

WATER REUSE AT HIGHWAY REST STATIONS

by

Michael A. Ritz
Graduate Assistant

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

Charlottesville, Virginia

November 1974

VHTRC 75 R1

TABLE OF CONTENTS

	<u>Page No.</u>
SUMMARY	ix
INTRODUCTION	1
Water Pollution Control	1
Rest Area Wastewater Treatment.	5
Rest Area Water Supply and Use.	7
Reuse of Water at Highway Rest Areas.	9
PURPOSE AND OBJECTIVES	13
LITERATURE REVIEW.	14
General	14
Industrial Reuse.	15
Municipal Reuse	16
THEORY OF RECYCLE.	21
EXTENDED AERATION BIOLOGICAL WASTEWATER TREATMENT.	24
Growth Kinetics of Biological Treatment Systems	26
Salinity and Biological Treatment	30
RESEARCH PROCEDURE	31
Pilot Plant	31
Synthetic Waste	33
Operating Procedure	34
PRESENTATION OF RESULTS.	39
DISCUSSION OF RESULTS.	46
Rest Area Wastewater Characteristics.	46
Synthetic Wastewater.	47
Pilot Plant Operation	48

TABLE OF CONTENTS (Continued)

CONCLUSIONS	50
RECOMMENDATIONS	50
REFERENCES	53
BIBLIOGRAPHY	61
APPENDIX	A-1

LIST OF FIGURES

Figure 1	4
Figure 2	5
Figure 3	8
Figure 4	11
Figure 5	12
Figure 6	15
Figure 7	18
Figure 8	23
Figure 9	25
Figure 10	25
Figure 11	32
Figure 12	35
Figure 13	38
Figure 14	45

LIST OF TABLES

Table 1	39
Table 2	40
Table 3	41
Table 4	42
Table 5	43
Table 6	44
Table 7	47

SUMMARY

A laboratory biological wastewater treatment system was operated to investigate the effects of wastewater effluent recycle on the treatment system and the effluent water quality. This concept is being investigated for use at highway rest areas in the Commonwealth of Virginia where it is desirable to utilize biologically treated and filtered effluent for flushing toilets because of water supply problems and difficulty in meeting water pollution stream standards. Although the concept of recycle has been applied to facilities with similar problems, there are no recycle systems of this nature in operation at any rest area in the United States.

Various percentages of treated effluent from an extended aeration pilot plant were reused to transport a synthetic waste to the pilot plant for treatment. The synthetic waste, which was similar in characteristics to bodily wastes and comparable in quality to that produced at highway rest areas, was made with laboratory chemicals and biological culture media. The effluent was analyzed to determine the quality of water produced and the treatment efficiency at each recycle rate.

Because recycling caused an increase in the organic load to the treatment system, biological suspended solids greatly increased in the extended aeration unit. The quality of effluent produced at high recycle rates was primarily dependent on the ability of the system to retain these biological solids, because a lower food-to-mass ratio was required to produce a satisfactory quality effluent for reuse. The dissolved salt concentration increased with the recycle rate and may have hindered biological activity.

Since the field design includes sand filtration of effluent before reuse and filter backwash recycle, retention of the biomass is assured, and satisfactory plant performance and water quality are expected. Further research is recommended to determine whether intentional sludge wastage would provide better control and operation than would effluent wastage.

WATER REUSE AT HIGHWAY REST STATIONS

by

Michael A. Ritz
Graduate Assistant

INTRODUCTION

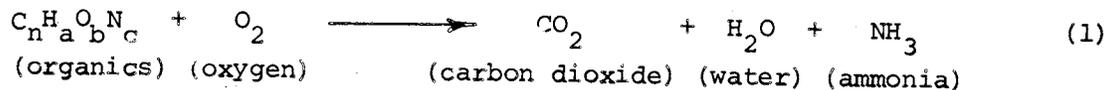
The highway system developed in the United States provides adequate roads for high speed, high volume, and long mileage travel. An outgrowth of the highway system is the rest area, which provides the traveler a place of respite in the interests of his safety and comfort.

The facilities provided at rest areas have advanced with the development of the highway system. A few years ago a rest area was no more than a picnic table with trash containers at the shoulder of the road. "Today, states are providing complete facilities, including ample parking spaces; toilet buildings with flush-type fixtures, lavatories, hand dryers, and drinking water; picnic tables and benches; shelters; cooking grills and fireplaces; public telephones; lighted, landscaped grounds; and the necessary systems for power supply, water supply, and sewage disposal."⁽¹⁾ Motorists now expect complete facilities at rest areas, and because of the response of highway departments to these expectations, rest areas have greatly increased in popularity.

Serious pollution problems may result from the intense use of rest areas because normally they are located in remote areas and their wastewaters discharge into small streams. Rest areas, like other facilities discharging wastes to receiving waters, must meet increasingly stringent water quality standards.

Water Pollution ControlGeneral Technological Review

Organisms found in all natural bodies of water have the ability to oxidize organic material to useful cell material, carbon dioxide, and water if proper inorganic nutrients are present. A simplification of the aerobic oxidation of organics is:



The amount of oxygen required by the bacteria to stabilize biodegradable organic matter is defined as the biochemical oxygen demand (BOD). This parameter is widely used to determine the strength or load of domestic and industrial wastes. A description of the generally accepted test procedure is found in Standard Methods For the Examination of Water and Wastewater.⁽²⁾ Since the biochemical reaction is both time and temperature dependent, a five day incubation period at 20°C is used and results are reported as a 5-day BOD (BOD₅). BOD₅ represents only a portion of the total or ultimate BOD.⁽³⁾ For domestic waste the BOD₅ value is usually 70-80% of the ultimate BOD.

