low temperatures, in the range of -23° to -29°C, were experienced over an extended period of time.) The subfreezing temperatures and the necessity for obtaining a replacement bowl for a frozen pump delayed the reopening of the rest area until March 15, 1977.

Prior to the second start-up water was released from the pre- and postfiltration tanks and the hydro-pneumatic tank to the holding pond. These tanks were refilled with potable water just prior to opening the rest area. Aeration in the extended aeration unit was resumed as soon as it and the settling basin thawed. Since this basin was never emptied and aeration was resumed prior to opening the rest area, the biological populations in the aeration basin were relatively inactive.

During both start-ups a blue food coloring dye, FD&C Blue No. 1, (Brilliant Blue), was injected into the water as it entered the hydro-pneumatic tank. It was not necessary to inject dye to color the water on a continuous basis since the treatment system did not remove the color. It was found that addition by hand was adequate and this was necessary on a very infrequent basis. Less than 5 pounds (2.3 kg) of dye was added during the entire study period.

Water treated and returned for reuse was metered between the hydro-pneumatic tank and the water closets. A weekly history of water use for the period of study is presented in Tables 3 and 4. Also shown in Table 3 is the ratio of water recycled and reused to the initial volume of water in the system. Although this ratio is not the actual recycle ratio, it is a close approximation and can be used to approximate the percent recycle. These water use data show that the potable water use varied between 2.0% and 9.0% of the total water used (flush water plus potable water) with an average of 5.8%.

Results of analyses for all water sampling locations are presented in Appendix C, Tables C-1 through C-5. Table C-6 in Appendix C presents data for the biological system prior to installation of the recycle system. Data for recycled water that had passed through the treatment system and was ready for reuse as a flushing fluid are presented in Figures 4 through 12 for summer operation until equilibrium occurred, and in Figures 13 through 20 for winter operation before freezing occurred. These data show the increase in the measured parameter as a function of the ratio of the accumulated total volume of water used to flush toilets (recycled and reused water) to the initial water volume in all units of the treatment system. For summer operation the leveling off of parameters unaffected by biological treatment, settling and filtration — such as conductivity, fixed solids, chlorides, and sulfates — indicates an equilibrium condition where user input of residual compounds and potable water use materially balances with the loss of water from the system by evaporation plus the overflow of water (with its residual materials) to the evaporation and storage pond.

Changing conditions in the aeration unit are documented in Table 5. The biomass was stringy in appearance and contained a lower percentage nitrogen than generally found in viable bacterial populations. Fungi were the dominate heterotrophic population present. This observation was supported by the appearance of the MLSS and the pH range that the biological system operated in, namely, 5.5 to 6.0. Nitrifier organisms were also present as indicated by the transformations of the forms of nitrogen; however, optional conditions were not present for these organisms.

Although the biomass in the aeration unit was stringy it settled without difficulty and left a clear supernatant. The MLSS level in the aeration basin was maintained between 2,300 and 7,100 mg/l. The system normally operated at an MLSS level between 3,500 and 5,500 mg/l.

Table 3

Flush Water Use

Date	Accumulated volume, used, gallons	Average daily flow, gpd	Maximum daily flow, gpd	Minimum daily flow, gpd	Ratio: Water recycled / Initial water in system	Avg. percent recycle water of total water use
3/17	8,245	2,061	2,870	1,660	0.19	92.0%
3/23	24,738	2,748	4,380	1,553	0.58	94.7%
3/30	44,080	2,763	5,165	1,295	1.03	94.3%
4/4	74,655	6,115	13,590	2,745	1.74	96.0%
4/11	167,195				3.89	
4/20	209,285	4,899	11,800	2,070	4.87	94.8%
4/27	237,715	4,061	5,480	3,010	5.53	95.1%
5/4	262,375	3,523	5,430	2,500	6.10	95.5%
5/11	290,045	3,953	5,540	2,510	6.75	94.8%
5/19	321,795	3,969	5,790	2,540	7.48	93.5%
5/25	352,935	5,190	7,850	3,480	8.21	95.4%
6/1	394,565	5,947	9,480	3,692	9.18	95.6%
6/8	426,945	4,626	4,710	2,570	9.93	95.8%
6/15	459,335	4,627	6,870	2,260	10.68	95.1%
6/21	493,535	5,700	7,430	3,480	11.48	91.3%
6/28	525,645	4,587	6,860	2,080	12.22	94.1%
7/6	579,435	6,724	10,775	4,190	13.48	94.6%
7/13	621,355	5,989	7,690	4,520	14.45	93.9%
7/20	658,775	5,346	7,436	4,030	15.32	92.3%
7/27	696,705	5,419	7,130	3,540	16.20	92.7%
8/3	737,335	5,804	7,050	4,320	17.15	93.7%
8/10	776,525	5,599	6,220	4,260	18.06	92.9%
8/17	813,205	5,240	6,930	2,210	18.91	92.4%
8/24	852,875	5,667	7,240	4,470	19.83	94.8%
8/31	882,615	4,249	5,540	2,670	20.53	92.8%

NOTE: 1 gallon = 3.785 litres

Table 4

Potable Water Use

Date	Accumulated volume used, gallons	Average Daily flow, gpd	Maximum Daily flow, gpd	Minimum Daily flow, gpd
3/17	721	144	176	107
3/23	1,645	154	207	85
3/30	2,811	167	221	119
4/4	4,079	254	391	163
4/11	5,684	229	392	106
4/20	8,096	268	385	153
4/27	9,556	209	271	93
5/4	10,720	166	215	156
5/11	12,234	216	320	140
5/19	14,437	275	392	161
5/25	15,941	251	432	136
6/1	17,862	274	583	128
6/8	19,291	204	290	134
6/15	20,949	237	305	144
6/21*	24,194	541	964	271
6/28	26,207	288	366	209
7/6	28,905	385	601	247
7/13	31,622	388	565	269
7/20	34,740	445	543	298
7/27	37,734	428	590	251
8/3	40,481	392	600	279
8/10	43,500	431	594	321
8/17	46,515	431	772	136
8/24	48,686	310	408	215
8/31	50,993	330	409	258

NOTE: 1 gallon = 3.785 litres

*New construction activity began at rest area, and not all potable water used was sewered.

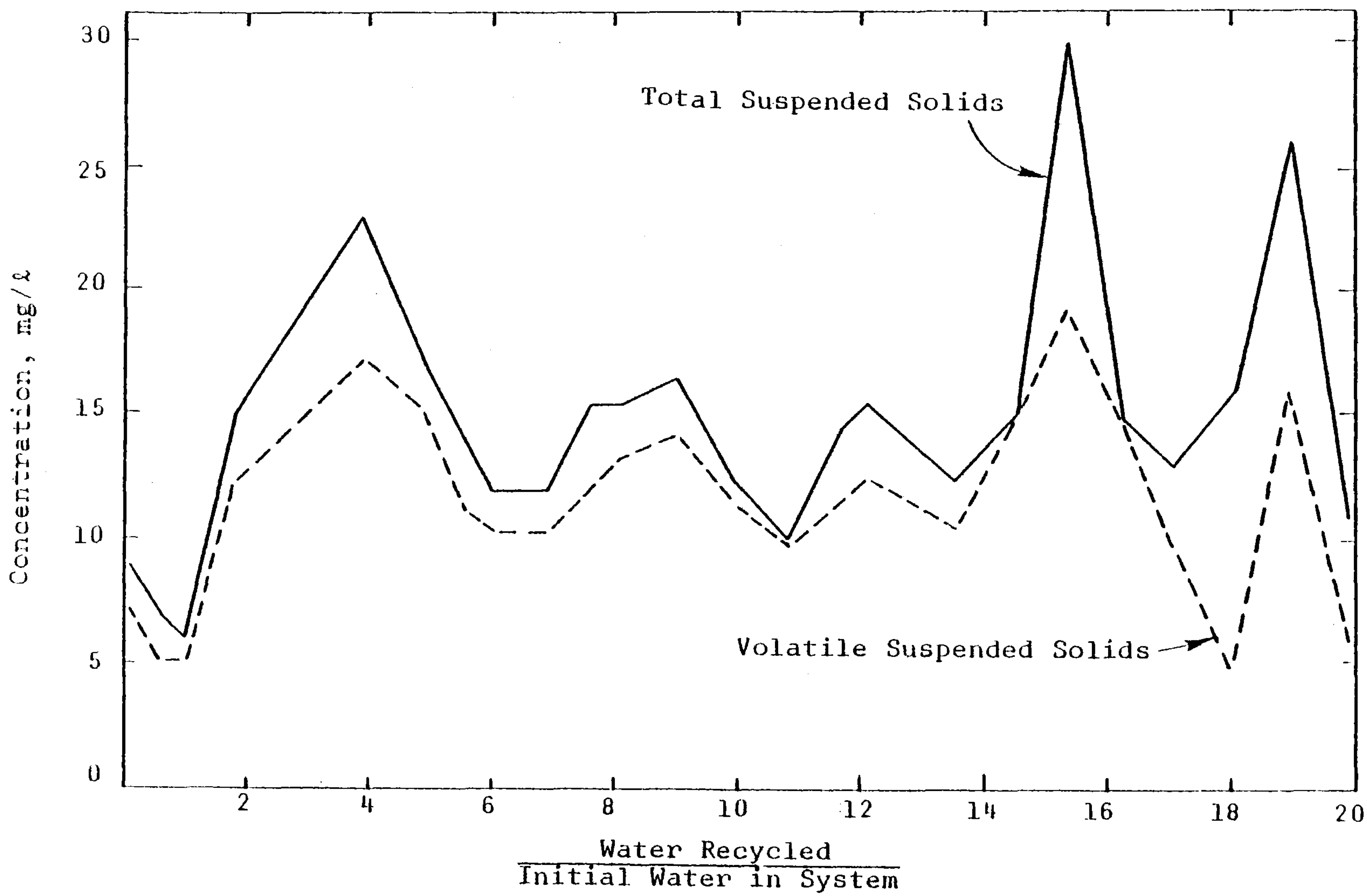

Figure 4. Summer operation: flush water suspended solids.

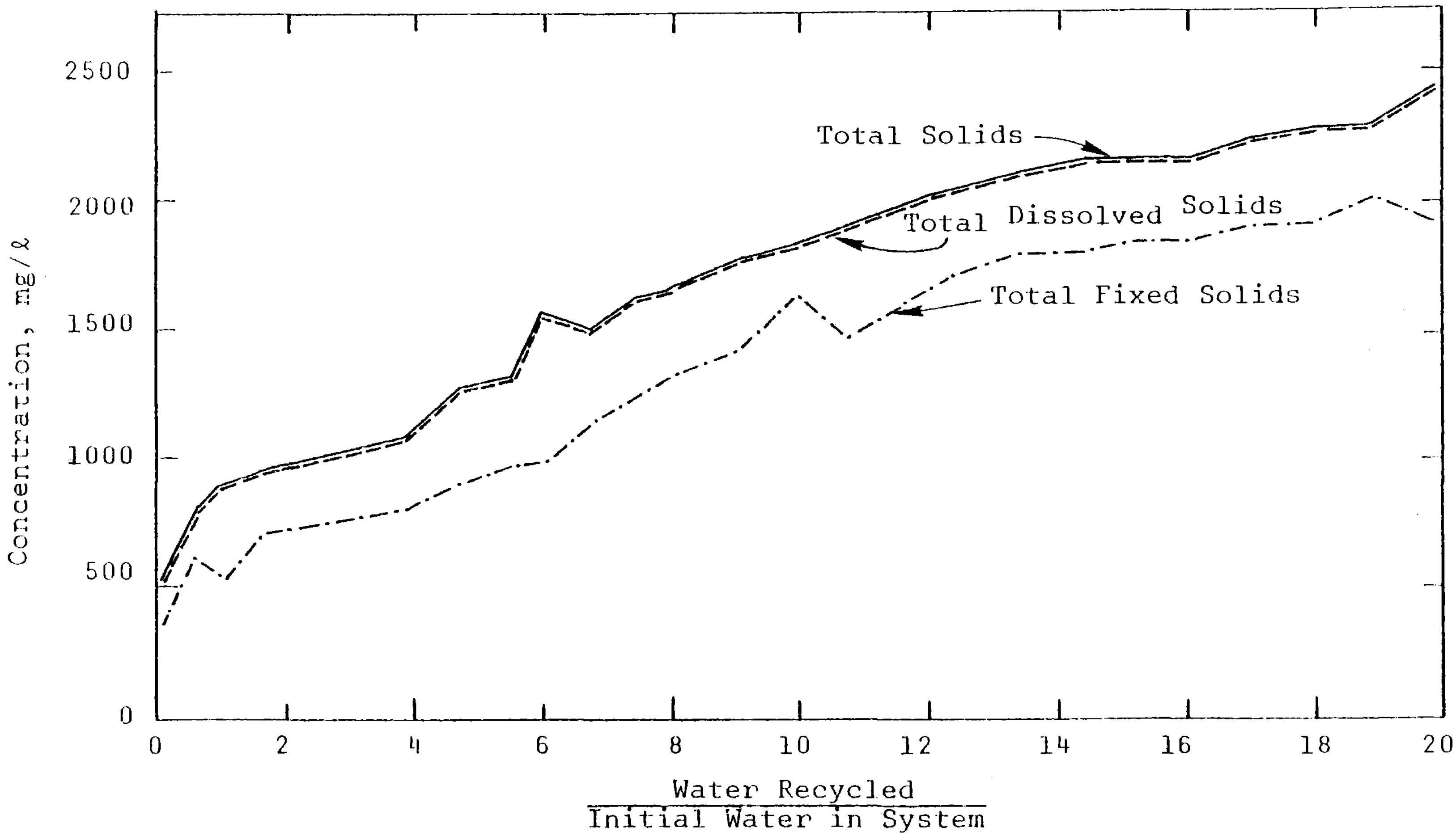

Figure 5. Summer operation: flush water total solids.

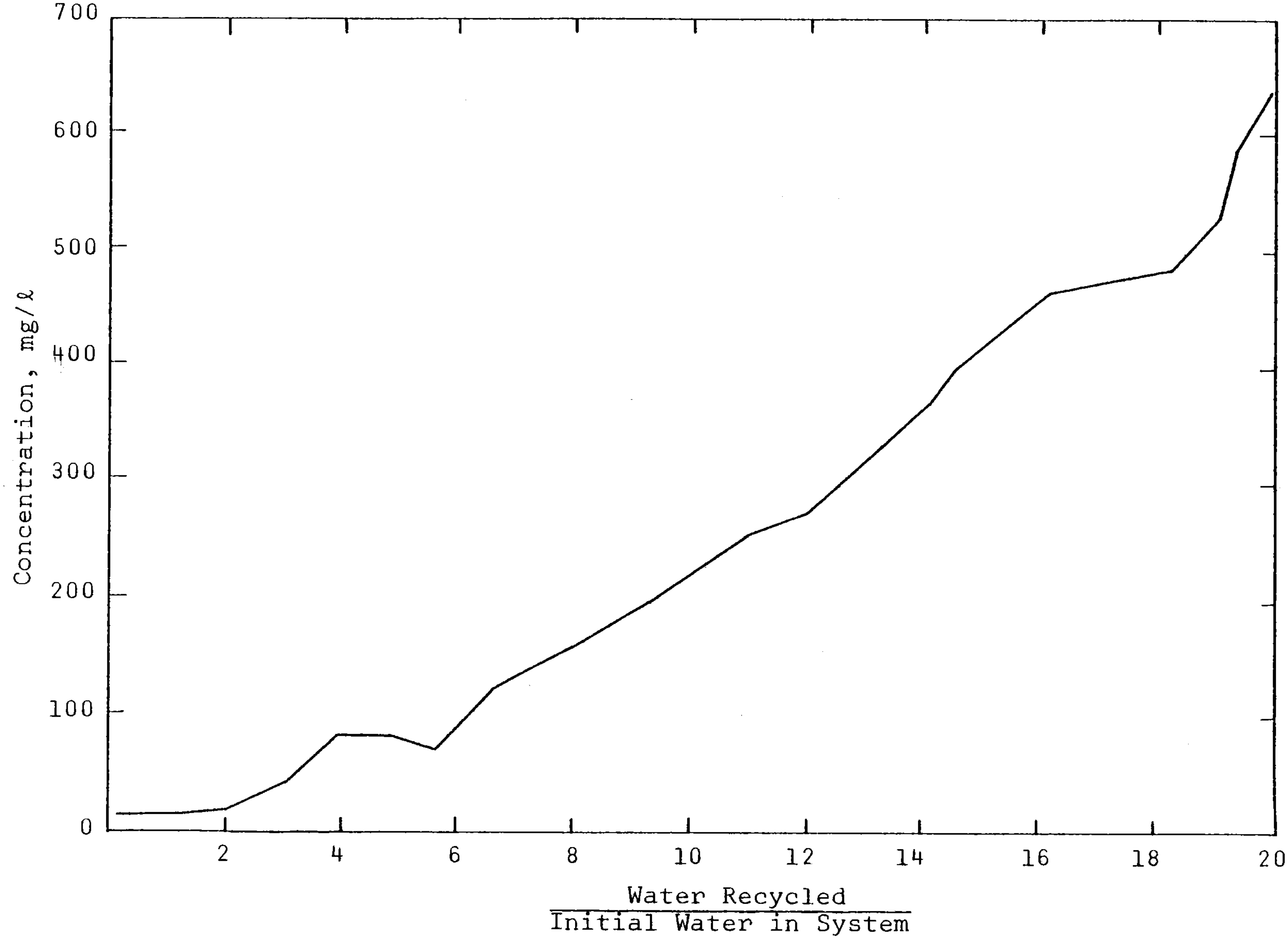

Figure 6. Summer operation: flush water chlorides.

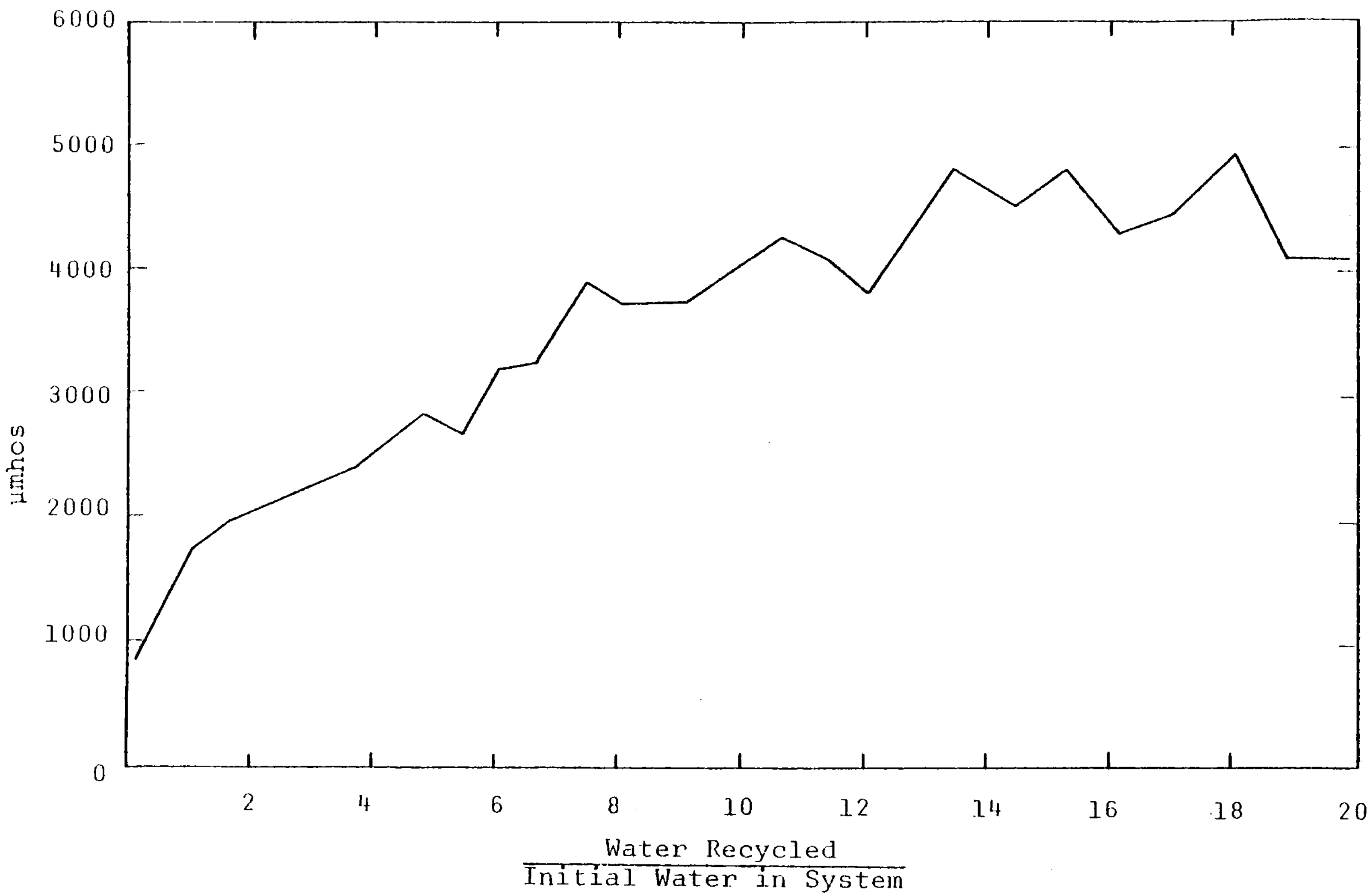

Figure 7. Summer operation: flush water conductivity.