Oxygen is poorly soluble in water, and ranges from 7-14.6 milligrams per liter (mg/l) in fresh water. Because solubility decreases with increasing salinity and temperature, saturation solubilities of less than 6.2 mg/l are possible.^(4, 5) Given the proper conditions, a waste discharge may completely deplete the dissolved oxygen (DO) in a receiving stream and kill aquatic life which depends upon oxygen for survival. Afterwards, organics may begin to decompose anaerobically, which produces objectionable odors.

Because of the significance of dissolved oxygen to the quality of receiving waters, most of the pollution control has been directed toward controlling the DO depletion, or "DO sag," in receiving waters. Stream standards are determined by calculating a maximum organic discharge which will not cause the stream dissolved oxygen to go below some designated minimum. Allowable discharges are calculated using a mathematical model which describes the DO depletion in terms of the reaeration capacity of the stream and the organic load. Most models are variations of the 1925 model presented by Streeter and Phelps.⁽⁶⁾

To meet regulatory stream standards, waste treatment systems have been developed to reduce the organic or BOD load of the discharges. Primary treatment, titled because it was the first treatment method used and usually is applied first in a treatment plant, is a general term referring to physical operations such as screening and sedimentation used to remove floating and settleable solids. Secondary treatment was developed to reduce the soluble organic material which depletes stream oxygen. The main secondary processes are stabilization lagoons, activated sludge systems, trickling filters, aerated lagoons, anaerobic lagoons, and anaerobic contact filters. Theory, application, and operating conditions are covered extensively elsewhere and will not be dealt with here.^(7, 8, 9)

Recently there has been much concern that secondary treatment may not be sufficient to prevent permanent damage to receiving waters. Certain inorganics in domestic and industrial wastes exert a BOD because they require oxygen to be oxidized to a stable form. The main inorganics which exert a BOD are organic and ammonia nitrogen. These use oxygen and a bacterial catalyst to be oxidized to nitrites and nitrates. Although nitrification takes place to a certain degree in most aerobic biological processes, there is

increased opinion that more complete nitrification or nitrogen removal may be necessary to prevent excessive stream degradation and lake eutrophication. Complete nitrification, conversion of all nitrogen forms to nitrates, would eliminate the oxygen demand; however, the nitrogen would still be available to aquatic organisms as a nutrient unless it were completely removed.

The phenomenon of eutrophication, which has contributed greatly to the increased emphasis on further wastewater treatment, occurs in all lakes to varying extents. The biological production caused by high organic and inorganic nutrient concentrations exceeds the capacity of the lake to mineralize the products. This leads to an accumulation of organic matter which settles to the bottom of the lake and gradually fills the lake up, thus converting the body of water to dry land over a long period of time. This natural aging occurs at a highly accelerated rate in some lakes. (10) Although lake aging is quite controversial, most researchers feel that a correlation exists between the phenomenon and the concentration of certain nutrients present, especially phosphorus and nitrogen. (11, 12, 13, 14) The conclusion of many is that phosphorus and nitrogen must be removed from secondary effluents to prevent excessive biological production in lakes and streams.

Tertiary or advanced treatment encompasses operations and processes used to remove contaminants not removed in primary and secondary treatment. (15) The removal of nitrogen and phosphorus from waste streams is included in this general treatment category. (16, 17) In addition, advanced treatment includes removal of fine suspended solids, trace organics, color, heavy metals, radioactive substances, salts, toxic materials, and heat. (18) Since advanced treatment is a relatively new concept, much of the technology is still in the developmental stages. The operations and processes receiving attention for advanced treatment are presented in Figure 1.

Processes do exist which can remove nearly every contaminant from domestic and industrial wastewaters and produce an effluent which meets drinking water standards. (20) At present, capital and operating costs for an advanced treatment system are tremendously high. In order to illustrate this point, four typical municipal wastewater treatment systems are compared in Figure 2. For a large, 80 million gallon per day, municipal treatment plant, primary treatment alone would cost about \$4,500 per day and primary and secondary treatment \$10,000 per day. In order to approach a very good water quality free of both phosphorus and nitrogen, costs would approach \$24,000 per day, or nearly 2½ times the cost of secondary treatment. Generally as the treatment plant gets smaller, the cost difference per million gallons of treated wastewater increases. It also should be stressed that many of the advanced unit operations and processes are highly complex and difficult to control. Experienced and well trained operators are required, which adds additional expense.