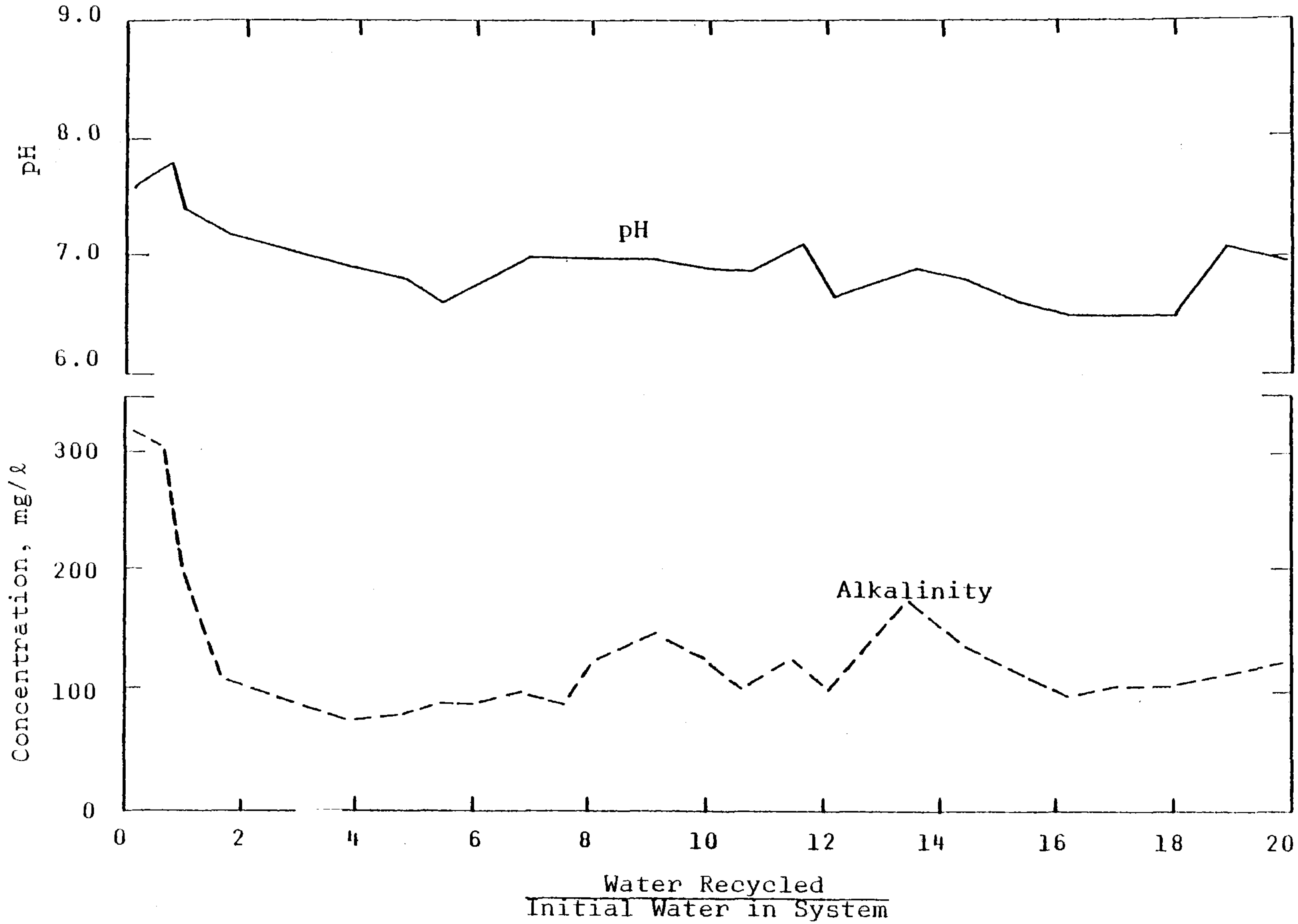

Figure 8. Summer operation: flush water pH and alkalinity.

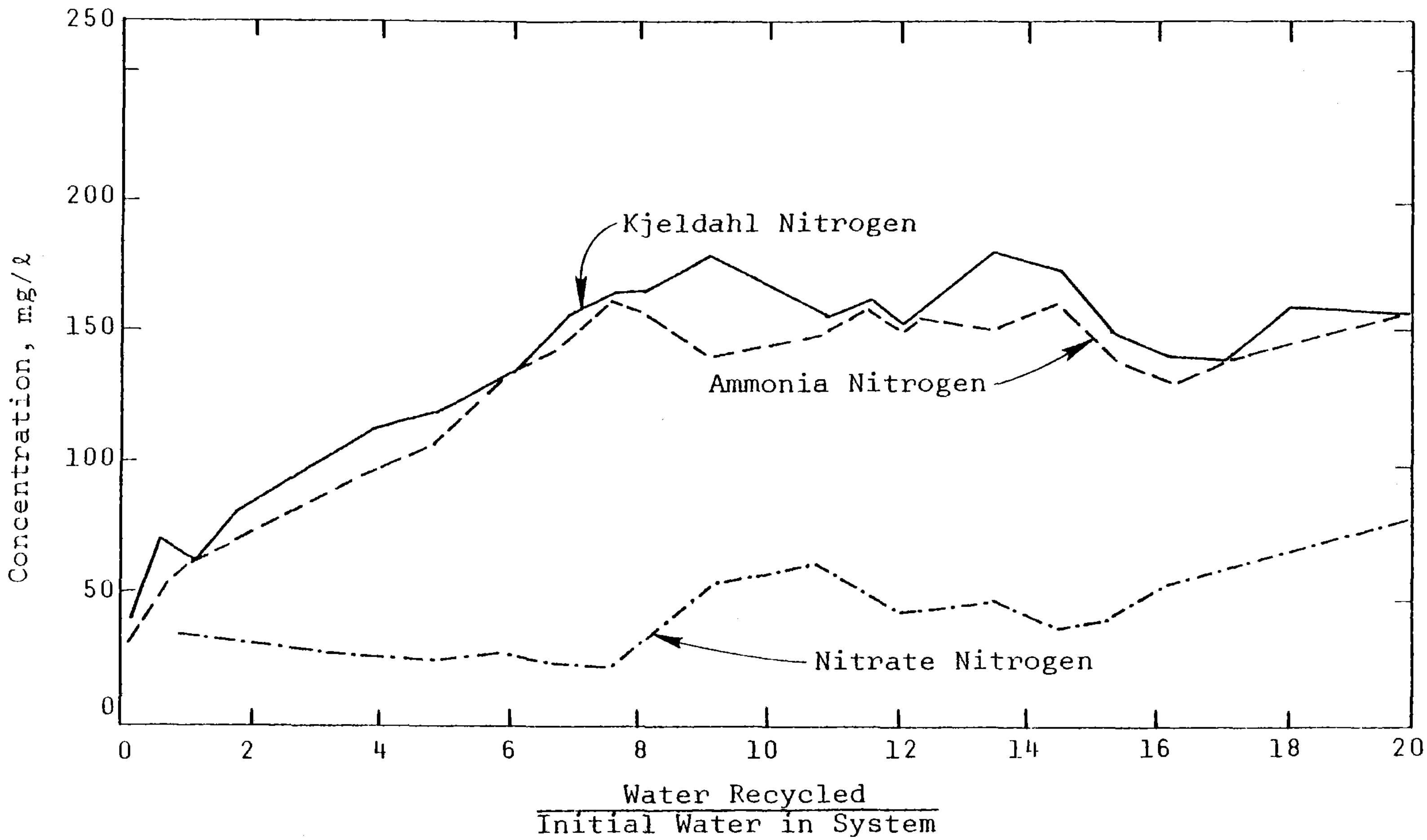

Figure 9. Summer operation: flush water nitrogen.

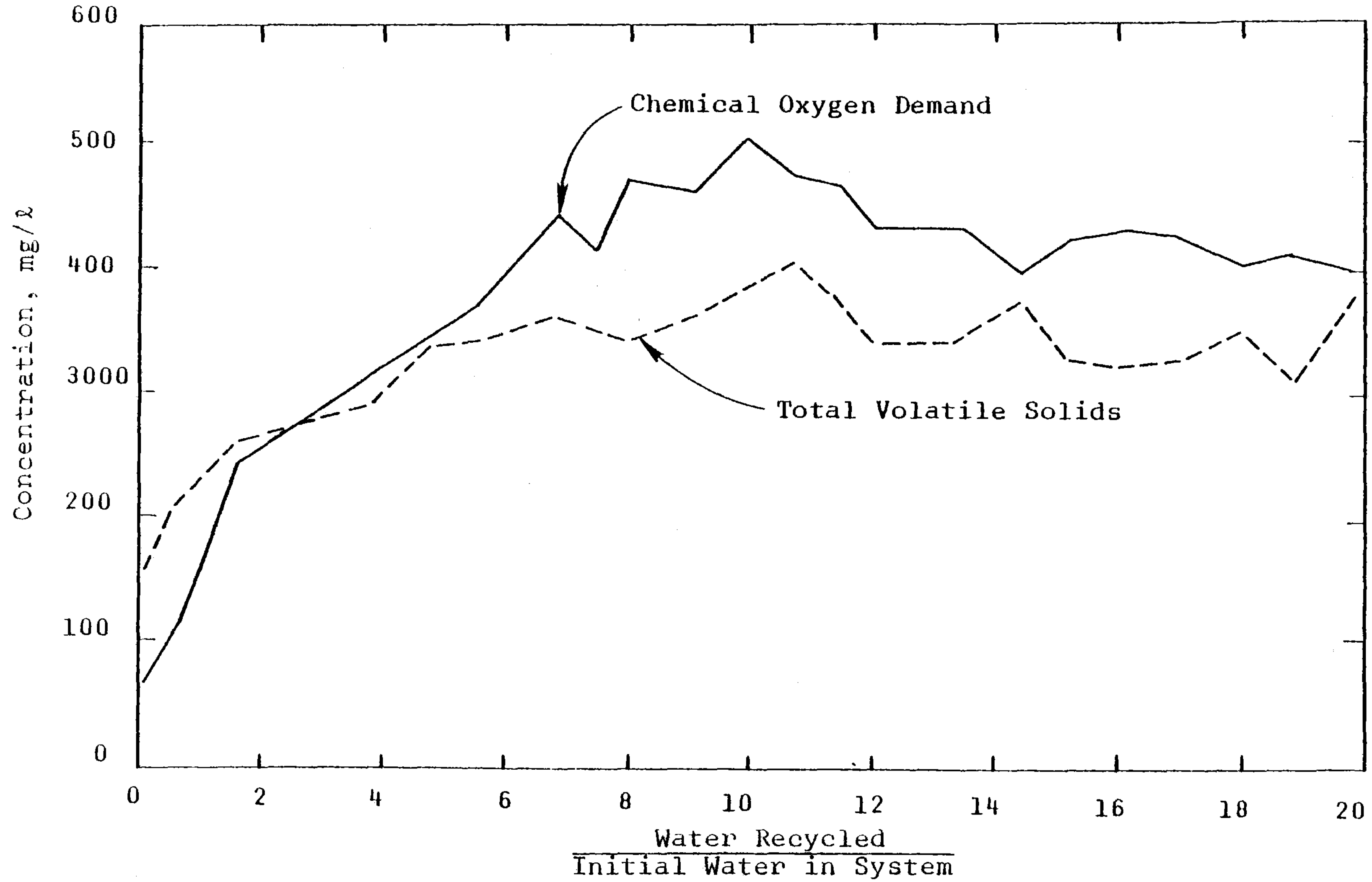

Figure 10. Summer operation: flush water COD and volatile solids.

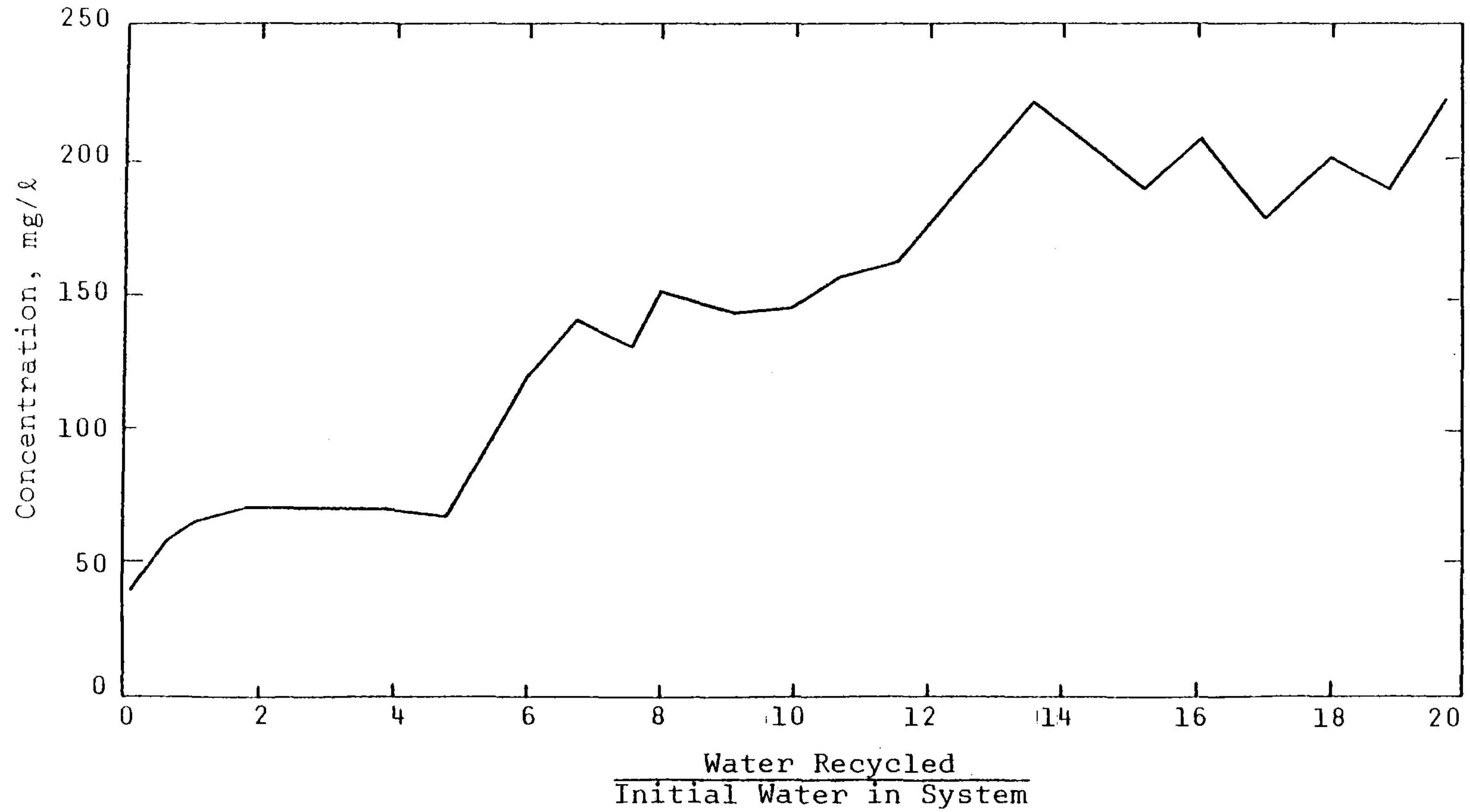

Figure 11. Summer operation: flush water sulfates.

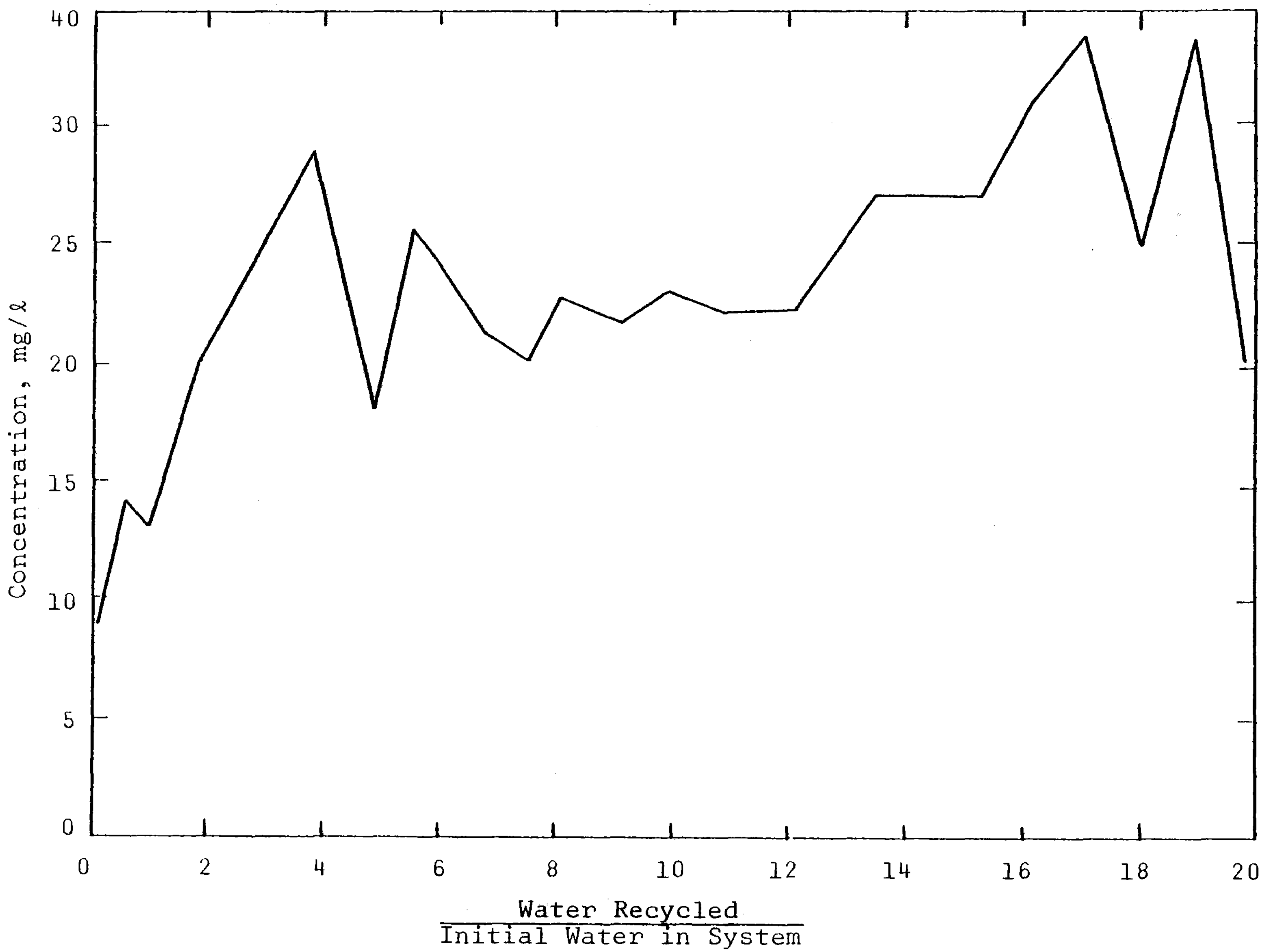

Figure 12. Summer operation: flush water phosphorus.