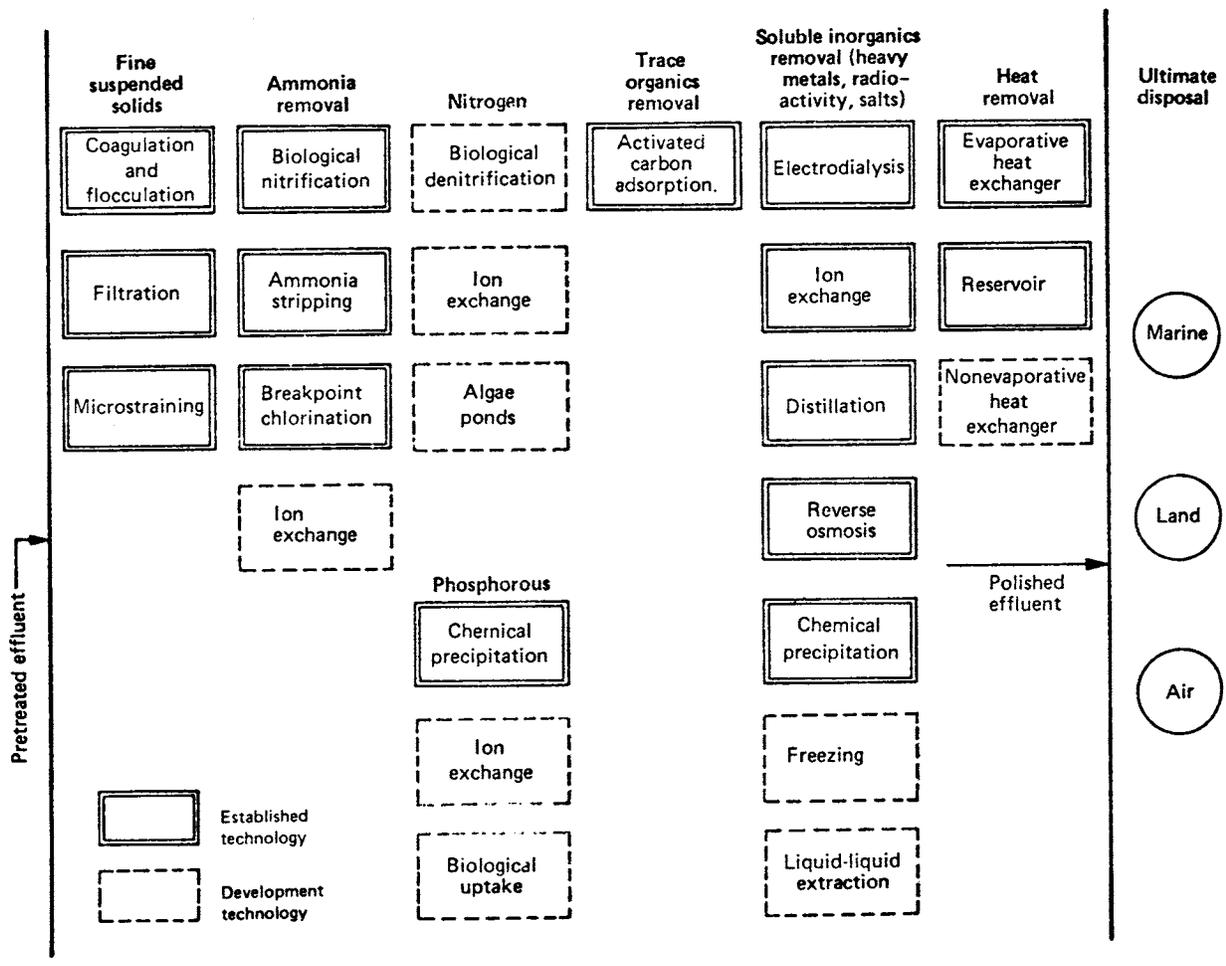


Figure 1. Advanced wastewater treatment alternatives. (From reference 19.)

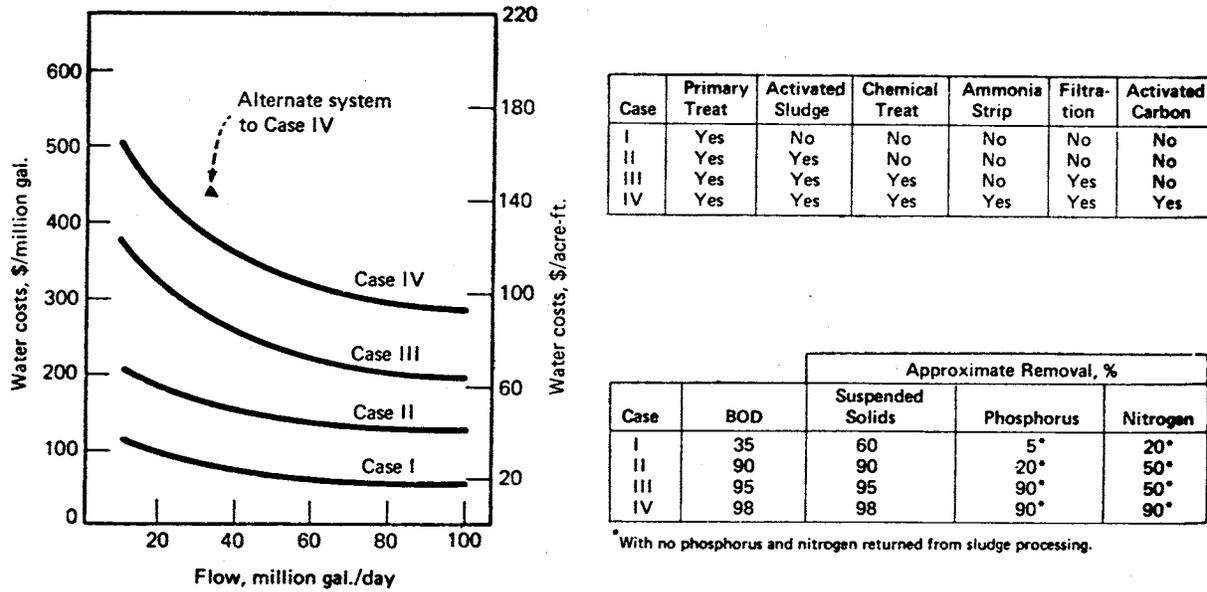


Figure 2. Comparison of costs and economics of size for four systems for treating municipal wastewaters. (From reference 21.)

Rest Area Wastewater Treatment

Despite their increased usage in recent years, highway rest areas discharge very low wastewater flow rates. In the state of Virginia, volumetric flow rates range from 7,500-75,000 gallons per day. The problem is that the wastes are normally discharged into very small receiving streams and thus cause significant pollution problems. Although municipal sewage disposal facilities are used whenever practical, these are not always available due to the remote locations of some rest areas. Various states are presently making use of 11 different systems for rest area waste treatment. (22, 23, 24)

- °Chemical vault holding tanks - 4 states
- °Biological package plants - 20 states
- °Package plants with supplements - 3 states
- °Septic tanks-leach fields - 26 states
- °Lagoons - 21 states
- °Recirculation-incineration - 1 state

°Spray irrigation	-	4 states
°Natural drainageway	-	3 states
°Pit toilets	-	4 states
°Physical, chemical, and combustion processes	-	1 state
°Solar evaporation		

The septic tank-drainage field disposal system has been the preferred method of disposal for rest areas in remote areas due to the simplicity of operation. Because septic tank effluents can infiltrate the ground water table, and clogging may occur where soil porosity is low, other methods are being recommended for future sites. ⁽²⁵⁾ In one state it became necessary to convert 27 of 28 rest areas from septic tanks to aeration package plants. ⁽²⁶⁾

As of February 1, 1973, twenty-three rest areas with sanitary facilities were in operation in the Commonwealth of Virginia. ⁽²⁷⁾ Six used municipal facilities for waste treatment. Twelve used extended aeration biological package plants, three used lagoons, and the remaining two were serviced by septic tank-leach fields.