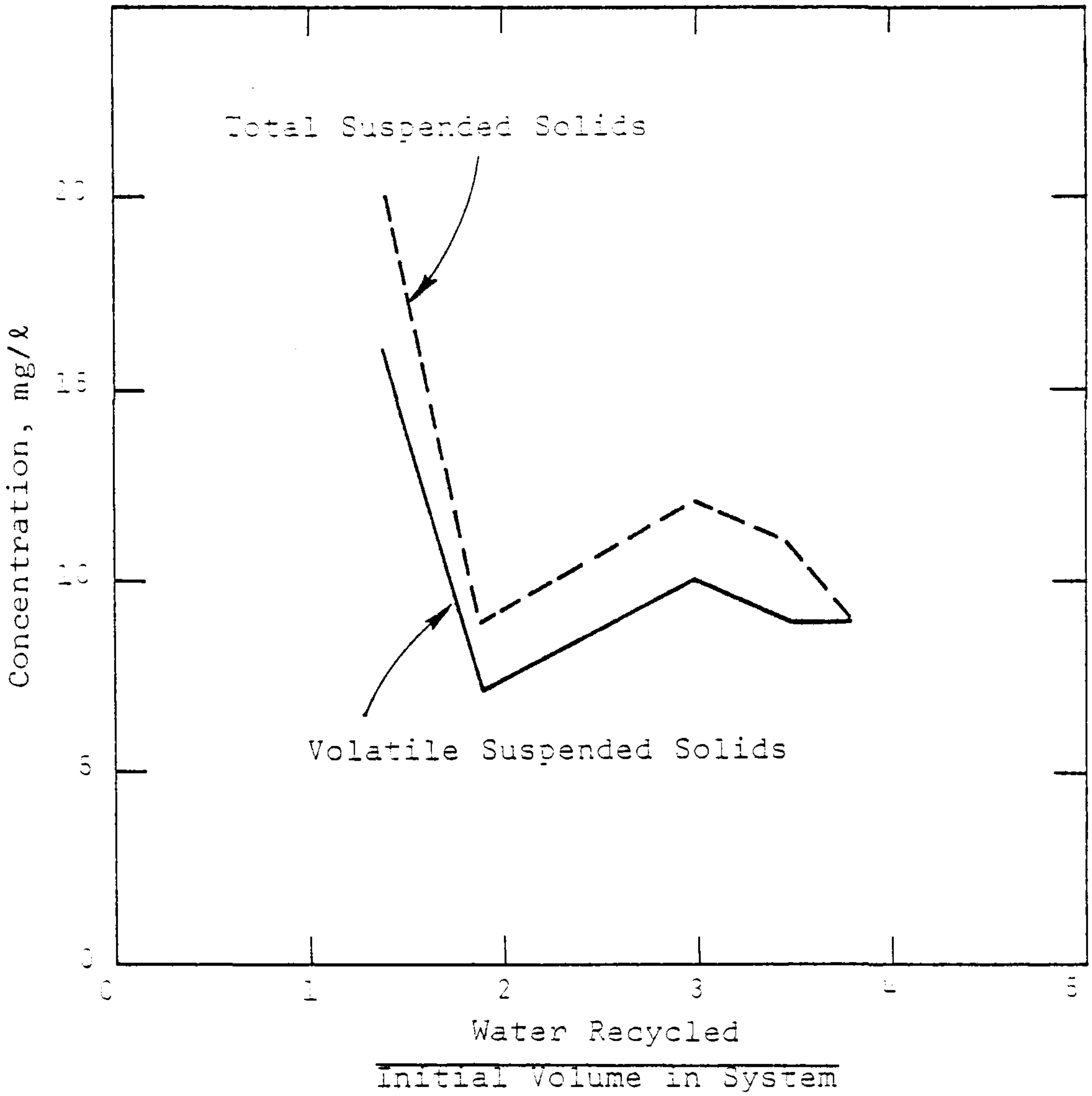

Figure 13. Winter operation: flush water suspended solids.

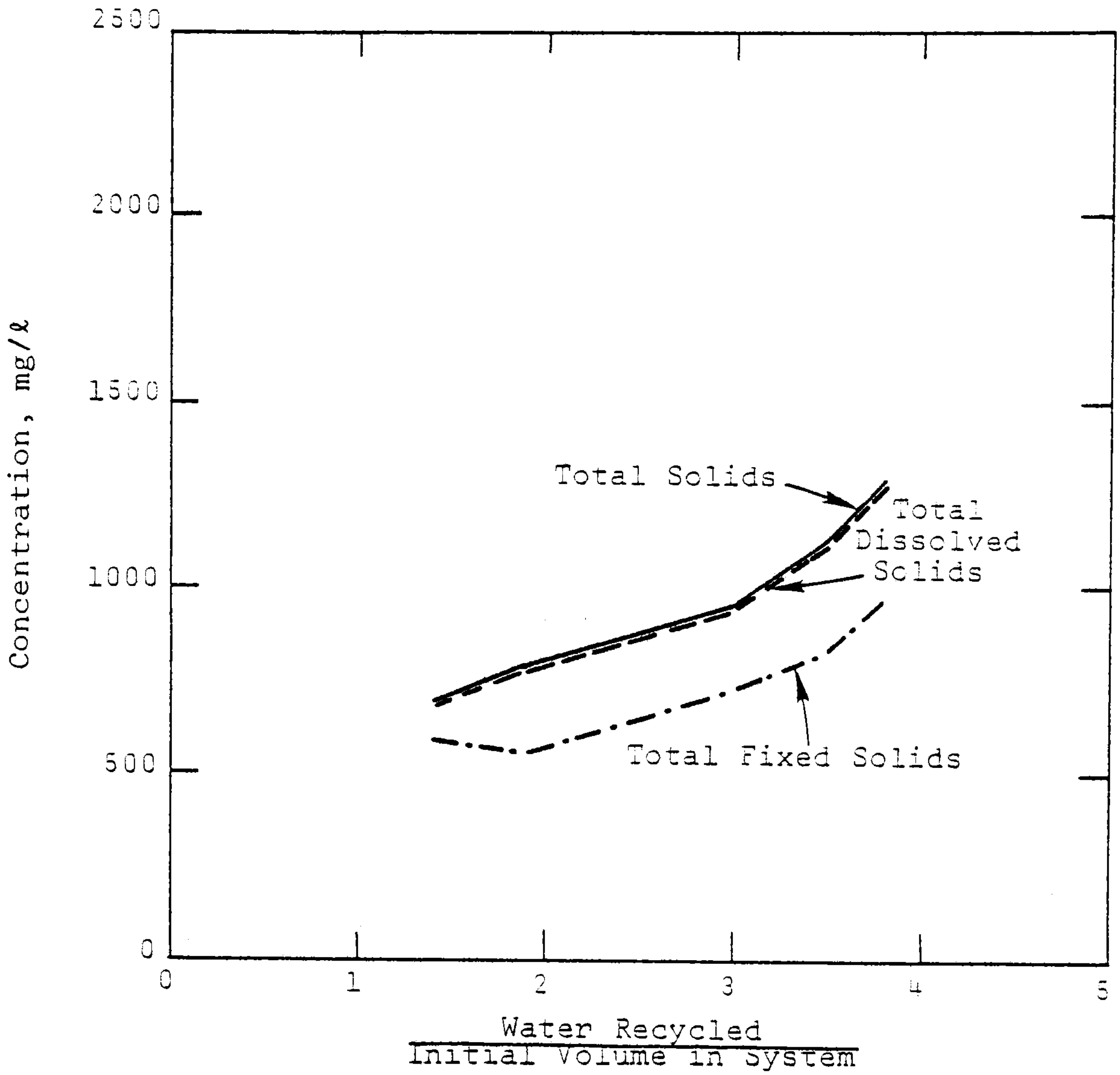

Figure 14. Winter operation: flush water total solids.

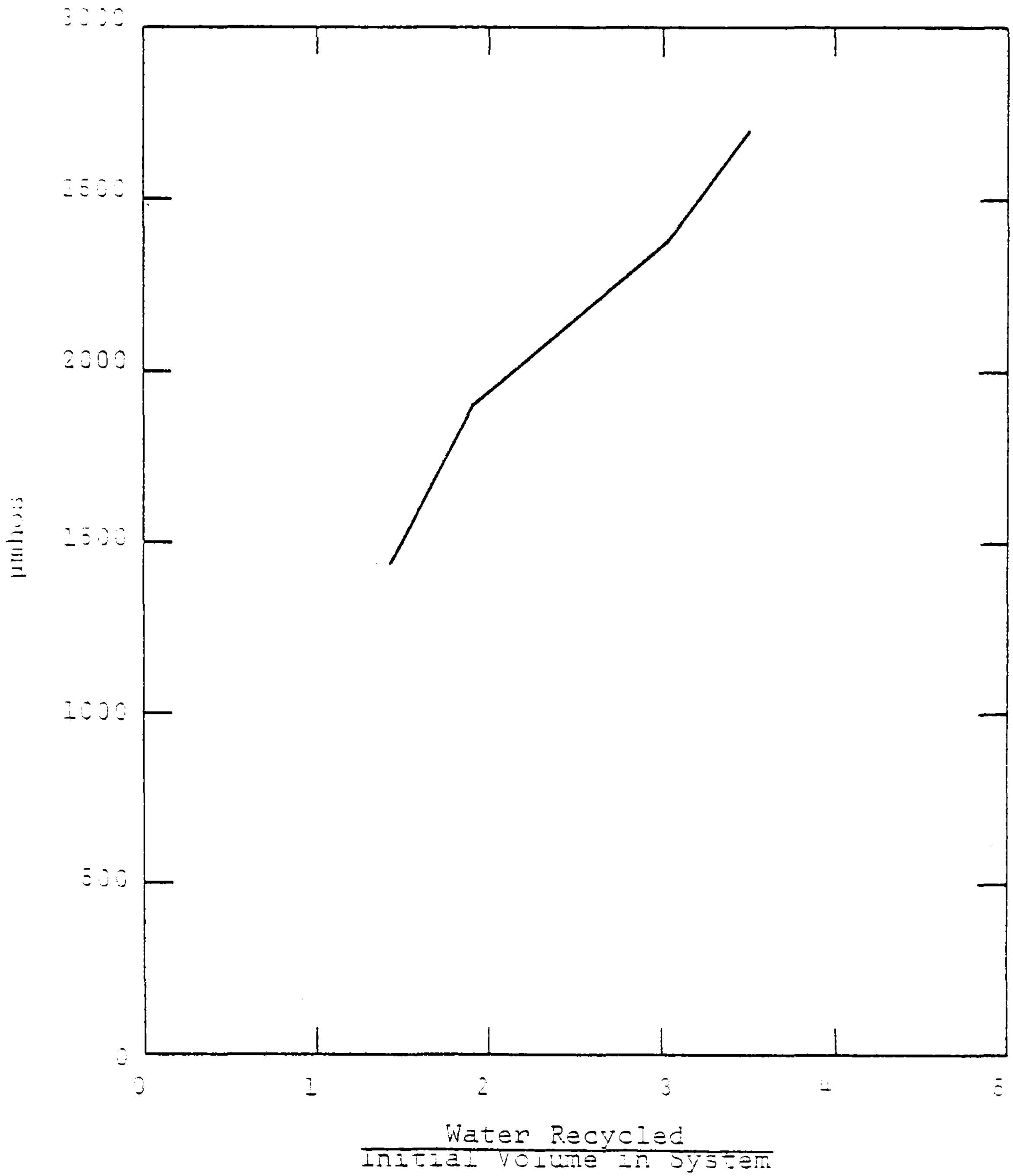

Figure 15. Winter operation: flush water conductivity.

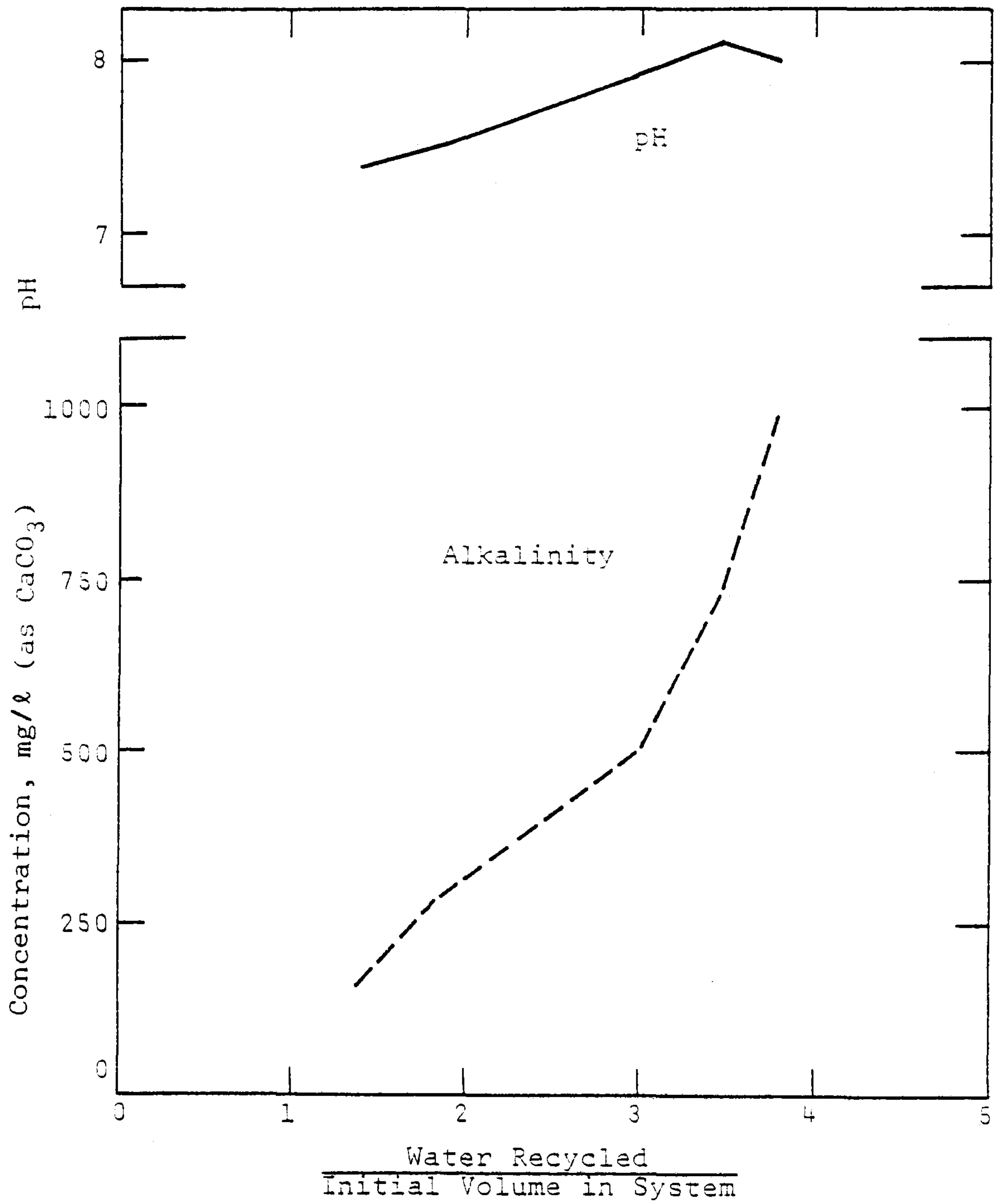

Figure 16. Winter operation: flush water pH and alkalinity.

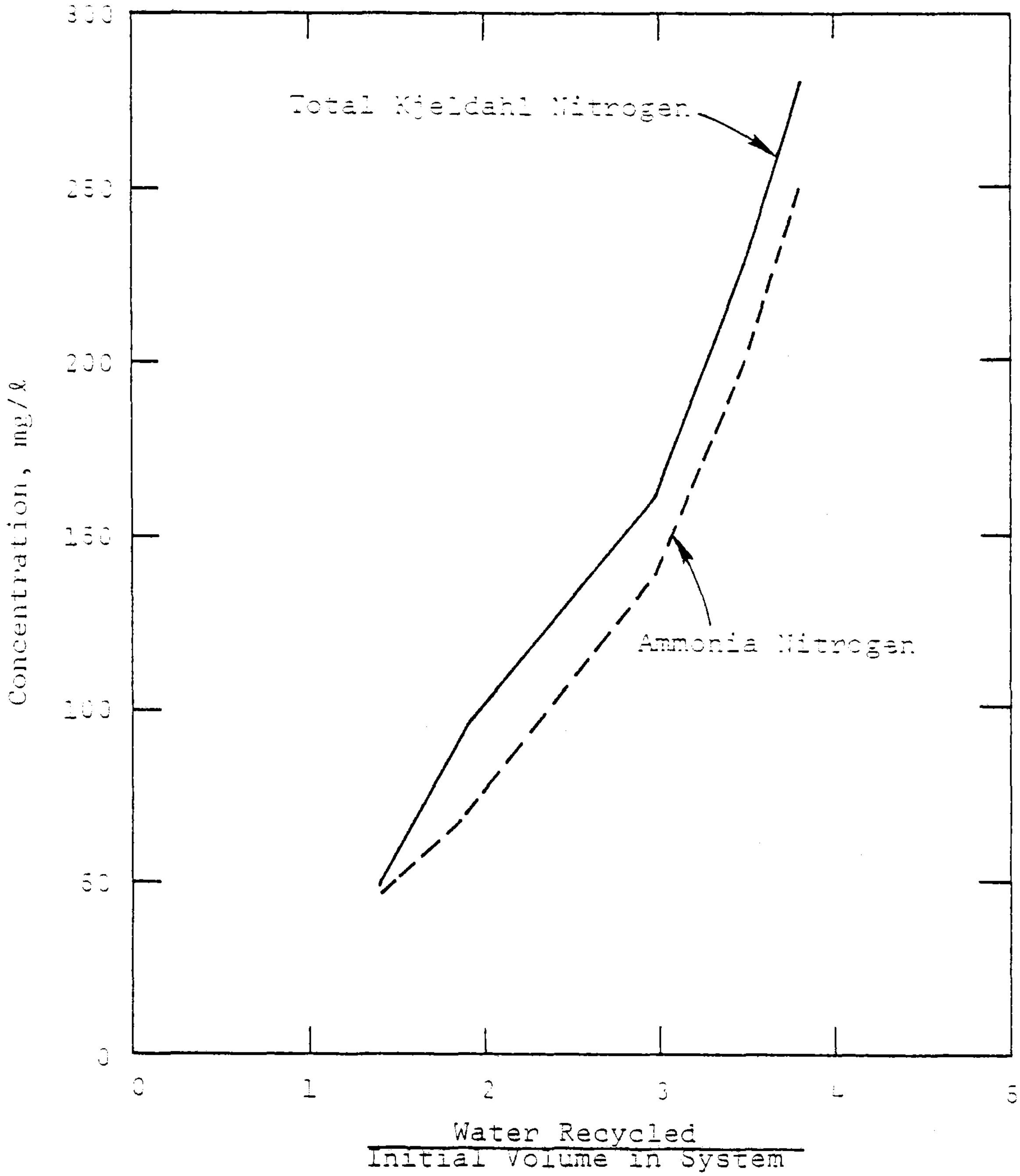

Figure 17. Winter operation: flush water nitrogen.

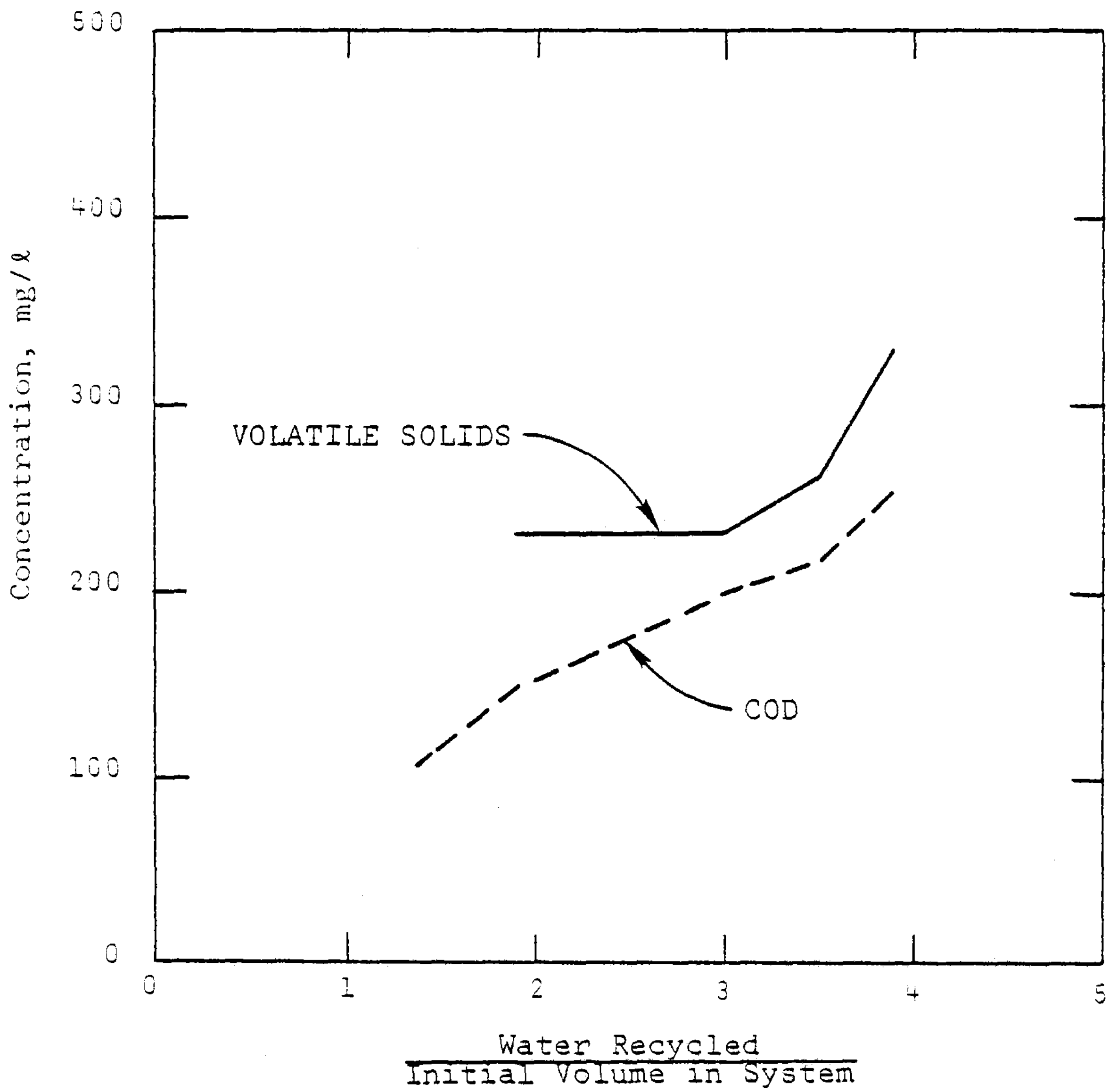

Figure 18. Winter operation: flush water COD and volatile solids.