In the Commonwealth, as in all states, State and Federal effluent and stream water pollution standards have become increasingly stringent. Some rest areas are not open due to inadequate treatment, and others will require further treatment in order to meet stream standards and the 1977 and 1983 effluent standards. ⁽²⁸⁾ Stream standards are normally more stringent than effluent standards when effluents are discharged into small streams, and almost exclusively apply for rest areas. ⁽²⁹⁾

To combat the pollution problem, three pollution control concepts are under consideration in Virginia. Spray irrigation, which has been successfully applied to rest areas in other states, may be attempted at a rest area which uses lagoons. ⁽³⁰⁾ The concept in spray irrigation, which eliminates a discharge directly to the stream, is that treated effluent percolates through the soil, enriching the ground while further treating the waste through filtration and bacterial action. Usually the land requirements are a drawback of this system.

Another possibility is to convert the sanitary facility to either chemical toilets or a mineral oil-incineration system. Chemical toilets which have been used in some states discharge a deodorant chemical upon flushing. Water is reused until such buildups occur that discharging is mandatory. This waste is generally transported to municipal treatment plants. High capital expenditure and possible operating problems make this system less attractive than first anticipated. ⁽³¹⁾

Originally designed for use on ships, the mineral oil-incineration system basically replaces water with a colored mineral oil. The waste is gravity separated out of the mineral oil and incinerated while the oil is recycled and reused. The system is being used at a new rest area in Texas where no treatment facilities had been installed. Although no operating problems have occurred, ⁽³²⁾ it is too early to determine the system's effectiveness at the rest area. Although specific details are not available, Maryland has recently decided that the ⁽³³⁾ use of the mineral oil-recycle system would be unacceptable for rest areas. Advantages of such a system may be no discharge directly to the stream, and greatly reduced water usage. However, because the system makes no use of existing treatment systems, the capital expenditure is significant and may make the system impractical for applications to rest areas which already include some form of waste treatment.

The third concept under consideration in Virginia is a recycle and re-use system which can be ⁽³⁴⁾ added directly to rest areas already equipped with secondary treatment. It has been determined that approximately 90-95% of the water usage at rest areas is for flushing toilets. ⁽³⁵⁾ The proposal being investigated is that extended aeration effluent should be of sufficient quality, with little additional treatment, for flushing toilets at highway rest areas. Advantages to this system would be greatly reduced water usage, and reduced volume of wastewater discharged to streams. The capital cost should be minimal when the system is applied to rest areas which already employ secondary treatment. Because this proposal is the foundation for the research covered in this report, it will be discussed in more detail later.

Rest Area Water Supply and Use

Water supply is an increasing problem in most parts of the world. As early as 1955, drought conditions in the United States caused tremendous water supply problems. ⁽³⁶⁾ Industrial use of water has increased drastically since World War II. In 1968, 75% of the 60,000 billion gallons of water used industrially was for cooling purposes. ⁽³⁷⁾ Estimates are that by 1980 the cooling water requirements of industry alone will equal the fresh water runoff of 1,200 billion gallons per day. ⁽³⁸⁾

In addition to these industrial uses, municipal needs are increasing as a result of population increases and the migration of people from rural areas to the cities. The population of the United States doubled from 1915 to 1968 and is expected to increase by the same amount by the year 2000. ⁽³⁹⁾ It is becoming increasingly difficult to maintain adequate water supplies in high demand areas. For example, Denver has undergone substantial growth while 50% of Colorado counties have lost population. ⁽⁴⁰⁾ Figure 3 indicates that water demand will surpass present water supply around the turn of the century in the Denver area if additional supplies are not found. ⁽⁴¹⁾ This illustration typifies the supply-demand situation for many areas like Denver.

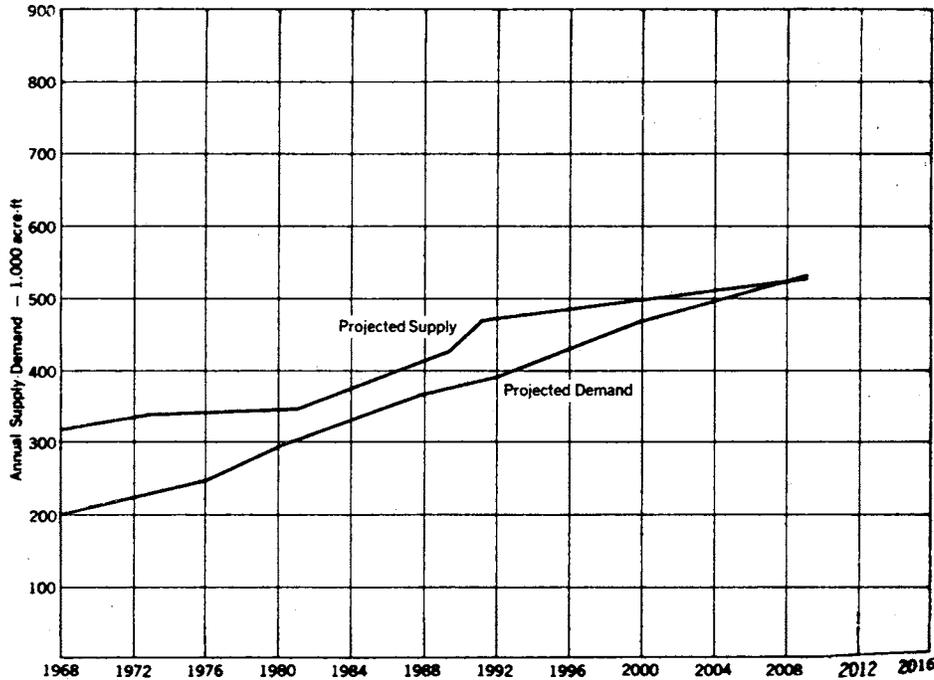


Figure 3. Comparison of Denver's raw-water requirement and supply projections. (From reference 41.)