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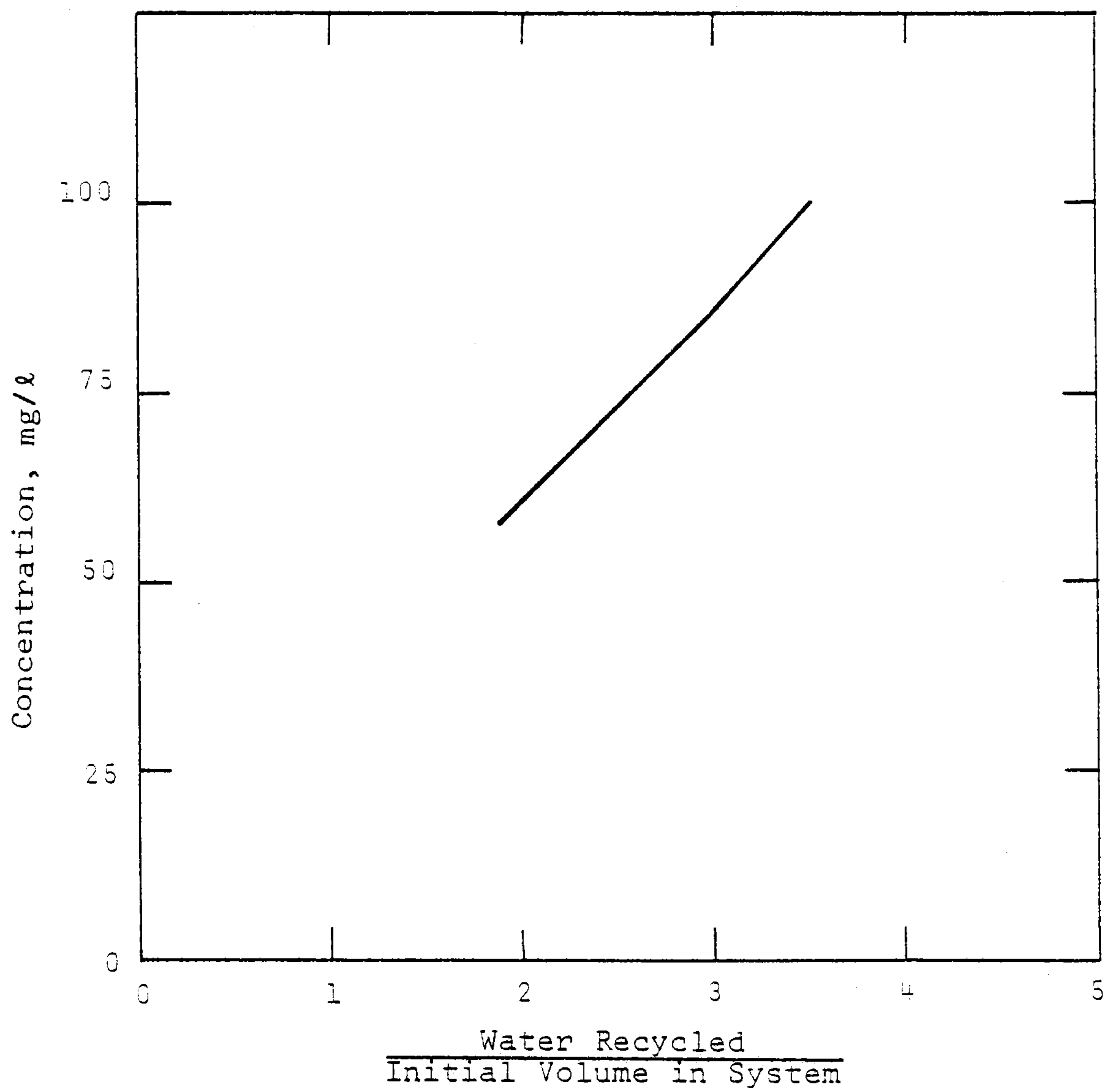

Figure 19. Winter operation: flush water sulfates.

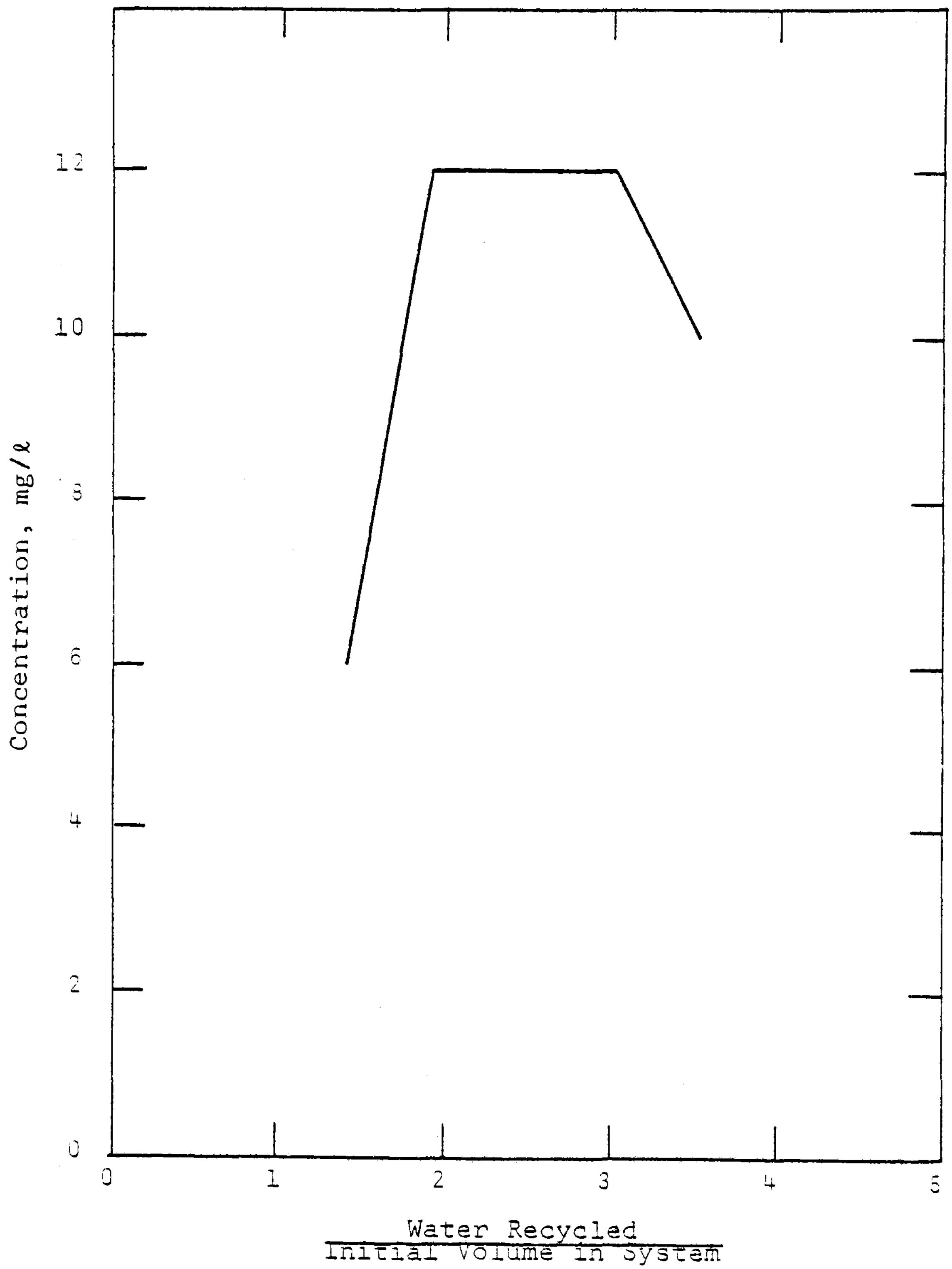

Figure 20. Winter operation: flush water phosphorus.

Table 5

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
3/17	- -	2300	1860	125	54	10	8.0	---
3/23	9.0	2900	2350	160	55	7	---	6.5
3/30	4.8	2650	2260	160	60	13	10.0	5.9
4/ 4	7.2	3040	2600	200	66	12	---	5.6
4/11	7.8	2630	2270	220	84	15	7.4	5.9
4/20	8.4	3310	2960	270	82	17	---	5.9
4/27	3.0	3040	2680	470	155	13	9.4	5.8
5/ 4	6.0	3480	3176	460	132	17	---	5.8
5/11	4.2	3720	3280	650	174	14	---	5.7
5/19	7.8	3990	3650	580	145	19	6.0	5.9
5/25	- -	5150	4760	680	132	19	6.0	6.1
6/ 1	10.8	4750	4380	650	136	21	8.3	6.3
6/ 8	5.7	5540	5090	850	153	16	8.6	5.5
6/15	10.7	5130	4800	720	140	--	---	5.9
6/21	10.8	4100	3720	500	122	21	---	6.5
6/28	11.4	4780	4460	600	126	22	---	6.0
7/ 6	17.0	3720	3420	600	221	25	3.4	6.0
7/13	16.1	5540	5200	740	134	25	4.0	5.9
7/20	14.7	5590	5160	760	136	26	---	6.0
7/27	10.2	5440	5080	820	151	22	---	5.9
8/ 3	14.2	5650	5260	800	142	24	---	5.9
8/10	15.0	7040	6570	920	131	26	---	5.9
8/17	8.1	3990	3710	500	125	24	---	6.3
8/24	10.5	6457	6038	790	122	23	---	6.1
8/31	12.0	4372	4100	800	183	25	---	---

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

(b) Sludge Volume Index.

Sludge wastage during the period March 15, 1977, to August 31, 1977, was consistent with wastage that can be expected from an extended aeration unit without recycle. Although wastage was slightly more frequent than in previous years of operation without recycle, the volume of wastage — 6,000 gallons (23,000 litres) — was estimated to be comparable to that of previous years.

DISCUSSION OF RESULTS

Biological Treatment Performance

The biological treatment system operated at a treatment level comparable to that of a system not providing for recycling. Recycling and reusing flush water did not impair the ability of the system to remove biodegradable organics. Changes in the chemical and physical characteristics were not as great as predicted by the bench-scale laboratory model used to evaluate the recycle-reuse concept.[2] The input of the nitrogen and phosphorus nutrients to the flushed waste was sufficiently adequate for biological growth.

Bench-scale studies had indicated that the most likely cause of failure of the biological system would involve changes in nitrogen, pH, and alkalinity. Figure 9 shows that nitrogen buildup occurred and then essentially leveled off and that complete conversion to nitrate was blocked. There is evidence in the literature to support the incomplete nitrification observed with this system. The blockage of nitrification has been attributed to low pH, low alkalinity, ammonia, nitrite, and nitrous oxide.[6,7] Alkalinity is a biochemical requirement and pH is an environmental requirement for optimal growth of nitrifiers; and ammonia, nitrite and nitrous oxide have been reported to have had inhibitory effects. It has also been reported in the literature that nitrifying organisms can become acclimated to these inhibitory effects and provide nitrification. It was not the intent of this work to explore inhibitory effects, but rather to provide evidence that a biological population capable of stabilizing the organics in the waste conveyed by recycled and reused water could be sustained. The results presented here demonstrate that the biological population adjusted to the characteristics brought about by the recycle and reuse of water, and that biodegradable organics were removed and no continuous buildup of these organics occurred.

Since complete nitrification was blocked, the oxygen requirements of the biomass under aeration decreased. The results presented here show that the oxygen concentration in the aeration basin was higher for the recycle-reuse system than those that had been previously determined for the system prior to recycle. This finding reflects the oxygen requirements for nitrification.

The low pH and alkalinity in the aeration basin can be attributed to nitrification reactions, since bicarbonate alkalinity is used and hydrogen ions are released. Ammonia in the water immediately after it has been flushed accounts for the high pH of the raw wastewater. This high pH is not sustained in the aeration basin; since the wastes are completely mixed in the basin, this characteristic of the incoming waste is diluted with the contents of the aeration basin and additional nitrification results in a lowering of the pH. (Only low nitrification rates have been reported for systems with pH values less than 7.0.)

Based on nitrogen inputs by the users, a high nitrogen buildup in some form was expected. However, as is evidenced by Figure 9, there was essentially a leveling off of all forms of nitrogen prior to the system's reaching equilibrium. Obviously, a nitrogen loss occurred. Two conditions were surmised to account for the loss: (1) loss of ammonia to the atmosphere and (2) denitrification. Equilibrium of ammonia between ionized and unionized ammonia is pH dependent. Free ammonia becomes favored as the pH rises above 7 and can be effectively stripped out of the water by agitation at summertime temperatures. Hence, ammonia could be lost from water as it passes through the treatment units. A check of the sewer line that conveyed the raw wastewater to the aeration unit revealed that ammonia was being released into the pipe. This, of course, was the most likely place for substantial ammonia stripping since the pH was higher here than anywhere else in the system, approximately 8.3. Ammonia released into the sewer was readily dissipated and no odors were detected. The other source of nitrogen loss was denitrification. Although some denitrification was evident across the filter, substantial denitrification was not thought to have occurred.

Low temperatures also affect nitrification; therefore, during winter operations less nitrification than experienced during the summer should be expected. As a result of less nitrification, an increase in pH and alkalinity should be experienced. These changes, however, are modified to some degree by the fact that during winter the rest area use is less and the detention time in the aeration basin is much greater.

The initial start-up during the winter resulted in an increase in pH to about 8.3 throughout the system. At present the wintertime pH cannot be predicted; however, it will probably be greater than that experienced during the summer. These conditions should lead to a shift in the ammonia equilibrium and in nitrates and nitrites. In addition, a shift in the biological population can be expected. Although certain winter and summer characteristics will differ it is expected that an acceptable water for flushing toilets will still be produced.

Biological treatment systems have been judged on their ability to remove BOD_5, which is considered representative of biodegradable organics. It should be recognized, however, that the BOD_5 test is not specific for organics. When autotrophic organisms that oxidize inorganic compounds are present and the environmental conditions are adequate for these organisms to function, a substantial amount of the oxygen in the BOD test is used to satisfy their oxygen needs. This is the case for the recycled and reused water produced in this study. The BOD test provides a buffered condition for the wastewater, which is high in ammonia nitrogen, and, of course, nitrifiers are present. The high use of oxygen by the nitrifiers is exemplified by the extremely high BOD_5 of the raw waste conveyed by the reused water as compared to that in rest areas without a reuse system. The results of this work show a net increase of BOD_5 for the flushed recycled water of 160 to 535 mg/l. Typical values for raw waste where potable water is used to flush toilets is 150 to 200 mg/l. Prior to water reuse the Fairfield rest area raw waste BOD_5 was within this range. Another factor supporting the influence of nitrogen on the BOD_5 test is the result of the ultimate BOD analysis. The primary oxygen use is accountable by oxidation of the total Kjeldahl nitrogen. The fact that the BOD_5 was drastically influenced by the ammonia nitrogen in the system was further supported by the erratic results obtained for samples collected on the completely treated water just before its reuse, and also by the fact that holding samples in containers at 25°C for as long as three weeks did not result in putrid odors or a malodorous condition. Results from the analyses of COD and total dissolved volatile solids also support a conclusion that the BOD_5 results were significantly affected by ammonia nitrogen. Hence, it is important to recognize that BOD_5 alone is not an adequate criterion upon which to judge the acceptability of recycled water. The BOD_5 results from a recycle system must be interpreted by individuals who have a good fundamental understanding of the nature of the process and characteristics of the recycled water. The possible reactions in the system and the relationship of BOD_5 to other parameters should be fully understood. The BOD_5 result in water reuse should be used only as another piece of data for interpreting all results. It does not represent biodegradable organics in the system and, therefore, cannot be used to evaluate the acceptability of the water with regard to this parameter.

The basis for evaluating the routine operations of an extended aeration biological system treating recycled-reused water does not differ to any large degree from that for the operation of the same system treating wastewater that is not recycled. Settleable solids, MLSS, pH, alkalinity, and temperature are the most useful parameters. It can be expected that the biochemical system will produce an effluent adequate for filtration and subsequent recycle and reuse if the range of values in Table 6 are maintained.

Table 6

Desired Treatment Characteristics

Parameter	Concentration Range
pH	5.5 to 8.3
Alkalinity	50 to 500 mg/l
MLSS	3000 to 5000 mg/l
Settleability (MLSS volume in litre graduated cylinder after 30 minutes' settling)	200 to 850 ml

The most desirable range for the MLSS will probably be 3,500 to 4,500 mg/l with a settleability of 400 to 600 ml.

Operation of a biological treatment system at low pH values will result in a significant growth of fungi. Since fungi result in a stringy biomass it has been generally considered undesirable to operate at low pH values due to the settling characteristics associated with this type of biomass. The operation of the extended aeration system to treat recycled water indicates that the biomass can be adequately separated from the water by gravity settling. The experience with this system was that at the high MLSS operating level used the biomass settled without difficulty. The resulting supernatant was clear and contained no more suspended solids than would be expected from operation without recycle and reuse. The biomass appeared to have a filtering effect as it settled and the water rose through the MLSS.

Foaming in the aeration basin was experienced; however, the degree of foaming was similar to that experienced with treatment of wastewater without recycle. From time to time there was some fluctuation in the amount of foam. It was not evident what caused the foam or why fluctuations occurred. A defoaming agent was added to the aeration unit on an unscheduled basis and it was effective in controlling the foam. The agent was not detrimental to the biological system and did not materially affect any of the parameters measured. Less than 50 gallons (200 litres) of defoaming agent per year would be required for the control of the foam. (Of course, the concentration of the agent will have a bearing on the use rate.)

Dye, FD & CBlue No. 1, used to color the water was not removed by the biological or filtration system. Therefore, the chemical feeder for the introduction of dye into the system was not used. Over an extended period of time the intensity of the dye changes due to the small percentage of sewered potable water entering the system. The periodic addition of dye into the aeration basin, prefiltration tank, or postfiltration tank by hand was necessary because of the very small dosages needed. This method of adding dye was entirely satisfactory. (An overdose of dye has to be guarded against to prevent the color intensity from being too dark.) As the recycles increased the water color changed from a blue to a turquoise and remained that color throughout the study. This color change was expected since the bench-scale studies indicated that recycled water followed only by sand filtration would take on a yellowish tint. The turquoise appearance was not objectionable since it was very much like the color produced from commercial agents sold for toilet use in the home.

Filter Performance

The filter material used in the bench-scale studies was different, both in composition and size, from that used at the rest areas. The bench-scale studies used sand with an effective size of 0.29 mm and a coefficient of nonuniformity of 2.22. The filter material in the field facility was granular, nonhydrous aluminum silicate having an effective size of 0.57 mm and a coefficient of nonuniformity of 1.66. This size difference may account for the finding of higher suspended solids in the field operation than in the bench-scale system. Another contributing factor was probably the fact that the filter used in the study was overdesigned. A properly designed filter will accumulate deposits that will assist in the removal of suspended solids as the filtration cycle continues. A filter that is properly sized for the conditions under which it operates will require backwashing every 2 to 7 days. (If backwash conditions are not met after 7 days, the filter should be backwashed to minimize bed cracking and prevent short circuiting through the filter.) The degree of overdesign is appropriately demonstrated by the frequency of backwash. In order to evaluate the filter operation, the filter was set to backwash at a 6 psig (41 KPa gauge) differential between the top and bottom of the bed. During this study period 880,000 gallons (3.3×10^6 litres) of water were treated and the filter backwashed only three times. The time intervals between backwashes were 28 days, 90 days, and 40 days.

Although the suspended solids passing through the filter were measured to be 10 to 15 mg/l, there was no evidence of settling of any solids in the postfiltration tank or the hydropneumatic tank. In addition, this level of solids was not visible when scrutinized in a glass container or in the water closet bowls. Based on the results found here, water with suspended solids of 15 mg/l or less is acceptable for flushing toilets.

Quality of Recycled Water

The chemical parameters determined indicate that the water recycled and reused at the rest area was chemically stable. There was no indication in the aeration basin or any other location in the system that precipitation was occurring. The relationship between total suspended solids and total volatile suspended solids throughout the system remained relatively constant, which indicated chemical stability.

The physical appearance of the recycled water with the dye was not objectionable. It was very similar in appearance to that found in toilet bowls where a commercial agent is placed in the flush water hold tank. No odor was detected in the rest area that could be attributed to the recycled water, and no odor was detected around the filter or any of the flush water storage tanks. At the biological treatment plant relatively little odor was detected, and when odors were detected they were typical of that found around any domestic wastewater extended aeration system.

Recycle and Reuse Concept

The recycle and reuse system evaluated will require very little modification for implementation. The flow scheme would be improved by modifying it to conform with that shown in Figure 21. This scheme contains only a slight modification to that used in this work. Unit sizes and specific arrangement of the units will have to be designed to meet the physical conditions at the site and the flow generated at the rest area. For all cases where water recycle is considered, particular attention should be given to flow requirements if the most economical solution is to be obtained. The system used in this work was oversized. The pumps, tank, and the filter added to provide water recycle were oversized by a factor of two. Oversizing of the system was not an oversight but was rather an attempt to provide some protection against unknowns that might develop during the evaluation of the reuse concept. The use of the oversized system had no real bearing on the operational results and acceptability of the water for flushing toilets.

The details of an economic comparison between water recycle-reuse and a mineral oil system are in Appendix D. This analysis indicates that the water recycle-reuse system is significantly more economical than a comparable mineral oil system. The decision, however, as to the system most suitable environmentally and economically must be made on a site-specific basis.

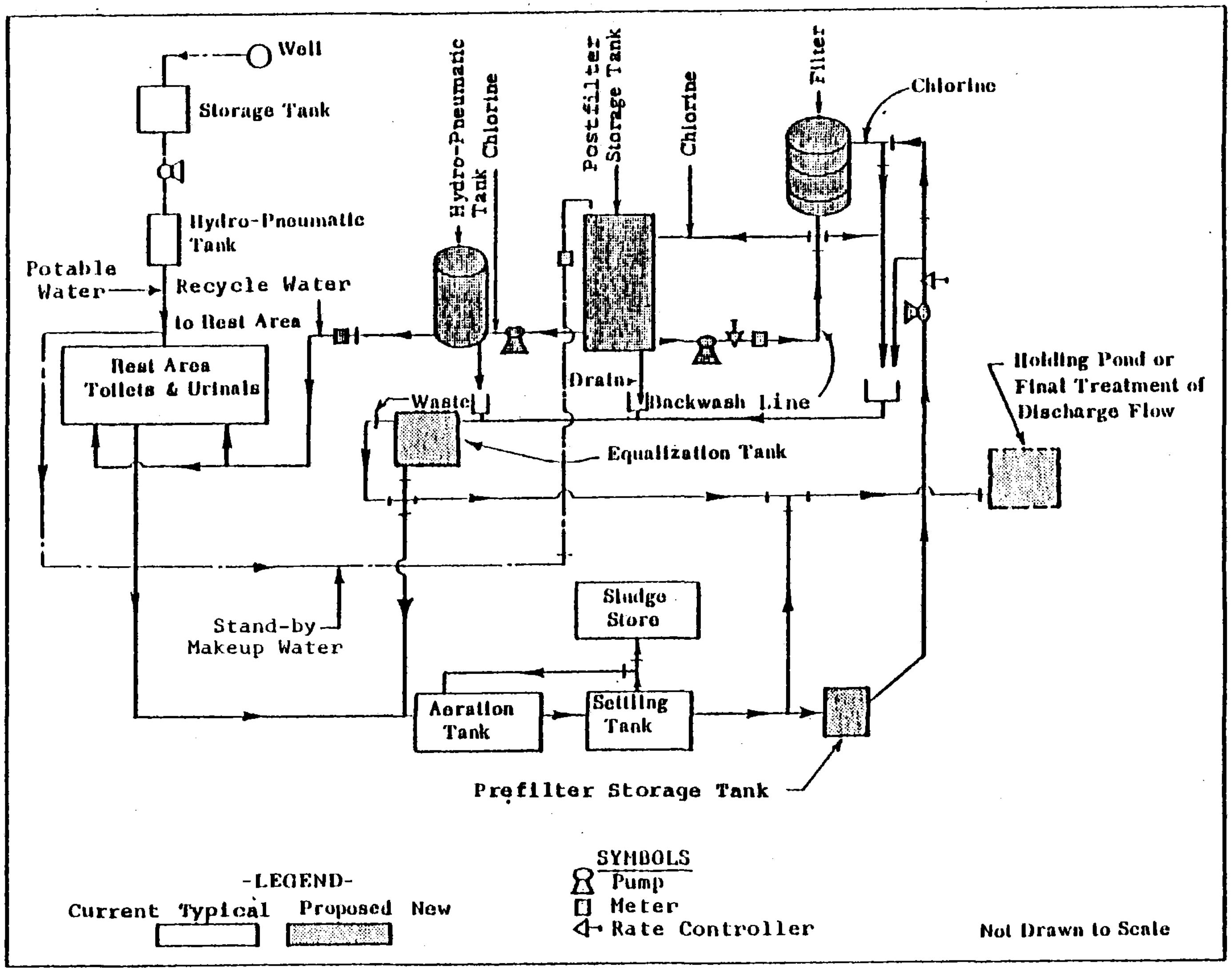

Figure 21. Schematic flow diagram for recycle and reuse of water to flush toilets at rest areas.

SUMMARY

Due to the scarcity of water available to rest areas and the wastewater treatment requirements to meet effluent quality criteria, the Virginia Department of Highways and Transportation embarked upon a program to identify water needs at rest areas and to explore the technology available for the reuse of water to flush water closets. The Virginia Highway and Transportation 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 model were used to design and construct a full-scale field recycle and reuse demonstration facility at an operating rest area.

The plumbing at an existing rest area using an extended aeration wastewater treatment system designed to treat 10,000 gpd (38,000 lpd) was modified to separate potable water use from water closet flush water use. A granular pressure filter with pre- and postfiltration storage tanks and a hydro-pneumatic tank were installed in a closed loop to filter effluent from the extended aeration unit and to return it to the water closets as a flush fluid. Filter backwash water was collected in a separate storage tank and returned to the influent of the extended aeration unit during off-peak use of the rest area. A blue food dye and a defoaming agent were added to the recycled water to assure public awareness and aesthetic conditions.

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.

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 dialy 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 of March 13, 1977, to August 31, 1977, 880,000 gallons (3.3×10^6 litres) 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 this research indicate water reuse at rest areas is more economical than a mineral oil system and can be considered as a viable alternative for solving water and wastewater problems at highway rest areas. The results provide 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.

CONCLUSIONS

The conclusions from this research are as follows:

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 imparted a turquoise color to the water that was not objectionable in appearance. No special cleaning of toilet bowls was required as a result of water recycle and reuse, and the recycled water met 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. The potable water input amounted to 5.8% of the total water used at the rest area and resulted in a water balance of 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 a 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 hetertrophic organisms that can satisfactorily 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 employs 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 hydro-pneumatic 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.

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APPENDIX A

COMBINATION BIOLOGICAL AND PHYSICAL SYSTEM USED TO TREAT WATER FOR RECYCLE AND REUSE AT THE FAIRFIELD REST AREA

System Design and Components

Wastewater from the rest area flows by gravity to a small extended aeration biological treatment plant approximately 400 yards (366 metres) to the north of the toilet facilities. This facility was designed to treat 10,000 gpd (38,000 lpd) and had been in use several years prior to the addition of the filtration system for water reuse. The wastewater treatment facilities are enclosed within a half-acre (.2 ha) cyclone fenced area. The treatment units include a comminutor, aeration basin, settling basin, sludge holding tank, lagoon, chlorine contact chamber, and a small brick structure used to house tools, equipment, and chlorine gas cylinders. The pumping within the entire aeration-settling basin system is provided by penumatic pumps operated by air blowers.

Raw wastewater flows by gravity to the treatment plant's comminutor, which shreds any solids in the waste stream to 1/4-inch (6 mm) sizes. The comminutor is capable of processing a flow of 140 gpm (530 lpm). An overflow bypass channel with a hand-cleaned medium bar screen is also provided. The flow then passes into a 10,000-gallon (38,000 litre) aeration basin. In the aeration basin the organics are brought in contact with bacteriological cells and oxygen in a water media. In order for this to be accomplished, the aeration basin is supplied oxygen by a pneumatic pump that forces the water against the conical deflector, thus mixing and aerating the mixed liquor. The oxygen transfer generated by this mixing action has a manufacturer's rating of 1.67 lb. 0.2 hr. (756 gm/hr). The pneumatic pump may be operated on either a manual or automatically timed sequence. Should a pressure loss develop, and to prevent a pump from burning out, a second pneumatic pump is available as a backup. The design detention time for the aeration basin is 24 hours, thus, the basin has a capacity equal to the average daily flow from the rest area. The aeration basin is a form of a completely mixed system, since theoretically any incoming volume of flow is instantaneously mixed throughout the basin. The wastewater flow into the settling basin is from the aeration basin. The settling basin provides a detention time of four hours at the design flow of 10,000 gpd (38,000 lpd). It is equipped with a skimming funnel which returns the scum and floating matter back to the aeration basin. To maintain a viable aerobic bacteriological cell mass, solids that settle out into the settling basin are returned. These returned solids are regulated and may be returned at a rate up to 28 gpm (110 lpm). The biological solids return from the settling basin is delivered by the pneumatic pump, which is coordinated with the same timed off-on cycle as the aeration system. A 4,000 gallon (15,000 litre) sludge holding tank is used to receive biological solids when they reach undesirably high levels in the aeration basin. Wasted biological solids are pumped from the settling basin into the holding tank when it is necessary to lower the biological solids under aeration, usually when they are greater than 5,500 mg/l. A tank truck is necessary to pump out and carry away sludge from the sludge holding tank.

The additions to the biological system for recycle-reuse of water include a mixed-media pressure filter, prefiltered storage tank, postfiltered storage tank, hydro-pneumatic tank, and equalization tank. Supplemental to these units are two chemical feed tanks, chlorine addition, control and safety systems, the necessary pumps, meters, and air compressor, and a temperature control system for the building housing the units, which is a constructed of prefabricated steel and has a concrete floor.

After biological treatment the effluent from the settling basin flows by gravity to a 20,000-gallon (76,000 litre) prefiltered storage tank. Here the water is held until it is manually or automatically called for and pumped up to a 6-foot (1.82 metre) diameter mixed media pressure filter. Some settling may occur in this tank, but by and large it is not a treatment unit. Water is pumped to the filter automatically when the water level in a 20,000-gallon (76,000 litre) postfiltered storage tank drops below a preset minimum control level. The water is pumped through the filter until shut off by a second probe set in the postfiltered storage tank at a maximum control level. The control probes are set so that the operating volume between the on-off sequence of filtration is 10,000 gallons (38,000 litres). In addition, as an emergency measure, the water level controls are set so that a continuous drop of water level in the postfiltration tank occurring past a certain reserve volume (water level) causes potable water to be automatically added to the tank and be available for flushing toilets. This level is set slightly above the outlet pipe to assure the use of recycled water except in emergency situations. The filtration rate is controlled by a butterfly valve in the filter building and is normally set at 65 gpm (245 lpm).

Since the prefiltered and postfiltered tanks have capacities of 20,000 gallons (78,000 litres), the postfiltered tank will contain no more than 10,000 gallons (39,000 litres) when the prefiltered tank contains 20,000 gallons (78,000 litres). Both tanks are equipped with overflows; the prefiltered tank has overflow drains to an evaporation pond and the postfilter tank has an overflow to the equalization basin.

The filter media consist of granular nonhydrous aluminum silicate supported by sand and stratified into layers in the bottom half of the filter. As the water passes through the filter, from the top to the bottom, any solid particles are strained, trapped, and adsorbed onto the filter bed at various depths depending upon the sizes of the particles and the physical attractive forces. In graunlar filters the upper portion of the filter traps a higher concentration of the solid particles than the lower depth to provide temporary increased efficiency of the filter. Eventually, the pressure of the water passing through the upper and lower portions of the filter media will be such that the filter's efficiency will be reduced and a cleaning of the filter becomes necessary. First, surface cleaning of the filter is initiated at a rate of 30 gpm (110 lpm) for 5 to 10 minutes. Then the filter bed is backwashed for 5 to 10 minutes at a rate of 240 gpm (910 lpm). The water for these washes is drawn from the postfiltered tank. Backwash water is discharged from the filter into a grate-covered drain which directs the backwash by gravity to a 5,000-gallon (19,000 litre) equalization basin. (Backwash of the filter expands the media bed and hydraulically removes the suspended solids with the flow. When the backwash is complete the bed settles back into stratified zones.) The equalization tank receives the backwash flow from the filter and regulates its discharge back into the head of the biological treatment plant. Pumping is controlled by a float switch activated through a timer. The timer provides for the selection of the times during the day that backwash water can enter the biological treatment unit. Flow from the equalization basin to the head of the treatment plant would normally be metered out during the night hours when low flows are expected. Backwash is initiated by any one of three modes: manually, time clock, or pressure differential. A properly sized filter should be backwashed 1 to 7 times a week.

Water is drawn from the postfiltered tank to the hydropneumatic tank when demand has dropped the water level and pressure in the hydro-pneumatic tank to a preselected value. The hydro-pneumatic tank maintains a water level within a foot of the center of its horizontal axis. The hydro-pneumatic tank's operating pressure is set between 40 to 60 psig (275 to 413 K Pa gauge). A float valve governs its water level and an air pressure switch is used to maintain tank pressure at the

60 psig (413 K Pa gauge) level. Another air pressure switch is used at the low pressure level to cut on the water pump that delivers water from the postfilter tank to the hydro-pneumatic tank. An air compressor serves both as the pressure source for maintaining the high air pressure in the hydro-pneumatic tank and the air pressure to operate solenoid valves on the filter. In summary, when water is needed at the rest area, it is delivered from the hydro-pneumatic tank within a preselected operating pressure range, normally 40 to 60 psig (275 to 413 K Pa gauge). When the water level drops in the pneumatic tank and the minimum pressure (40 psig — 275 K Pa gauge) is reached, a pump delivers postfiltered water to the pneumatic tank until it is cut off by the water level sensitive switch. Then, if the maximum operating pressure is not reached, a solenoid to the air compressor opens and brings the pressure in the pneumatic tank up to its maximum operating pressure.

Two 55 gallon (210 litre) drum chemical addition tanks are provided in the system. Each is equipped to automatically inject a liquid into the flow at a rate of 0 to 5 gph (0 to 19 l/hr). (These two chemical addition tanks were to be used as a filter-aid addition and a dye dosage addition, but were not needed.) One tank can inject into the flow prior to filtering and the other can inject into the flow as it leaves the hydro-pneumatic tank. Both manual and automatic modes are provided for operating these tanks.

In addition to the recycle treatment units, tanks, compressor, valves, pumps, and pipes, there is a warning system that lights a panel on its control box, and activates a warning horn. The warning system warns of (1) a low water level in the postfiltered tank, (2) low building heat, (3) insufficient pressure in the hydro-pneumatic tank, and (4) a prolonged backwash cycle.

Operational Modes

The biological treatment system and the recycle-reuse system could operate independently, except for the fact that they are hydraulically connected and changes in flow conditions and water quality through one influences the operation of the other. To provide a clear understanding of the operational features of the integrated system, the operational modes are separately described as (1) biological treatment, (2) filtration in progress, (3) filter surface wash and backwash cycle, (4) pneumatic tank, (5) recycle to toilet, (6) equalization tank, (7) chlorination for recycle system, and (8) wastage of recycle water through meter M-3. Step by step descriptions of each operational mode with the operational characteristics are outlined in the following subsections. A description of the units added to the biological treatment system is presented in Table A-1 and drawings of the recycle-reuse modifications are shown in Figures A-1, A-2 and A-3. Figures A-2 and A-3 are enlargements taken from Figure A-1 and show the location of valves described under the operational modes.

Biological Treatment

1. Flush water enters biological treatment system through comminutor.

2. Comminutor shreds large solids in flushed water — i.e., wastewater.

3. Wastewater enters aeration basin.

4. Blowers on. Note: Blowers supply air to air lift pumps (pneumatic) that are used to:

    a. Pump aeration basin contents against a cone for mixing and aeration;

    b. return sludge to aeration basin from settling basin;

    c. to waste sludge; and

    d. to skim floating matter from settling basin.

5. Wastewater aerated in aeration basin in contact with biological solids, called mixed liquor suspended solids (MLSS).

6. Aerated wastewater with MLSS enters center of settling basin.

7. MLSS settle and are returned to aeration unit by air lift pump.

8. Clear water overflows weir to side chamber and into the effluent pipe.

9. Water flows in effluent pipe to T-1 to be returned for reuse. This becomes prefiltered water that is pumped to the filter by P-1 during filtration.

10. Bypass to lagoon from settling basin used only for emergency.

Filtration in Progress

1. P-1 on, provides water from T-1 to filter.
2. Water flow rate is controlled by butterfly valve BV-1.
3. Water is metered by M-1.
4. Pneumatic valves PN-1 and PN-2 are open.
5. Pneumatic valves PN-3, PN-4, PN-5, PN-6 and PN-7 are closed.
6. Water flows into top of T-2.
7. Water level in T-2 reaches high water level cut-off, T-2 full.
8. P-1 off, filtration stops.

Filter Surface Wash and Backwash Cycle

1. Filtration off, P-1 off.
2. Pneumatic valves PN-1 and PN-2 close.
3. P-3 on, provides flow from T-2 for surface wash.
4. Flow rate is controlled by control valve FV-1.
5. Pneumatic valves PN-3 and PN-4 open.
6. Surface wash begins.
7. Flow rate indicated by rotometer R-1.
8. Pneumatic valves PN-3 and PN-4 close.
9. P-3 off.
10. Surface wash complete.
11. P-2 on, provides flow from T-2 for backwash.
12. Flow rate is controlled by butterfly valve BV-2.
13. Pneumatic valves PN-5 and PN-6 open.

14. Backwash begins.

15. Backwash water metered by M-2.

16. Backwash wastewater enters sump and flows to T-7, where it will be returned to the beginning of the biological system under controlled flow conditions.

17. Pneumatic valves PN-5 and PN-6 close.

18. P-2 off.

19. Backwash complete.

20. Filter rinse begins.

21. P-1 on.

22. Pneumatic valves PN-1 and PN-7 open. (Note: PN-2 is closed.)

23. Filtration of water from T-1 begins and filtered water goes to drain sump.

24. Pneumatic valve PN-7 closes.

25. Filter rinse completed.

26. Pneumatic valve PN-2 opens.

27. Filtration in progress, water flows to T-2.

<u>Operational Mode Hydro-Pneumatic Tank</u>

1. Assume tank T-3 water at maximum level and maximum pressure. Toilet flushing lowers water level from maximum level and maximum pressure.

2. Water level cut-off switch for P-4 cuts on, but low pressure switch overrides to keep P-4 off.

3. Water use drops water pressure to minimum low pressure and low pressure switch cuts on, P-4 on. (Note: After initial water level drop from maximum water level, cut-off switch goes to on position and remains on until tank is refilled.

4. T-3 fills by P-4 from T-2.

5. Water reaches high water level and water level float switch cuts off P-4.

6. T-3 filled to maximum water level and maximum pressure.

Recycle to Toilet

1. Water leaves pneumatic tank T-3 on toilet demand.

2. Metered by M-4.

3. Recycle water used in chlorinator. Water take-off to chlorinator on discharge side of M-4, gate valve in wate-line to chlorinator at take-off.