Rest area water problems are similar to those of the nation's cities but on a smaller scale. Increased water usage due to increased popularity and traffic makes water supply a significant problem. Although it is highly desirable to make use of municipal water supplies whenever possible, they will rarely be available in larger states where rest areas must be placed in remote areas. Most rest areas without a municipal water source must rely on drilled wells. (42) Because rest areas fluctuate drastically with hour-of-the-day, day-of-the-week and month-of-the-year water usage, storage requirements are hard to predict and satisfy. The state of Washington reported that many of the rest areas were using from 4-5 times the amount of water in August as in January. (43) The minimum daily flow for one rest area was reported as 50 cubic feet per day (375 gallons) while the maximum daily flow for the same rest area was 1,370 cubic feet per day (10,275 gallons). Unless water supplies are carefully planned, it is possible to run out of water at a rest area during a peak demand period. One rest area in the state of Virginia ran out of water on four separate occasions in 1973, requiring approximately 9,000 gallons of water to be hauled in by truck at an expense of 2¢ per gallon. (44) Another area in Virginia found it necessary to add additional storage capacity to prevent water shortages. (45) A few rest areas are presently closed due to an inadequate water supply.

Reuse of Water At Highway Rest Areas

As previously mentioned, it has been proposed that secondary effluent can be recycled and reused for flushing toilets at highway rest areas. The water supply problems of rest areas should be alleviated if this program is successful. Water usage should be sharply reduced so as to eliminate the possibility of running short of water and to provide a significant cost savings. In addition, the reuse of water could greatly reduce or eliminate the hydraulic and organic load on the receiving streams. The organics and nutrients would be more concentrated in the reduced effluent flow rate, making advanced treatment much more economical if required in the future. As previously mentioned, the recycle system proposed is readily adaptable to existing water and wastewater systems at nearly every rest area in the state.

The proposed demonstration wastewater recycle project is scheduled to begin some time during calendar year 1974 at the Fairfield rest area on Interstate 81, located in Rockbridge County just north of Lexington, Virginia. This site was selected because:

- ° It experienced several days of water shortage during peak water use.
- ° It is a relatively new facility and its wastewater treatment system is presently operating below design capacity.
- ° It is relatively close to the Virginia Highway Research Council and the University of Virginia, which will conduct the field research.
- ° Because it services only one side of the interstate, connections underneath the road surface will not be necessary.
- ° The waste treatment system used is an extended aeration biological treatment system typical of those in other areas. It is readily adapted to the recycle system.
- ° The waste treatment system presently incorporates the use of a 15-day polishing pond that may be converted to an emergency holding pond to prevent undesired discharges.

The wastewater treatment system at the Fairfield rest area, shown schematically in Figure 4, is a standard, biological package plant, extended aeration arrangement. Presently the wastes are flushed from the toilets and urinals by water from the potable supply to a common sewer, where they combine with wastewater from the sinks and flow by gravity to the treatment plant. No primary settling of suspended solids is used. The extended aeration unit consists of a quasi-completely-mixed aeration tank designed for 20-24 hours of aeration time. In the aeration basin the organic waste is

converted to bacterial cell material and carbon dioxide by the concentrated biological population. The effluent overflows the aeration basin into a clarifier, where most of the bacterial sludge solids are separated from the liquid. Presently, the cell sludge is entirely recycled with only occasional sludge wastage and the effluent flows into a polishing pond. This pond provides further stabilization before chlorination and discharge to a small creek.

The proposed water reuse system would return the effluent from the aeration basin to a pressurized storage tank and use the effluent for flushing toilets after suspended solids removal and chlorination. A simplified diagram of the reuse schematic is shown in Figure 5. The storage tank provides equilibrium and a reserve capacity for flow balance. If needed, make-up water may be added at this point to improve the quality of the water. A detailed schematic diagram of the field design is included as an appendix.

As with any reuse system, there are many questions which can be answered only in actual operation. A necessary and essential step before field exploration and demonstration is a bench scale evaluation to assess design and operational variables. The results presented in this report are from the evaluation of a bench scale recycle and reuse system.