4. Water use in commodes and urinals.

5. Flush water sewered to biological treatment unit.

Equalization Tank

1. Equalization tank, T-7, receives all drain water from filter building, including surface wash water, backwash water, and filter rinse water.

2. Water enters T-7, lifts float switch for pump P-7 to on position but timer switch overrides to keep P-7 off until a preselected discharge time occurs.

3. Preselected discharge time arrives, timer switch to P-7 on.

4. Float switch on to P-7 and timer switch on to P-7 pump cuts on.

5. P-7 on, pumps to sewer entering biological system.

6. Water level drops until float valve cuts off P-7 or until preselected time on timer switch expires. (Note: Float switch to P-7 off, pump remains off and system remains off until 2, 3, and 4 above occur.)

7. Water flow rate controlled by gate valve to prevent high flow rate from entering biological system.

Chlorination for Recycle System

General Description

Recycle water is used in chlorinator to chlorinate water in T-1 and T-2. The recycle water used by the chlorinator comes from a connection to the recycle line that conveys water to the toilets. The connection is at the discharge side of meter M-4 and has a gate valve in the line immediately after the connection. A single line runs water from this connection to the chlorinator in the chlorine building. One chlorinator supplies chlorine to chlorinate water in T-1, water entering T-2, and any discharge that may come from the lagoon.

Operational Mode

1. Recycle water feeds chlorinator where chlorine gas is introduced into the water stream.

2. Chlorine feed rate is adjusted by a needle valve at base of Cl_2 gas rotameter to desired application rate.

3. Water stream with chlorine (chlorine water) is split to T-1, T-2, and lagoon effluent structure. Each is adjustable by gate valve.

4. Chlorine water to T-1.

    a. Select desired application rate.

    b. Calculate amount of chlorine water needed at chlorinator gas feed rate to meet desired application rate.

    c. Adjust combinations of chlorine water flow and time of application to obtain desired application rate. Flow is adjusted by gate valve between chlorinator and T-1. Times of application for both days of week and time of day are set by timer.

    d. Timer rotates to desired application time, solenoid opens, chlorine water enters T-1.

    e. Timer rotates to time off, solenoid closes to shut off chlorine water to T-1.

5. Chlorine water to T-2.

    a. Select desired application rate.

    b. Calculate amount of chlorine water needed based on P-1 pump rate and the chlorinator gas feed rate.

    c. Adjust gate valve before chlorine water rotameter R-2 to set desired chlorine water flow rate. This rate is calculated from 5b. above.

    d. P-1 on, solenoid SN-1 in chlorine line connected to postfilter water line entering T-2 opens, and chlorination is in progress.

    e. P-1 off, solenoid SN-1 in chlorine line closes, and chlorination ceases.

6. Chlorine water to overflow from lagoon.

    a. Establish that an overflow occurs.

    b. See 4a above.

    c. See 4b above.

    d. Adjust gate valve in chlorine water line between the chlorinator and the chlorine contact chamber to obtain the desired flow of chlorine water to the chlorine contact chamber.

Wastage of Recycle Water Through Meter M-3

1. Establish that wastage should occur.

2. Manual wastage.

    a. Fill T-3 to high water level by manual operation of P-4.

    b. Read meter M-4.

    c. Close gate valve between P-4 and T-3.

    d. Open gate valves in wastage line.

    e. Push manual operation for P-4 to on.

f. Solenoids in wastage line SV-3, SV-4, open. (Note: Solenoids SV-3 and SV-4 always open when P-4 is on and always close when P-4 in off.)

g. Waste amount desired as measured by M-4.

h. Push manual operation for P-4 to off.

i. Close gate valves in wastage line.

j. Open gage valve between P-4 and T-3.

k. Push automatic operation for P-4.

3. Automatic wastage of percentage of flow going into T-3.

a. Establish percentage wastage desired.

b. Establish average flow rate of water pumped into T-3 by P-4 between low and high operating pressure of T-3. Pump rate is 45 gpm (170 Lpm) at operating range between 40 and 62 psig (275 to 410 KPa gauge).

c. Put T-3 in filling mode with P-4 on (filling from low level and pressure to high level and pressure).

d. Adjust gate valves in wastage line and record volume of water passing through M-4 against time.

e. Calculate wastage rate.

f. Repeat 3d. and 3e. until the desired percentage at P-4 pumping rate is attained.

g. Return P-4 to automatic.

Table A-1.

Description of Units Installed

Number	Name	Size	Material	Remarks
		Filters		
F-1	Pressure	65 gpm, 6'-0" Dia.	Steel-painted	2.3 gpm/sf 15 gpm Back-wash
F-2	Activated carbon	Small experimental	-	-
		Meters (Integrator and Rotameter)		
M-1	Prefilter water	65 gpm with integrator	Bronze	1-1/2" disc type with sweep dial & register
M-2	Backwash water	425 gpm with integrator	Bronze	4" turbine type with sweep dial 4" register
M-3	Water wasted from system	0-30 gpm with integrator	Bronze	1" x 1-1/4" disc type
M-4	Water to toilets	0-100 gpm with integrator	Bronze	1-1/2" disc type
M-5	Potable water	0-100 gpm with integrator	Bronze	1-1/2" disc type
R-1	Filter surface wash: Rotameter	0-60 gpm	Steel & glass	Size, 1-1/2"
R-2	Chlorine water: Rotameter	0-5 gpm	PVC & pyrex	Size, 1"
R-3	Carbon filter: Rotameter	0-5 gpm	PVC & pyrex	Size, 1"
		Pumps		
P-1	Filter feed	65 gpm @ 95' TDH- 5 HP @ 1750 rpm	Steel & bronze	Vertical type sump, 2" discharge
P-2	Filter backwash	425 gpm @ 45' TDH - 7-1/2 HP @ 1750 rpm	Steel & bronze	Horz. close couple, 1 stage, 5" suction, 4" discharge
P-3	Filter surface wash	30 gpm @ 140' TDH - 3 HP @ 3600 rpm	Steel & bronze	Horz. close couple, 1 stage, 1-1/2" suction, 1-1/4" discharge
P-4	Hydro-pneumatic pressurizing	65 gpm @ 140' TDH - 5 HP @ 3600 rpm	Steel & bronze	Horz. close couple, 1 stage, 1-1/2" suction, 1-1/4" discharge
P-5	Chemical injection	0-5 gph @ 150 psig 1/2 HP	Steel & bronze	Packaged with variable delivery
P-6	Chemical injection	0-5 gph @ 150 psig 1/2 HP	Steel & bronze	Packaged with variable delivery
P-7	Drain and backwash waste equalization	15 gpm @ 12' TDH 1/2 HP @ 1750 rpm	Steel & bronze	Vertical type sump, 1-1/2" discharge
		Tanks		
T-1	Prefilter water stage	22' ϕ x 8' high 20,000 gal.	Steel	Open top, exterior & interior coated with bituminous material
T-2	Postfilter water stage	12' ϕ x 24' high 20,000 gal.	Steel	Open top
T-3	Hydro-pneumatic	6'0 x 14' long 5,000 gal 100 psig design	Steel	Interior painted with bituminous coating operates 40-60 psig

'able A-1 (cont.)

Number	Name	Size	Material	Remarks
		Tanks (continued)		
T-4	Air receiver	16" ϕ x 38" long 30 gal. 150 psig design	Steel	Packaged unit with C-1
T-5	Chemical mix	55 gal. drum.	Steel, polyethylene lined	Packaged system with P-5 & A-Y
T-6	Chemical mix	55 gal. drum	Steel, polyethylene lined	Packaged system with P-6 & A-2
T-7	Equalization (Backwash and drains)	11'6" ϕ x 7' high 4500 gal.	Steel	Open top, exterior coated with bituminous material
		Agitators		
A-1	Chemical tank	1/2 HP	Steel	Package unit with T-5 & P-5
A-2	Chemical tank	1/2 HP	Steel	Package unit with T-6 & P-6
		Compressor		
C-1	Air	4.00 cfm @ 90 psig 1 HP	Steel	Packaged unit with compressor on receiver (Tank T-4)

NOTE: 1 gallon = 3.785 litres
1 foot = .3048 metres
1 inch = 2.540 centimetres
1 pound/square inch = 6.894 kilopascals

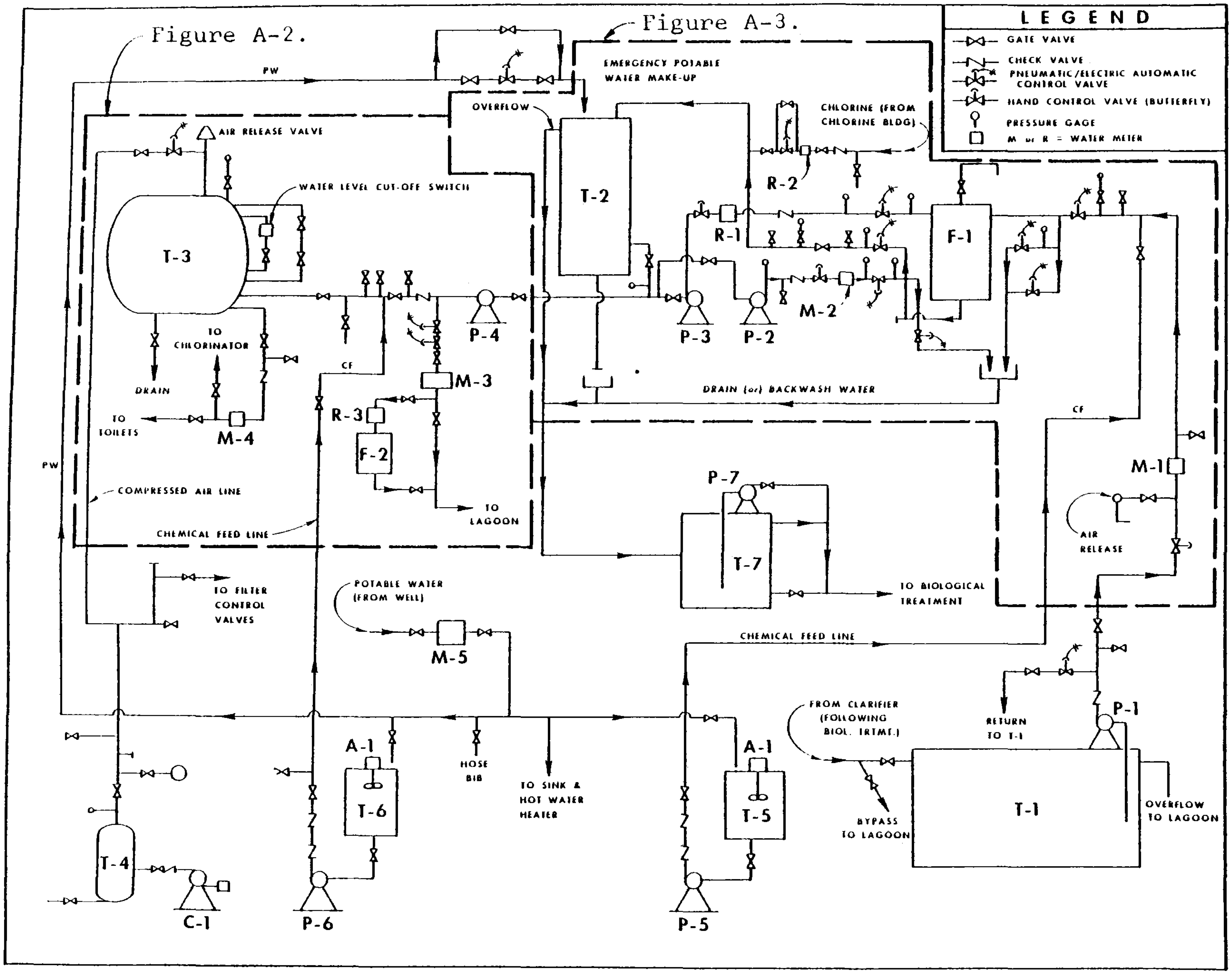

Figure A-1. Storage, filter and hydro-pneumatic piping arrangement.

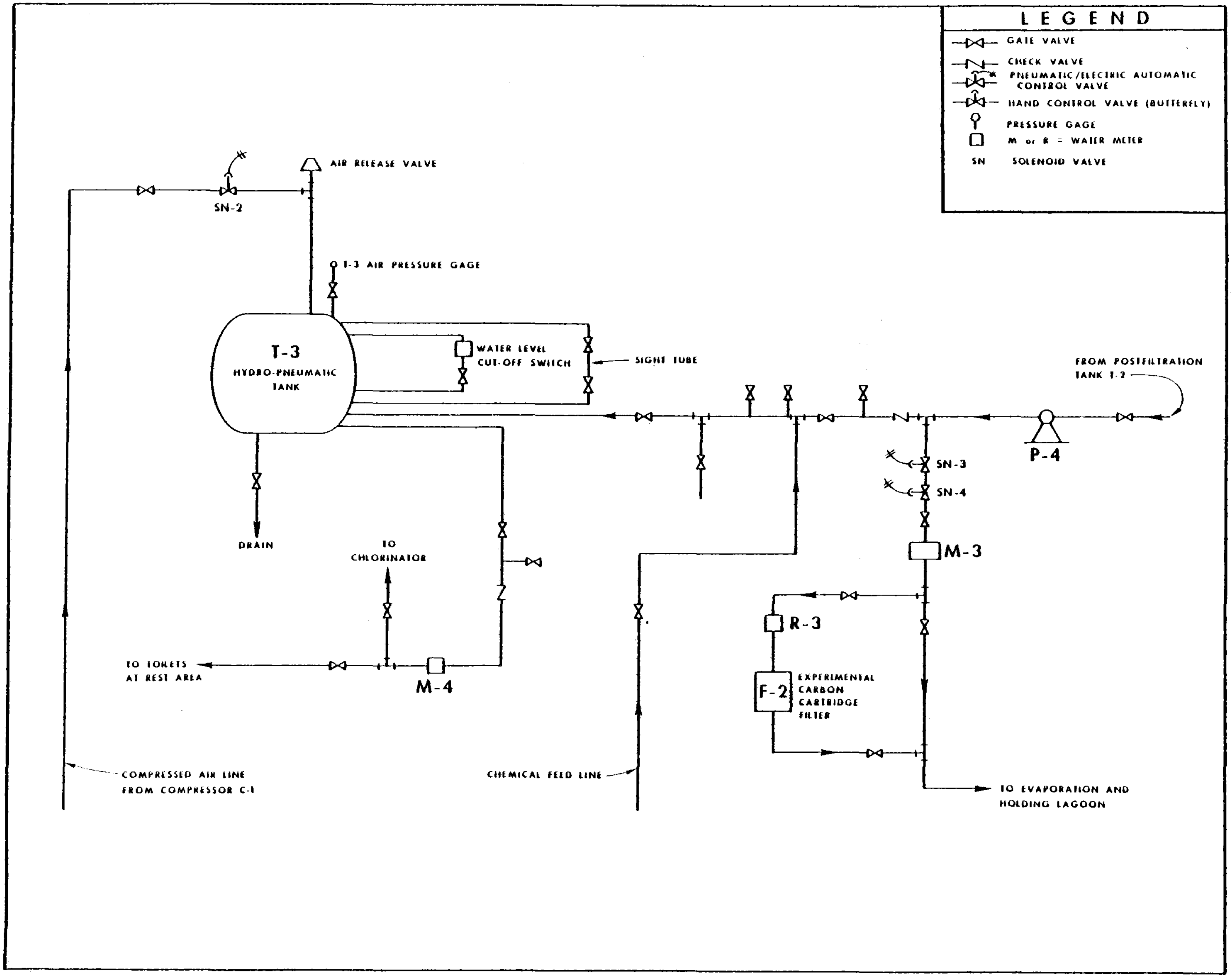

Figure A-2. Expanded view of hydro-pneumatic piping.

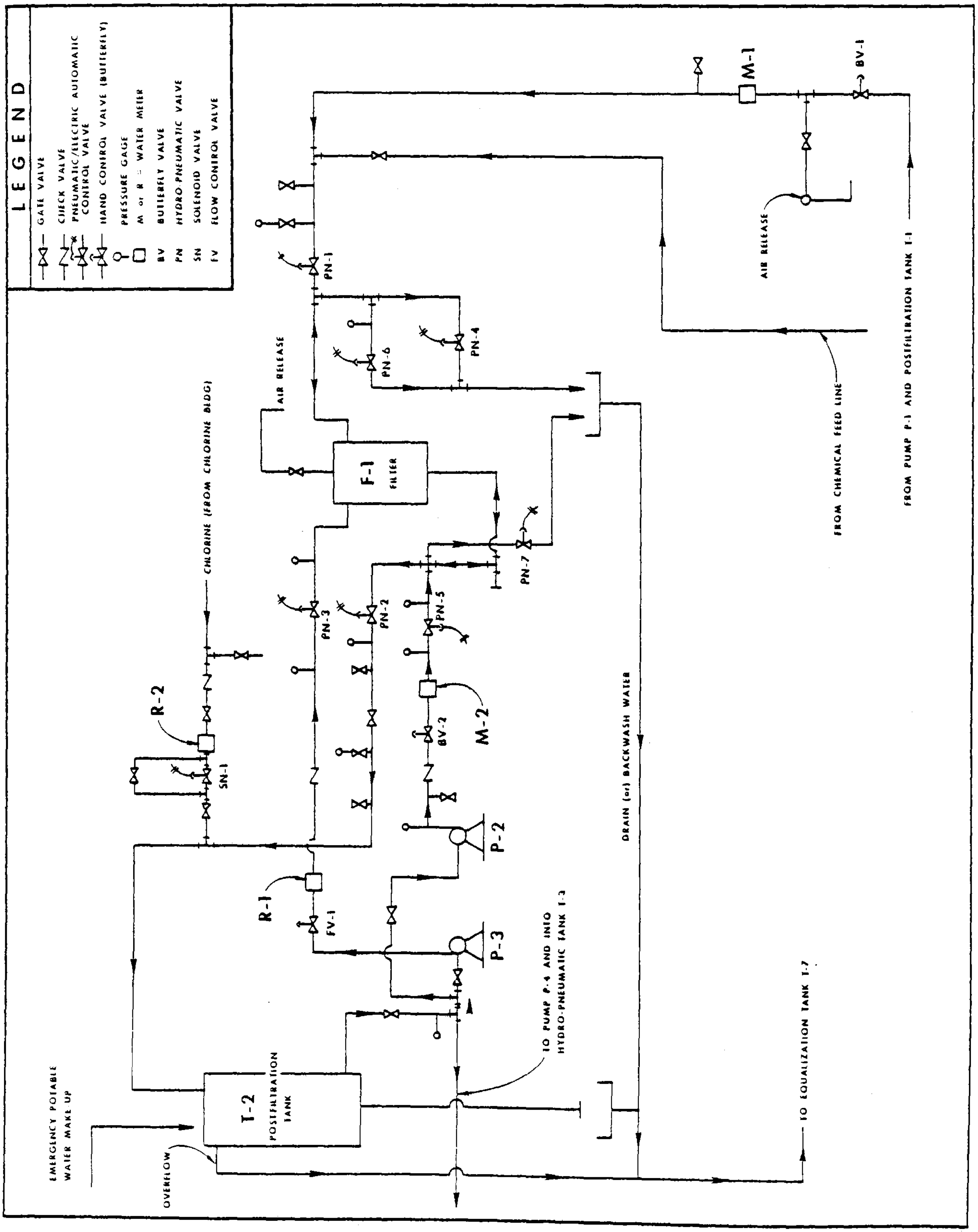

Figure A-3. Expanded view of filtration piping.

APPENDIX B

DESIGN CONSIDERATIONS FOR WATER RECYCLE-REUSE SYSTEM FOR REST AREAS SIMILAR TO FAIRFIELD

Components in the recycle system have been evaluated with regard to the toilet flush water requirement, since this requirement is a fundamental parameter in the design and operation of the system. Potable water and flush water use at the existing system were extensively metered. In addition, use of the facilities was monitored to evaluate water storage and pumping requirements during periods of peak use. Resident time in the toilet facility by the user and flush water use per user were determined from on-site measurements. It was found that the average resident time in the toilet facility by the user for non-standing-in-line conditions was 2.57 minutes. Based on the distribution of resident times observed, it was concluded that an average resident time of 2.5 minutes could be used for typical daily use, and resident times of 2.0 minutes and 1.5 minutes were minimum values that could be expected for maximum daily and maximum hourly use, respectively. (Maximum use is defined as the highest intensity of use expected; i.e. standing-in-line conditions.)