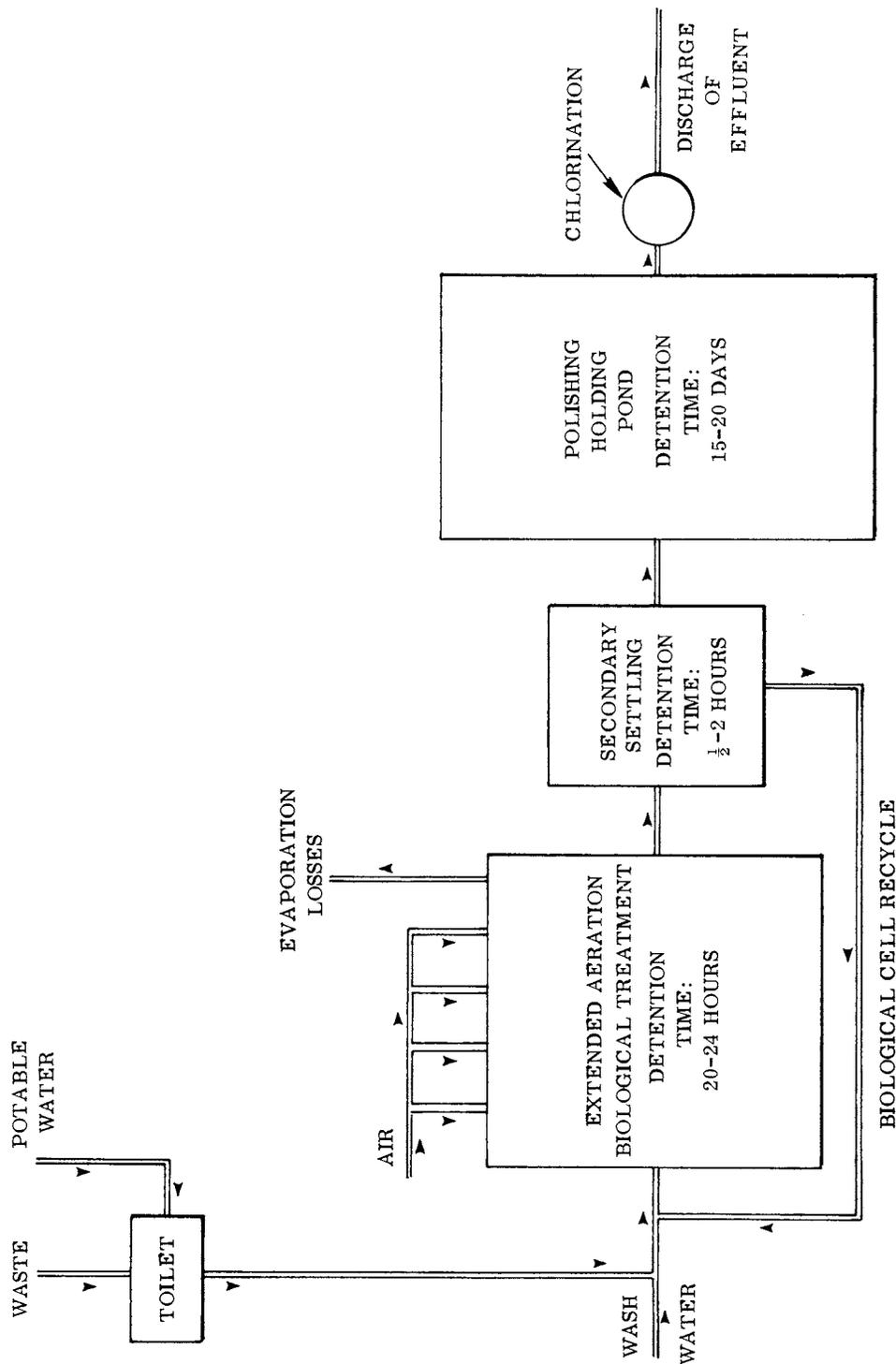


Figure 4. A typical biological package wastewater treatment plant used at highway rest areas.