The Fairfield rest area has 10 toilet fixtures, 8 commodes, and 2 urinals. Toilet flushing evaluations indicate that the average water per flush is 3.35 gallons (12.68 litres) but the average toilet flush water use per user is 3.96 gallons (14.99 litres). (This of course indicates that on the average, one out of every five users flush the toilet twice.) Based on the flush water use data and the resident time of the users, recycle storage and pumping systems serving rest area designs of the type at Fairfield should be designed for an average daily flow of 16 gpm (61 l/min) and a sustained maximum daily flow of 20 gpm (76 l/min) with maximum hourly peaks of 27 gpm (102 l/min). It should be recognized that intense use occurs during a 12-to 16-hour period; therefore, daily requirements will normally be based on a 16-hour day and not a 24-hour day. In addition, hourly peaks would rarely occur due to the low probability of users of all 10 toilets maintaining a resident time rate of 1.5 minutes over any substantial period of time.

An evaluation of toilet delivery demands and storage and filtration requirements are presented in Table B-1. The design and operational guidelines for future water recycle and reuse designs are presented in Table B-2.

Table B-1

Comparison of Storage and Pumping Requirements

Total Delivery Rate, gpm	Filtration Rate, gpm	Total Storage Volume, Gallons	Gallons Storage Filter Pump Activates	Gallons Storage Volume Used Before Filter Pump Activates	Volume Available, Gallons: Initial Storage At Maximum	Volume Available, Gallons: Initial Storage At Filter Pump Activation	Delivery Duration, Hours: At Maximum Storage	Delivery Duration, Hours: Storage At Filter Pump Activation
65	28[a]	10,000	8,000	2,000	16,000	14,040	4.11	3.60
45	28	10,000	8,000	2,000	23,176	21,176	8.58	7.84
40	28	10,000	8,000	2,000	28,664	26,664	11.94	11.11
65	50[b]	5,000	3,000	2,000	14,987	12,987	3.84	3.33
45	50	5,000	3,000	2,000	N/A	N/A	N/A	(6.67)[c]
40	50	5,000	3,000	2,000	N/A	N/A	N/A	(3.33)[c]
28	28	10,000	8,000	2,000	Delivery equals Filtration Rate			
20	28	10,000	8,000	2,000	N/A	N/A	N/A	(4.17)[c]
40	28	5,000	3,000	2,000	12,000	10,000	5.00	4.17
28	14[d]	10,000	8,000	2,000	18,000	16,000	10.78	9.59
28	25[e]	5,000	3,000	2,000	30,000	28,000	17.88	16.67

(a) Rate for 3.0 foot diameter filter at 4 gpm/ft^2.

(b) Rate for 4.0 foot diameter filter at 4 gpm/ft^2.

(c) Filtration rate exceeds toilet delivery rate.
Time to restore storage tank to maximum capacity while water is being supplied to the toilet at the indicated rate.

(d) Rate for 3.0 foot diameter filter at 2 gpm/ft^2.

(e) Rate for 4.0 foot diameter filter at 2 gpm/ft^2.

NOTE: 1 gallon = 3.785 litres
1 ft = .305 metre
1 gpm/ft^2 = 40.7 $litre/min/metre^2$

Table B-2

Design and Operation Parameters

A. Unit Sizes (10,000 gpd design flow)

Description	Existing	Proposed	
Prefilter storage tank, gal.	20,000	10,000 or	5,000
Filter diameter, ft.	6.0	3.0	4.0
Postfilter storage tank, gal.	20,000	10,000	5,000
Filter pump, gpm	0-65	0-30	0-50
Filter backwash pump, gpm	0-240	0-100	0-200
Surface wash pump, gpm	0-30	0-10	0-15
Postfilter storage tank operating vol., gal.	9,700	2,000	2,000
Postfilter storage tank reserve & backwash vol., gal.	9,200	8,000	3,000
Equalization tank vol., gal.	4,500	1,500	3,000
Filter building size, $ft.^2$	896	500	500
Hydro-pneumatic tank, gal.	5,000	2,500	2,500
Hydro-pneumatic tank operating vol., gal.	1,400	600	600
Hydro-pneumatic tank operating pressure, psig	40-60	Same	Same
Hydro-pneumatic tank depletion time at max. use, min.	50	20	20
Chemical feed, gph	2 @ 0-5	None	None
Storage lagoon, gal.	150,000	Same	Same
Biological trt. aeration basin, gal.	10,000	Same	Same
Biological settling basin, gal.	2,000	Same	Same
Biological sludge storage, gal.	4,400	Same	Same
Aeration units (blowers), hp.	2 @ 3	Same	Same

B. System Control and Operational Requirements

Description	Existing	Proposed
Prefilter storage tank	Overflow to lagoon	Same
Filter pump	Return line to prefilter tank above water surface for mixing	
Pipe loop from filter pump to equalization basin	None	Yes
Filter cycle control	Automatic air control with either manual, pressure differential, or timer activated	Same or electrical
Hydro-pneumatic tank		
a) Add air	Automatic control	Manual control
b) Low water level pump on switch (minimum pressure)	Automatic pressure switch	Same
c) High water level pump off switch (maximum pressure)	Float switch	Same
d) Sight gauge	Clear tube, valved both ends	Same
e) Pipe to float switch	Valve at one end	Valve both ends
Chlorination	Prefilter tank, timer, & postfilter tank, flow control	Same
Chlorination dose range	Set by equipment prior to recycle addition	0 to 1 lb. per day

Table B-2 (continued)

B. System Control and Operational Requirements (continued)

Description	Existing	Proposed
Equalization basin return flow	Flow controlled by pump with timer or an overflow or drain line, all discharge to inlet of aeration basin	Same
Chemical feed	Automatic	None
Dye feed	Automatic	None (add by hand as needed)
Operational warning signals	In filter building	Same plus in custodial bldg.
Prefilter and postfilter storage tank location	Separated	At filter bldg. access opening in building
Recycle water meters	Prefilter, backwash, toilet delivery, equalization tank discharge & water wastage	Backwash & toilet
Dye used	FDC Blue No. 1	Same
Recycle water color	Green, not removed by treatment	Same
Dye dosage	As needed by hand; approximately 5 lb. per 10^6 gallons recycled	Same
Defoaming agent	As needed by hand; approximately 1 lb. per 60,000 gallons recycled	Same
Manpower	Operation check daily by custodian; estimated 4 hours per week required by supervisor	Same
Maintenance	Nil weekly, daily or monthly; exact to be established	Same

NOTE: 1 gallon = 3,785 litres
1 ft^2 = .0929 $metre^2$
1 psi = 6.894 kilopascals
1 ft. = 0.3048 metre
1 hp = 0.746 Kw
1 lb = 0.454 Kgm

APPENDIX C

RESULTS FOR BIOLOGICAL, CHEMICAL AND PHYSICAL ANALYSES

Table C-1

Raw Wastewater Characteristics

Date	°C	pH	Cond.[1] µmohs	Concentration in mg/l. Alk.[2]	BOD_5	COD	TKN	NH_3-N	NO_3-N	NO_2-N	TS	TFS	TVS	TDS	SS	SVS	P	Cl^-	$SO_4^=$
Dec. 1	---	8.7	1450	480	115	620	200	140	---	---	1080	650	860	920	320	280	14	---	---
Dec. 5	8	8.6	1680	600	160	370	230	170	---	---	830	560	270	720	120	100	---	---	---
Dec. 7	8	8.5	1750	550	>1020	1890	280	---	---	---	1740	760	990	510	1230	970	---	---	---
Dec. 10	7	8.5	1500	490	155	500	190	130	---	---	1240	740	500	910	330	240	23	---	---
Dec. 12	8	8.6	2010	620	75	330	250	170	---	---	930	630	300	690	240	220	8	---	---
Dec. 15	8	8.6	1900	640	140	360	180	150	---	---	980	650	330	890	84	78	9	---	68
Dec. 20	8	8.5	2010	615	100	>1000	270	180	---	---	1440	820	620	960	470	410	---	---	53
Dec. 28	7	8.4	2390	770	275	>1000	360	210	---	---	1680	890	790	1230	450	400	26	---	39
Dec. 31	4	8.9	2550	1040	---	610	---	290	---	---	1460	990	470	1280	180	170	---	---	90
Jan. 4	6	8.6	2690	1040	110	400	360	300	---	---	1390	990	400	1300	88	60	8	---	110
Jan. 8	3	8.8	2940	1390	130	540	450	350	---	---	1350	1030	320	1210	140	100	8	---	83
Jan. 13	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Jan. 15	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
March 15	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
March 17	8	8.3	1100	415	80	220	110	70	---	---	710	370	340	610	100	86	12	130	38
March 23	7	8.6	2000	770	102	345	220	170	---	---	1040	700	340	880	160	100	54	200	65
March 30	11	8.4	2300	570	---	370	190	150	24	---	1130	750	380	1020	120	110	8	250	67
April 4	12	8.6	2510	375	---	515	220	200	---	---	1380	830	550	1210	170	140	114	240	80
April 11	13	7.4	2610	160	80	425	150	120	23	---	1380	890	480	1240	140	92	46	280	78
April 20	15	8.2	3200	370	86	490	200	190	20	---	1420	1030	390	1280	140	130	23	310	70
April 27	13	8.3	3150	490	155	1000	---	---	---	---	2060	1120	860	1260	780	690	40	360	94
May 4	16	8.5	3750	575	>435	690	270	260	21	---	1910	1240	680	1590	320	290	25	400	100
May 11	14	8.3	3390	590	160	670	240	220	12	---	1640	1070	580	1450	190	170	28	390	140
May 19	20	8.3	4350	745	125	755	330	300	17	---	2040	1330	710	1760	280	250	25	---	150
May 25	18	8.3	4000	550	140	945	260	240	19	---	1850	1310	530	1760	90	73	17	---	120
June 1	20	8.6	4220	815	>500	1770	330	230	22	---	3080	540	1540	2120	100	830	>100	520	98
June 8	17	8.3	3820	690	480	945	280	---	33	---	2120	1560	560	1860	260	200	45	520	160
June 15	---	8.1	4700	580	410	920	270	230	39	---	2150	1580	570	1840	300	270	60	540	140
June 21	21	8.6	4300	555	540	920	270	250	44	---	2130	1590	540	1900	230	200	20	570	140
June 28	22	8.1	3850	580	350	965	260	280	32	---	2340	1660	680	1940	390	310	24	570	150
July 6	24	8.2	5000	680	500	810	290	260	26	170	2180	1770	410	2050	130	110	26	600	200
July 13	25	8.1	4700	580	535	1770	270	230	30	100	2576	1810	770	2100	480	370	42	640	---
July 20	25	8.1	5000	595	220	970	280	220	24	120	2700	1890	810	2130	580	410	50	630	180
July 27	23	8.1	4850	490	270	1120	250	180	44	120	2480	1840	650	2050	440	320	37	670	190
Aug. 3	24	8.0	4490	610	185	1020	270	220	27	110	2620	1980	640	2220	390	310	35	700	190
Aug. 10	25	7.8	4900	400	160	830	220	---	---	130	2220	1830	390	2110	110	100	37	670	180
Aug. 17	24	8.5	4800	590	290	1660	---	---	---	100	2670	2000	660	2110	560	440	30	700	150
Aug. 24	22	8.4	3900	530	---	710	255	260	48	115	2560	1840	720	2200	350	320	28	690	190
Aug. 31	24	8.4	4680	560	60	960	280	260	41	80	2620	1930	690	2110	510	450	---	690	230

Table C-2

Settling Basin Effluent Characteristics

Date	°C	pH	Cond. µmohs [1]	Alk. [2]	BOD_5	COD	TKN	NH_3-N	NO_3-N	NO_2-N	TS	TTS	TVS	TDS	SS	SVS	P	Cl^-	$SO_4^=$
				Concentration in mg/L															
Dec. 1	---	7.9	1100	225	50	235	100	85	---	---	880	1200	570	860	54	48	8	---	---
Dec. 5	4	7.8	1290	400	15	225	110	100	---	---	920	730	190	870	53	42	---	---	---
Dec. 7	6	7.8	1590	305	---	255	170	---	---	---	920	620	300	950	74	60	---	---	---
Dec. 10	4	7.8	1420	330	29	275	180	100	---	---	1050	720	330	960	86	68	11	---	---
Dec. 12	6	7.9	1800	380	86	280	150	120	---	---	930	700	230	840	83	62	12	---	---
Dec. 15	5	7.9	1690	300	11	280	140	120	---	---	980	710	270	900	77	58	11	---	74
Dec. 20	7	7.9	1960	465	32	270	170	140	---	---	970	770	200	910	58	43	---	---	74
Dec. 28	6	7.9	2500	730	---	265	230	210	---	---	1110	870	250	1080	38	33	10	---	93
Dec. 31	2	8.2	2330	855	32	250	---	230	---	---	1230	980	250	1190	34	27	---	---	72
Jan. 4	3	8.5	2900	1000	31	290	320	270	---	---	1290	1010	280	1240	46	38	9	---	78
Jan. 8	1	8.2	2690	980	---	290	300	280	---	---	1270	1010	250	1230	33	27	9	---	68
Jan. 13	---	8.1	2710	980	---	320	290	260	---	---	1250	910	340	1200	52	42	---	---	---
Jan. 15	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
March 15	---	7.7	1550	310	115	225	110	79	---	---	800	550	250	740	60	54	19	---	---
March 17	9	7.6	1400	250	28	195	88	71	---	---	800	540	260	750	48	40	25	140	70
March 23	5	7.8	1490	70	19	210	61	50	---	---	870	630	240	810	60	46	18	150	63
March 30	14	7.0	1960	35	---	400	---	60	37	---	1120	680	440	990	62	52	24	190	50
April 4	12	7.2	2050	45	---	350	78	65	---	---	1220	700	520	1160	62	52	26	250	76
April 11	15	6.5	2770	35	55	440	130	110	29	---	1290	890	400	1220	76	60	31	250	82
April 20	17	6.7	3100	35	37	550	130	120	26	---	1370	1020	350	1320	50	48	16	300	88
April 27	13	6.5	2950	30	30	495	---	---	---	---	1450	1020	430	1400	46	39	24	400	84
May 4	17	7.0	3400	40	50	480	150	140	30	---	1600	170	430	1550	44	38	26	370	110
May 11	14	7.2	3550	35	34	555	170	150	25	---	1650	1260	390	1610	39	35	24	400	140
May 19	19	7.0	4070	30	15	535	170	150	28	---	1800	---	---	1750	46	40	23	---	130
May 25	19	7.3	3750	35	22	530	160	160	26	---	1830	1380	450	1800	34	30	23	440	140
June 1	21	6.9	3850	80	63	535	160	130	59	---	1860	1490	370	1830	34	30	25	470	140
June 8	16	7.2	3880	30	63	585	160	---	63	---	2350	1580	770	2350	30	20	23	490	150
June 15	---	6.8	4330	30	13	525	160	140	58	---	2160	1570	590	2140	24	24	22	510	150
June 21	20	7.0	4190	640	79	510	---	160	45	---	2220	1700	520	2190	28	22	23	550	150
June 28	22	6.9	3900	35	78	500	---	170	66	---	2250	1730	520	2210	32	27	26	550	160
July 6	---	6.2	4620	70	68	460	160	160	51	230	2300	1840	460	2280	27	22	32	580	200
July 13	24	5.8	4100	40	57	415	150	130	35	250	2190	1700	490	2160	31	23	29	610	---
July 20	25	5.8	4700	45	24	445	140	130	47	210	2340	1870	470	2310	34	22	30	610	190
July 27	22	5.4	4500	50	15	455	140	120	69	190	2330	1860	470	2300	31	23	35	620	180
Aug. 3	24	5.7	4420	40	14	470	130	130	60	145	2360	1920	430	2320	35	23	37	660	190
Aug. 10	25	5.8	4500	50	21	450	145	---	---	210	2400	1940	460	2370	34	26	40	670	200
Aug. 17	24	6.1	4150	45	20	480	---	---	---	195	2390	2000	390	2350	41	31	43	670	190
Aug. 24	22	6.2	4190	55	23	445	160	140	86	195	2450	1940	520	2430	25	21	25	690	220
Aug. 31	24	6.1	4520	40	16	465	165	150	76	160	2340	1950	390	2320	23	20	---	680	290

Table C-3

Prefiltration Tank Characteristics

Date	°C	pH	Cond.[1] µmohs	Alk.[2]	BOD_5	COD	TKN	NH_3-N	NO_3-N	NO_2-N	TS	TFS	TVS	TDS	SS	SVS	P	Cl^-	$SO_4^=$
				Concentration in mg/l.															
Dec. 1	---	7.6	1000	225	9	150	83	72	---	---	720	480	960	710	34	28	8	---	---
Dec. 5	6	7.7	1200	240	8	175	91	78	---	---	930	560	370	910	25	20	---	---	---
Dec. 7	6	7.7	1450	250	26	175	120	---	---	---	840	520	320	820	20	19	---	---	---
Dec. 10	6	7.8	1310	270	22	175	130	79	---	---	930	640	290	910	23	17	10	---	---
Dec. 12	7	7.8	1580	300	13	175	110	94	---	---	850	630	220	830	22	16	12	---	---
Dec. 15	6	7.8	1510	340	16	---	---	---	---	---	830	650	180	810	19	15	---	---	70
Dec. 20	7	7.9	1850	410	9	205	130	120	---	---	900	690	210	870	22	16	---	---	74
Dec. 28	4	8.0	2200	640	19	230	200	170	---	---	1010	840	170	990	20	18	10	---	81
Dec. 31	3	8.3	2150	760	---	235	230	200	---	---	1140	910	230	1130	19	16	---	---	88
Jan. 4	3	8.1	2650	955	19	245	270	250	---	---	1210	950	260	1180	25	19	9	---	88
Jan. 8	3	8.2	2550	945	18	265	280	250	---	---	1230	990	240	1210	18	16	9	---	100
Jan. 13	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Jan. 15	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
March 15	---	7.7	1350	280	>110	175	78	57	---	---	730	440	290	700	28	26	16	---	---
March 17	10	7.6	1290	280	15	150	74	63	---	---	790	550	240	780	14	12	18	120	60
March 23	8	7.8	1450	255	7	170	81	67	---	---	810	550	250	800	11	8	16	130	55
March 30	12	7.0	1800	115	---	205	65	62	35	---	940	620	320	920	16	12	13	190	60
April 4	11	7.2	2050	110	---	290	85	73	---	---	1000	730	270	970	31	26	21	240	78
April 11	14	6.5	2600	50	32	380	110	99	27	---	1420	780	640	1380	43	34	30	250	72
April 20	12	6.7	3000	75	28	465	130	120	26	---	1310	980	330	1280	31	26	---	290	72
April 27	13	6.5	2900	70	21	425	---	---	---	---	2090	1750	340	2070	26	19	24	320	100
May 4	15	7.0	3340	90	29	410	150	140	27	---	1560	1160	400	1530	34	27	27	350	110
May 11	14	7.2	3390	105	21	485	160	150	23	---	1530	1200	330	1520	17	15	26	380	130
May 19	15	7.0	3910	105	9	480	170	160	24	---	1710	1350	370	1690	26	21	20	---	140
May 25	16	7.3	3800	110	24	515	170	170	24	---	1820	1380	430	1800	19	16	24	---	150
June 1	21	6.9	4050	120	21	495	180	140	49	---	1790	1450	340	1770	17	15	24	460	150
June 8	17	7.2	3990	110	44	515	170	---	66	---	1880	1490	390	1830	50	50	23	480	160
June 15	---	6.8	4220	100	17	500	160	150	60	---	1920	1500	420	1900	17	17	23	500	160
June 21	22	7.0	4160	100	18	490	---	170	49	---	2000	1630	370	1970	28	22	24	520	150
June 28	19	6.9	3890	110	19	470	---	180	58	---	2050	1670	380	2020	31	25	22	540	170
July 6	20	6.8	4440	160	23	435	---	170	49	---	2130	870	1260	2120	14	13	32	580	200
July 13	25	6.6	4100	100	13	415	---	160	33	---	2130	1740	380	2100	25	25	30	600	---
July 20	26	6.5	4900	85	10	425	---	140	51	---	2189	1830	350	2160	25	15	33	610	200
July 27	22	6.5	4500	95	19	450	---	120	59	---	2200	1860	340	2170	29	20	35	610	210
Aug. 3	22	6.5	4420	90	22	455	---	140	50	---	2290	1940	360	2260	34	22	30	660	190
Aug. 10	25	6.5	4800	105	38	420	---	---	---	---	2300	1940	360	2270	25	17	43	670	200
Aug. 17	25	6.9	4500	110	29	405	---	---	---	---	2350	2020	320	2320	24	16	40	680	190
Aug. 24	21	7.0	4100	120	24	430	---	160	79	---	2370	1960	410	2360	14	10	21	700	210
Aug. 31	24	7.0	4580	130	20	410	---	170	73	---	2360	2030	330	2350	14	14	---	690	270