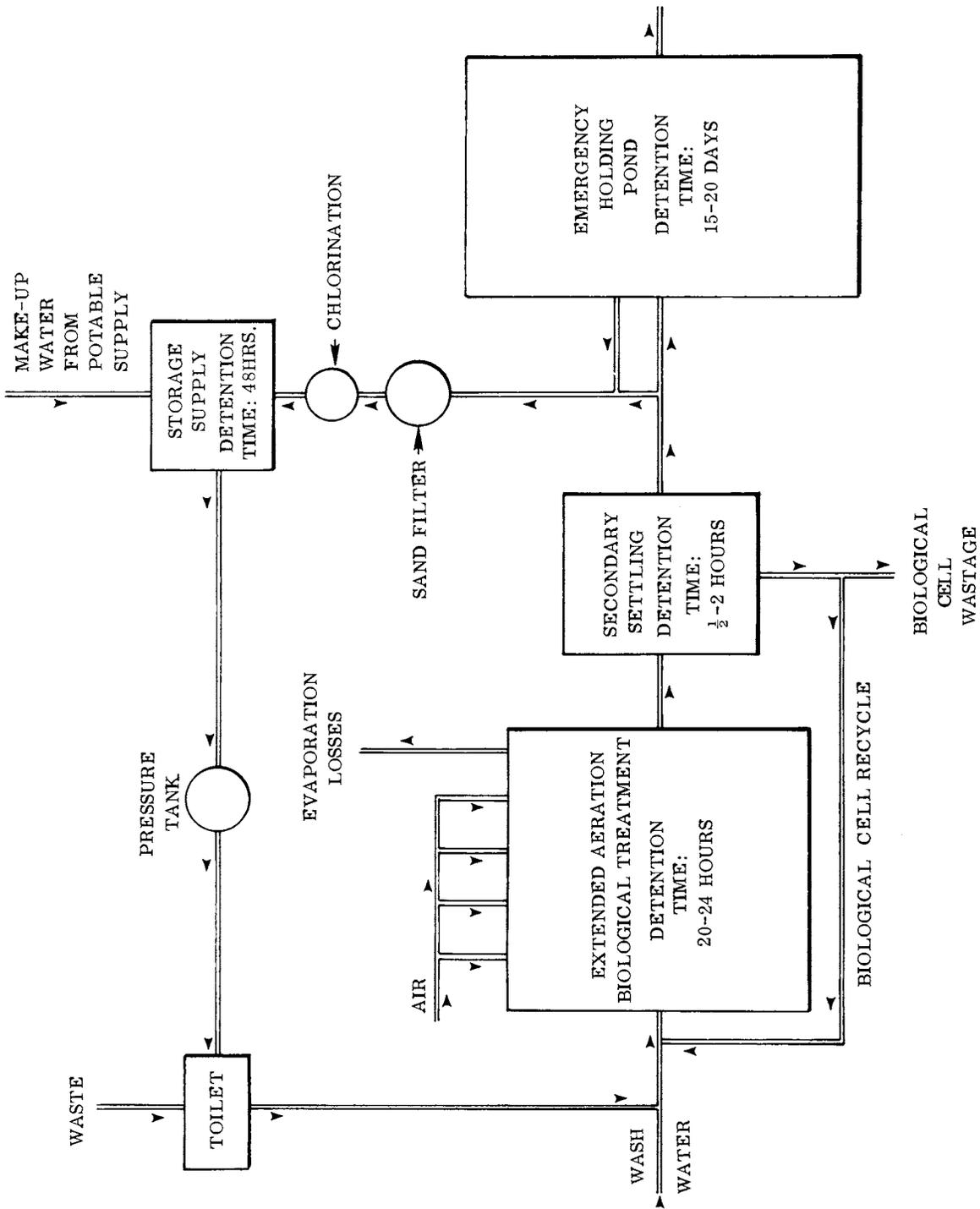


Figure 5. A possible recycle wastewater treatment system for use at highway rest areas.

PURPOSE AND OBJECTIVES

The purpose of this research was to investigate the effects of recycling water at highway rest stations on the biological treatment system and the quality and stability of the water produced. Recycling inherently builds up substances in the recycled water which, although trivial at normal concentrations, become significant at high recycle ratios. Through a simple material balance calculation it can be shown that with 90% recycle the nondepletable materials should reach equilibrium concentrations of ten times their initial concentrations. ⁽⁴⁶⁾ It is possible that substances which normally have no effect on biological activity may become an inhibition to bacterial efficiency or even become toxic to the organisms at these higher concentrations.

The buildup of substances due to recycling may cause significant precipitation of substances when their concentrations exceed their solubility product. The solubility product concept is well-known and will not be repeated here. ^(47, 48) Let it suffice to mention that as concentrations of a substance increase, saturation is reached, and additional increases will cause precipitation to occur. The stability of an aqueous solution generally refers to the ability of the water to dissolve or precipitate calcium carbonate. ⁽⁴⁹⁾ This definition will be extended here to include all substances which might be precipitated. Precipitates may not only cause restricted pipe lines with resultant high pressure drops, but may cause stains and clog sand beds. However, precipitation could result in a better quality of water.

The quality of water produced is most important because, besides the engineering significance, it must meet certain aesthetic requirements.

- *It must produce no objectionable odors.
- *It must contain no objectionable colors, real or apparent.
- *It must not foam.
- *It must be biologically stable with a low bacterial count.

A laboratory pilot plant was operated in order to investigate the following objectives:

1. Determine the effects of recycling water on a biological treatment system.
2. Determine the effect of recycling on the chemical stability of the water produced.
3. Determine quality changes resulting from different recycle ratios.
4. Determine previously undiscovered problem areas in the field design and operation.

5. Find a suitable dye which would distinguish the recycled water from the potable supply and appear aesthetically pleasing.
6. Determine limiting organic removal with generally accepted mixed bacterial cell concentrations maintained under aeration.

LITERATURE REVIEW

General

Presently there are no effluent recycle systems employed at highway rest areas in the United States. However, recycle systems have been effectively employed at other facilities. ⁽⁵⁰⁾ Although water reuse programs have been employed at highway rest areas, none have ⁽⁵¹⁾ treated the wastewater, recycled it, and reused it for flushing toilets.

Water recycle, reuse, reclamation, and multiple use are terms which are often used interchangeably, but, strictly speaking, these terms are not synonymous. Multiple use implies use more than once, but each time for a different purpose. This type of reuse is done because processes are available which require progressively lower quality water. Recycle implies water usage over and over for the same application. An industrial example of these concepts can be seen in Figure 6. Reclamation, which normally precedes either recycle or reuse, implies quality improvement through impoundment or processing. Examples of reclamation are polishing ponds, chemical treatment, and filtration.

There are several general categories of wastewater disposal means which are considered reuse systems. Municipal effluents have been used for agriculture irrigation, groundwater recharge lawn sprinkling, industrial ⁽⁵³⁾ cooling, recreational lakes, domestic water supply, and toilet flushing.

Water use methods

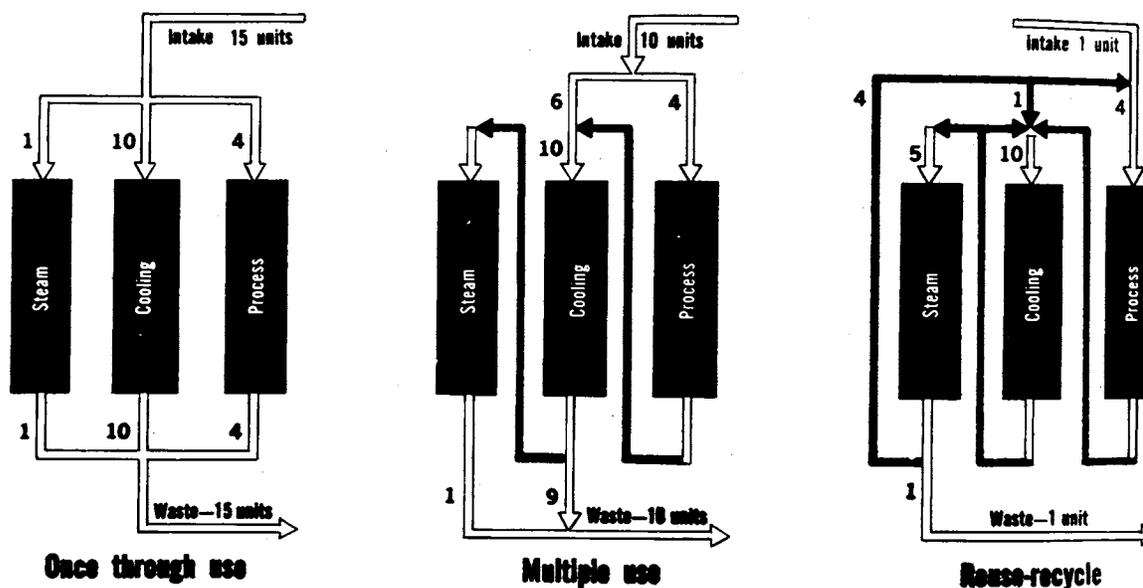


Figure 6. Differentiation of multiple water use and recycle.
(From reference 52.)