Table C-4

Filter Effluent Characteristics

Date	°C	pH	Cond.[1] µmohs	Alk.[2]	BOD_5	COD	TKN	NH_3-N	NO_3-N	NO_2-N	TS	TFS	TVS	TDS	SS	SVS	P	Cl^-	$SO_4^=$
				Concentration in mg/L															
Dec. 1	---	7.5	990	225	19	175	79	70	---	---	1540	920	620	1510	34	30	8	---	---
Dec. 5	8	7.4	1190	225	5	135	73	69	---	---	770	540	230	760	11	8	---	---	---
Dec. 7	8	7.5	1450	250	10	150	110	---	---	---	840	560	280	840	8	6	---	---	---
Dec. 10	13	7.4	1210	260	11	140	110	77	---	---	860	620	240	860	5	4	9	---	---
Dec. 12	7	7.7	1550	300	7	170	130	95	---	---	810	630	180	800	9	7	11	---	---
Dec. 15	11	7.5	1450	340	7	150	110	93	---	---	840	630	210	820	12	7	10	---	74
Dec. 20	12	7.7	1780	395	7	180	140	110	---	---	830	720	110	820	12	10	---	---	74
Dec. 28	11	7.9	2240	610	12	205	200	170	---	---	990	820	170	980	11	10	10	---	100
Dec. 31	4	8.1	2010	750	---	255	210	190	---	---	1150	920	230	1130	17	12	---	---	84
Jan. 4	10	8.2	2700	850	14	225	270	230	---	---	1200	940	260	1180	13	10	10	---	93
Jan. 8	6	8.1	2490	940	15	235	270	240	---	---	1180	980	200	1180	11	10	9	---	100
Jan. 13	11	8.1	2550	960	---	200	270	240	---	---	1160	880	260	1160	8	7	---	---	---
Jan. 15	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
March 15	---	7.6	1300	280	>52	145	75	24	---	---	690	450	240	680	12	11	14	---	---
March 17	15	7.6	930	370	6	65	58	32	---	---	550	370	180	540	7	6	7	80	60
March 23	13	7.8	1550	365	5	115	82	55	---	---	750	540	210	740	8	6	15	130	70
March 30	18	7.5	1690	205	---	160	67	61	31	---	880	560	320	880	7	5	16	190	70
April 4	15	7.3	2000	130	---	255	84	68	---	---	1000	720	280	990	14	11	24	230	70
April 11	15	6.9	2500	100	21	320	110	98	23	---	1160	874	290	1140	19	13	29	250	60
April 20	19	7.1	2900	120	22	390	130	110	23	---	1280	990	290	1270	16	14	15	290	60
April 27	17	7.2	2750	160	23	390	---	---	---	---	1290	1000	290	1280	13	11	23	310	90
May 4	19	7.4	3200	185	43	375	150	140	22	---	1460	1070	390	1443	15	13	25	350	110
May 11	17	7.5	3210	200	31	445	160	150	19	---	1500	1160	340	1480	20	17	22	380	130
May 19	20	7.3	3960	155	12	465	170	160	21	---	1680	1340	350	1660	20	17	21	---	140
May 25	22	7.6	3500	245	25	430	170	160	19	---	1650	1330	320	1630	22	20	19	430	130
June 1	20	7.0	4050	135	16	490	180	140	51	---	1790	1450	330	1780	12	11	23	470	160
June 8	21	7.5	3800	260	22	460	170	---	34	---	1780	1430	340	1760	16	16	22	480	190
June 15	---	7.5	3920	275	14	415	160	150	39	---	1800	1400	410	1790	13	13	22	400	160
June 21	24	7.8	3990	225	34	420	---	170	34	---	1910	1540	370	1890	20	17	22	540	160
June 28	24	7.5	3600	280	24	395	---	180	31	---	1920	1570	360	1890	30	26	21	540	160
July 6	20	7.2	4400	255	35	440	---	150	29	---	2070	1730	340	2050	20	17	26	580	210
July 13	26	7.0	4200	180	18	405	---	160	37	---	2130	1760	370	2110	16	16	29	620	---
July 20	27	6.6	4800	90	6	430	---	140	40	---	2200	1840	370	2180	24	15	30	610	200
July 27	24	6.7	4500	120	17	430	---	130	54	---	2170	1810	360	2150	13	13	35	620	190
Aug. 3	25	6.5	4800	135	13	420	---	140	59	---	2260	1920	340	2250	14	10	37	660	180
Aug. 10	26	6.5	4200	105	18	420	---	---	---	---	2290	1910	380	2280	15	4	41	670	210
Aug. 17	25	7.3	4400	145	18	405	---	---	---	---	2300	1980	330	2290	14	9	39	670	180
Aug. 24	23	7.2	4100	150	14	400	---	170	73	---	2350	1950	400	2340	6	6	27	690	220
Aug. 31	25	7.2	4480	145	20	405	---	170	74	---	2360	2030	340	2360	6	6	---	690	240

Table C-5

Flush Water Characteristics

Date	°C	pH	Cond.[1] µmohs	Concentration in mg/L															
				Alk.[2]	BOD_5	COD	TKN	NH_3-N	NO_3-N	NO_2-N	TS	TFS	TVS	TDS	SS	SVS	P	Cl^-	$SO_4^=$
Dec. 1	---	7.4	1450	155	2	110	48	45	---	---	700	870	520	690	20	16	6	---	---
Dec. 5	5	7.5	1680	180	4	120	58	51	---	---	760	580	180	750	8	6	---	---	---
Dec. 7	5	7.4	1750	180	7	130	100	---	---	---	820	440	370	810	6	6	---	---	---
Dec. 10	4	7.4	1500	195	12	125	100	60	---	---	930	620	310	920	6	5	10	---	---
Dec. 12	9	7.5	2010	220	6	140	84	67	---	---	750	590	160	740	7	5	10	---	---
Dec. 15	6	7.5	1900	290	4	150	88	72	---	---	780	550	230	770	9	7	12	---	58
Dec. 20	10	7.7	2010	305	5	160	100	91	---	---	820	430	390	810	9	6	---	---	65
Dec. 28	7	7.9	2390	510	14	200	160	140	---	---	950	720	230	930	12	10	12	---	85
Dec. 31	2	8.1	2550	630	---	210	180	160	---	---	1070	830	240	1050	13	9	---	---	84
Jan. 4	2	8.1	2690	745	12	215	230	200	---	---	1130	870	260	1120	11	9	10	---	98
Jan. 8	1	8.2	2940	620	13	235	240	210	---	---	1140	920	220	1130	10	8	10	---	90
Jan. 13	1	8.0	---	985	---	245	280	250	---	---	1310	980	330	1300	9	9	---	---	---
Jan. 15	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
March 15	---	7.6	800	310	>57	65	45	24	---	---	560	560	290	530	22	12	7	---	---
March 17	12	7.6	850	320	5	65	42	32	---	---	530	380	150	520	9	7	9	70	40
March 23	6	7.8	1250	305	4	115	71	55	---	---	830	620	210	820	7	5	14	110	56
March 30	17	7.4	1670	200	---	155	63	61	34	---	900	520	370	890	6	5	13	170	65
April 4	13	7.2	1400	115	---	245	82	68	---	---	950	690	260	930	15	12	20	220	72
April 11	19	7.0	2400	80	15	320	110	98	26	---	1080	790	290	1060	23	17	29	230	70
April 20	20	6.8	2820	80	13	350	120	110	25	---	1260	720	340	1240	17	15	18	260	66
April 27	13	6.6	2700	90	14	370	---	---	---	---	1310	770	340	1290	14	11	26	300	100
May 4	18	6.8	3200	90	22	395	140	140	26	---	1570	950	620	1560	12	10	24	330	120
May 11	14	7.0	3280	100	14	445	160	150	23	---	1490	1130	360	1480	12	10	21	370	140
May 19	21	7.0	3910	90	9	410	160	160	23	---	1620	---	---	1600	16	12	20	---	130
May 25	20	7.0	3690	125	19	465	160	160	30	---	1650	1310	340	1640	16	14	23	420	150
June 1	21	7.0	3750	150	17	460	180	140	54	---	1780	1420	360	1760	17	15	22	440	140
June 8	16	6.9	4000	125	16	500	170	---	56	---	1810	1610	200	1800	13	12	23	470	150
June 15	---	6.9	4250	105	14	475	160	150	61	---	1860	1450	410	1850	10	10	22	490	160
June 21	24	7.1	4100	125	18	460	160	170	47	---	1950	1576	380	1940	15	12	---	540	160
June 28	24	6.7	3790	105	15	425	150	180	56	---	1990	1650	340	1970	16	13	22	520	160
July 6	21	6.9	4800	180	41	425	180	150	48	220	2030	1740	340	2060	17	11	27	570	220
July 13	26	6.8	4500	140	17	395	170	160	37	180	2130	1760	370	2120	15	15	27	620	---
July 20	28	6.6	4800	115	13	425	150	140	40	240	2170	1840	330	2140	30	19	27	610	190
July 27	23	6.5	4300	95	38	435	140	130	54	180	2150	1830	320	2140	15	15	32	610	210
Aug. 3	25	6.5	4430	105	>46	430	140	140	59	180	2230	1900	330	2220	13	10	37	650	180
Aug. 10	27	6.5	4900	105	>46	405	160	---	---	230	2280	1930	350	2270	16	5	25	670	200
Aug. 17	26	7.1	4200	115	84	415	---	---	---	220	2290	1980	310	2260	26	16	37	680	190
Aug. 24	23	7.0	4200	125	>46	395	155	160	80	210	2410	1930	480	2400	11	6	20	680	220
Aug. 31	26	7.1	4550	140	24	390	175	180	70	180	2320	1990	330	2320	6	5	---	700	230

Table C-6

Fairfield Rest Area Treatment Characteristics for Summer 1976

TEST[(a)]	LOCATION			
	Potable Water	Raw Influent	Aeration Basin	Settling Basin
BOD_5	---	160	---	15
COD	---	410	---	44
TKN	---	99	---	2
NH_3-N	---	44	5	2
P	---	5.4	---	5.4
Alk	245	460	60	100
Cl^-	---	40	52	48
Hardness	305	325	---	330
SO_4	---	20	24	27
TS	305	1020	---	855
TFS	195	515	---	390
TDS	---	740	---	835
SS	---	280	---	20
VSS	---	250	---	20
MLSS	---	---	5290	---
MLVSS	---	---	4640	---
DO	---	---	0.9	---
pH[(b)]	7.5	8.3	6.4	6.4
Cond.[(c)]	430	950	870	870
SVI[(d)]	---	---	87	---
O_2 uptake[(e)]	---	---	15	---

(a) Concentration in mg/l except as noted.
(b) pH measured as pH units.
(c) Conductivity measured as µmhos.
(d) Sludge Volume Index is dimensionless number.
(e) O_2 uptake measured as mg/l/hr.

APPENDIX D

COST COMPARISON OF AQUA SANS MINERAL OIL RECYCLE SYSTEM AND WATER RECYCLE SYSTEM FOR USE AT REST AREAS

by

Gary R. Allen
Research Economist

The information presented here is intended as a supplement to the technical analysis comprising the body of this report. The raw data upon which the cost comparison is based were made available by Austin Brockenbrough and Associates, Consulting Engineers.

Using the data presented in Tables D-1, D-2, D-3 and D-4, a cost comparison is made of the Aqua Sans Mineral Oil System and the water recycle system. While the Aqua Sans system requires less capital outlay initially, the annual operating and maintenance costs for it are approximately $21,000 greater per year than for a comparably sized (10,000 gallon per day — 35,000 litre per day) water recycle system. Simply examining average annual cost or initial capital cost without regard to the fact that dollars expended at a future date are less valuable than a capital outlay today can be quite misleading. There is a particular danger, for example, of overestimating the cost savings associated with a specific alternative. In the case of the water recycle system, total operating and maintenance cost savings based solely upon a projection of first year cost differences for the Aqua Sans and water recycle system would indicate a 20-year savings of $430,000. However, such a comparison overstates the attractiveness of the water recycle system, mainly because it ignores initial capital costs and doesn't account properly for the fact that operating expenditures occur over a 20-year period. To account for these factors, the author has developed in Table D-5 a present value cost comparison of the two systems.

The information in Table D-5 shows that the water recycle system is about 80% as costly as the Aqua Sans system using an 8% discount rate, and about 68% as costly as the Aqua Sans using a 10% discount rate. Effectively, this means that by choosing a water recycle system with a 10,000 gallon (38,000 litre) per day capacity, the Department will save approximately $53,000 in 1977 dollars.

Several additional comments are offered to place the information in Tables D-1-D-5 in perspective. These are presented below.

1. It should be noted that the data tables do not include the cost of piping sewer and water in the rest area building, nor do they include any costs for site development, which would be equal regardless of the system selected. In addition, the disposal of excess water from the biological system is assumed to be accomplished by ponding then releasing through chlorination-post aeration facilities. This arrangement may not suffice for some applications; however, the pond will still provide for retaining the liquid for trucking to a suitable disposal location.

2. Manpower Skills

   A. Biological System

      Operator — The operator can be the custodian of the facility with a minimum of training (2 weeks) in operation of the system. The system is not overly complicated and not highly automated.

      Maintenance — The equipment is identical to that in most rest areas in service throughout the state and the components are not difficult to maintain nor is a single source supplier required for spare or replacement parts. Electrical components are not as complex as those of the Chrysler Aqua-Sans system.

   B. Mineral Oil System

      Operator-Maintenance — The entire system should be operated and maintained by the same person. The basic mechanic skills are comparable to those needed for the water recycle system, except that the electrical components and controls are more complex.

3. Mineral Oil Losses

   The amount of mineral oil losses are difficult to evaluate since unusual losses have occurred at the New Kent Rest Area. However, it has been assumed that 0.05% of the quantity circulated is lost by line leaks, burning, filter changes, and other routine or emergency maintenance repairs that involve opening pumps, tanks, or pipe lines. The losses at this rate are as follows:

   10,000 gpd = 5 gpd = 1825 gallons/year (6,907 litres/year)

   20,000 gpd = 10 gpd = 3650 gallons/year (13,815 litres/year)

4. Mineral Oil Replacement

The mineral oil should not require a complete system exchange unless something unusual should be placed into the system by rest area users.

5. Incineration of Waste

The rate of 1 gallon (3.8 litres) of fuel oil per 3 gallons (11 litres) of waste has been used as indicated in the descriptive literature by Chrysler. It should be noted that this portion of the Chrysler system has been the greatest source of problems and failure. For example, refractory failure at New Kent has required replacement on-site and it is not certain how long the refractory material will last.

6. Cold Weather Performance

A. Mineral Oil System — The mineral oil system is contained within heated buildings and not subjected to extensive temperature changes.

B. Biological System — As estimated in the tables, the water recycle has all buried tanks with heated buildings above. The only location in the system subject to freezing would be the aeration-clarifiers; however, the heat added by processing and building space may offset the losses at that location during cold weather.

Table D-1

Recycle Wastewater System

Capital Costs		10,000 gpd	20,000 gpd
1. Comminutor, Bar Screen, & Structure		$ 3,500	$ 4,000
2. Concrete biological plant including aeration, clarifier, sludge storage & blowers & control		35,000	48,000
3. Recycle System			
(a) Concrete holding tank		9,000	17,000
(b) Concrete-filtered water storage tank		5,000	7,200
(c) Hydropneumatic tank & pump (1)		8,000	8,000
(d) Filter unit and pumps (3)		7,500	7,500
(e) Filter Control panel		6,000	6,000
(f) Hydro Control Panel		5,000	5,000
(g) Equalization Tank & Pump		5,000	6,000
(h) Piping in Building		6,000	7,500
(i) Building (Masonry)	432 SF	21,600	
	576 SF		28,800
(j) Electrical Service 240 V, 3 Phase, 60 hz		10,000	10,000
(k) Holding Pond (5% - 60 day) lined		30,000	37,000
(l) Chlorination & post Aeration		10,000	12,000
(m) Misc. Concrete, Rail & Appurtenance		7,500	10,000
TOTAL CAPITAL COST		$169,100	$214,000

NOTE: 1 gallon = 3.785 litres

Table D-2

Aqua San Recycle System

Captial Costs		10,000 gpd	20,000 gpd
1. Chrysler Aqua-Sans System including Separation, Reservior, Pump Unit, Surge Tank, Hold Tank, and Incinerator plus all controls - Purchased only Model C - 10,000; Model D - 20,000		$ 48,000	$ 65,000
2. Building Equipment erection		8,000	10,000
3. Building Piping		10,000	12,000
4. Fuel Oil Tank and Piping		3,000	4,000
5. Initial Mineral Oil to Charge System		5,000	7,500
6. Building (two story)	648 SF 720 SF	32,400	36,000
7. Outside Concrete & Fence		5,000	6,000
8. Special Flush Valves at Rest Area		1,000	2,000
9. Electrical Service		10,000	10,000
10. Misc. Construction		5,000	7,500
TOTAL CAPITAL COST		$127,400	$160,000

NOTE: 1 gallon = 3.785 litres

Table D-3

Recycle System Operation & Maintenance

Operating Items	10,000 gpd	20,000 gpd
Electricity (10 hp) @ 5 phase KWH - 16 hrs	$ 2,200	$ 2,400
Water	250	450
Compressed Air (1 hp)	100	100
Testing 1 hr/day @ 7.50/hr	2,750	2,750
Cleanup & Chemical Additions	500	500
Operating 3 hours/day @ 7.50/hr	8,250	8,250
TOTAL OPERATING	$14,050	$14,450

Maintenance	10,000 gpd	20,000 gpd
Lubrication	$ 1,000	$ 1,200
Pump Maintenance	1,000	1,200
Valve Maintenance	500	500
Electrical Control	1,000	1,000
Piping	750	750
Painting	500	600
Miscellaneous	700	1,000
TOTAL MAINTENANCE	$ 5,450	$ 6,250

NOTE: 1 gallon = 3.785 litres

Table D-4

Aqua Sans Recycle System Operation & Maintenance

Operating Items	10,000 gpd	20,000 gpd
Electricity 10 hp @ 5 phase KWH - 24 hrs.	$ 3,300	$ 3,700
Water	150	250
Compressed Air (part of unit)		
Cleanup	1,000	1,000
Operating 4 hours/day @ $7.50	10,950	10,950
Fuel Oils 3:1 fuel Ratio @ $.50/gal 130 gpd 240 gpd	7,900	 15,800
Waste Disposal 4 hours/week @ $7.50	2,950	2,950
TOTAL OPERATING	$ 26,250	$ 34,650

Maintenance	10,000 gpd	20,000 gpd
Lubrication	$ 500	$ 600
Pump	1,000	1,000
Electrical Control	1,500	1,500
Piping	1,000	1,000
Painting	700	800
Filter Replacement - Cartridge 2/mo	360	
4/mo		720
Carbon 2/mo	1,200	
4/mo		2,400
Diat. Earth 2/mo	1,400	
4/mo		2,800
Chlorine Pellets 2 lbs/week/10,000	140	280
Coalescing Filters	480	480
Bags in Resorvoir	720	720
Mineral Oil losses @ 0.05%/yr	5,000	10,000
MANHOURS FOR FILTER REPLACEMENT	750	1,500
TOTAL MAINTENANCE	$14,750	$23,800

NOTE: 1 gallon = 3.785 litres

Table D-5

Present Value Cost Comparison of Systems Having 20-Year Life
@ 8% Discount

	10,000 gallons per day		20,000 gallons per day	
	Water Recycle	Aqua-Sans	Water Recycle	Aqua-Sans
Capital Cost*	$182,633	$137,595	$231,126	$172,804
Operating	63,863	119,318	65,681	157,500
Maintenance	24,772	67,045	28,409	108,181
Total	$271,268	$323,958	$325,213	$438,485
Cost Savings of Water Recycle	$52,690		$113,272	

@ 10% discount

Capital	$182,824	$140,000	$235,164	$175,824
Operating	93,666	175,000	96,333	231,100
Maintenance	36,333	98,333	41,666	158,666
Total	$283,123	$413,333	$373,163	$565,590
Cost Savings of Water Recycle	$130,210		$192,427	

NOTE: 1 gallon = 3.785 litres

* Capital cost present value is calculated by assuming that opportunity cost after year 1 is zero. If the capital was placed on interest for 20 years it would not be appropriate to discount the capital outlay for only 1 year, but since an outlay of some kind would likely be made, the assumption seems appropriate.