Industrial Reuse

The three major categories of water usage by industry are process water, steam, and cooling water. (54) The cooling water requirement for all industry is about 67% of the industrial usage, and in the chemical and petroleum industries between 80-90%. The quality of process water and cooling water generally must be extremely high, sometimes even higher than that of drinking water. Due to increased demand and reduced supply of high quality water, industrial reuse programs have increased. Although industrial water supplies are generally obtained from potable supplies, wells, and rivers, plant or municipal effluents have been reused for cooling and process water without reclamation. (55, 56, 57, 58) In some cases, biological or chemical treatment is required to upgrade effluents for reuse. (59, 60, 61) Chemically treated secondary municipal effluent has been used as a supply for multiple uses by industry. (62, 63, 64) Effluent from an Amarillo, Texas, activated sludge treatment plant has proven a dependable and satisfactory source of industrial cooling and process water. (65)

Municipal Reuse

Unintentional reuse of wastewaters has existed for as long as communities have settled along rivers. The wastewater discharged to the receiving stream by one community is reused by the community downstream as a water supply. Of course the wastewater must be highly diluted and sufficient time and dissolved oxygen must be available for complete oxidation. In urban areas, population growth increases the loads on the receiving streams and water quality worsens. High wastewater flow rates which are discharged to small streams make water resource and water quality control planning necessary.

Many states have extensive reuse programs to conserve water and prevent water pollution. California has had a reuse program since the turn of the century, mainly using municipal wastewater effluent for irrigation purposes. (66) Because of the shortage of water supply in certain areas of the state, the program in California is quite extensive. (67) Denver, which has had a very active water reuse program, employs a 10 mgd industrial reuse system. (68) The industrial water quality requirements dictate removal of dissolved solids and nitrification in addition to normal secondary treatment. (69) The plant is being expanded to 100 mgd with the eventual purpose of using the reclaimed water as a potable supply. (70) More advanced treatment unit operations will be added to the present treatment system to upgrade the effluent quality for drinking purposes.

Soil percolation and groundwater recharge are often used in areas where soil is porous and groundwater tables are deep. (71, 72) A Florida rest area reportedly sprays secondary effluent into a nearby forest, where the treated waste percolates through the soil. (73)

At Grand Canyon Village on the south rim of the Colorado River, wastewater has been recycled for various purposes, including toilet flushing, since 1924. (74) Due to the geological slope, there are few springs on the south wall of the canyon. Ironically, the south wall is the more accessible and, therefore, the more frequented by visitors. Because well drilling has yielded no water, a scarcity of water exists in this area. The reclaimed water is generated by treating domestic waste with conventional activated sludge followed by anthracite coal filtration and chlorination. Public acceptance has been good because the quality of water has been unobjectionable.

Municipal waste treatment effluent was used as the source for potable water in Chanute, Kansas, during a severe drought in the 1950's. (75) The city of Chanute, population 12,000, obtained its water supply exclusively from the Neosho River, but in 1956 the river ceased to flow due to a four-year drought. After all other conservation programs had been tried to maintain the water demand of 1.4-2.0 mgd, arrangements were made to discharge the sewage treatment effluent into the holding pond which served as the water treatment plant influent. A schematic of the resulting recycle system is shown in Figure 7. The municipal wastewater treatment plant consisted of

normal primary treatment, trickling filter secondary treatment, and secondary clarification. The water treatment facility included primary settling, chemical softening, recarbonation, secondary settling, rapid sand filtration, and chlorination.

The recycle process was employed for five months, in which time the same water passed through the treatment plant about seven times. (77) The treated water was colored and tasted unpleasant. It foamed when agitated and had a slight odor. Although drinking water was shipped in and sold in jars during the drought, the recycled water was available through the distribution system. There were no known reports of adverse health effects resulting from the use of the water.

More recently, Windhoek, South-west Africa has employed advanced treatment to augment the water supply due to a scarcity of surface resources. (78, 79) In 1968, the city began reclaiming 1.4 mgd of wastewater, or one-third of the city's total water supply. (80) The reclamation treatment plant includes flocculation-flotation, foam fractionation, lime treatment, disinfection, settling, sand filtration, activated carbon treatment, and final chlorination. The effluent, which easily meets standards of the World Health Organization, is used as a normal potable supply, which includes drinking water.

At Pikes Peak, Colorado, a 5,000 gallon per day test package plant is employed to treat wastewater from a tourist shop and produces a water of sufficient quality for secondary needs such as flushing toilets. (81) The purpose of the reuse is to reduce the pollution load and minimize the need for trucking water up to the 14,110 foot summit from Colorado Springs. The portable package plant, developed by Dorr-Oliver, consists of conventional activated sludge followed by ultrafiltration. The activated sludge-ultrafiltration process, named the IOPOR system, produced a water which contained only 1 mg/l BOD₅, .1 mg/l suspended solids and a coliform count of 1 per 100 ml during a 30-day test run before recycling began. The ultrafiltration unit, which follows screening of the activated sludge biomass, consists of cartridge filters using a thin film as the filter media. Bacteria and viruses are removed under 20-50 psig pressure. The system apparently requires little operator follow-up since the activated sludge portion can operate effectively over a wide range of solids. Additional process units such as nitrogen and phosphorus removal can be added without modification of the present process.

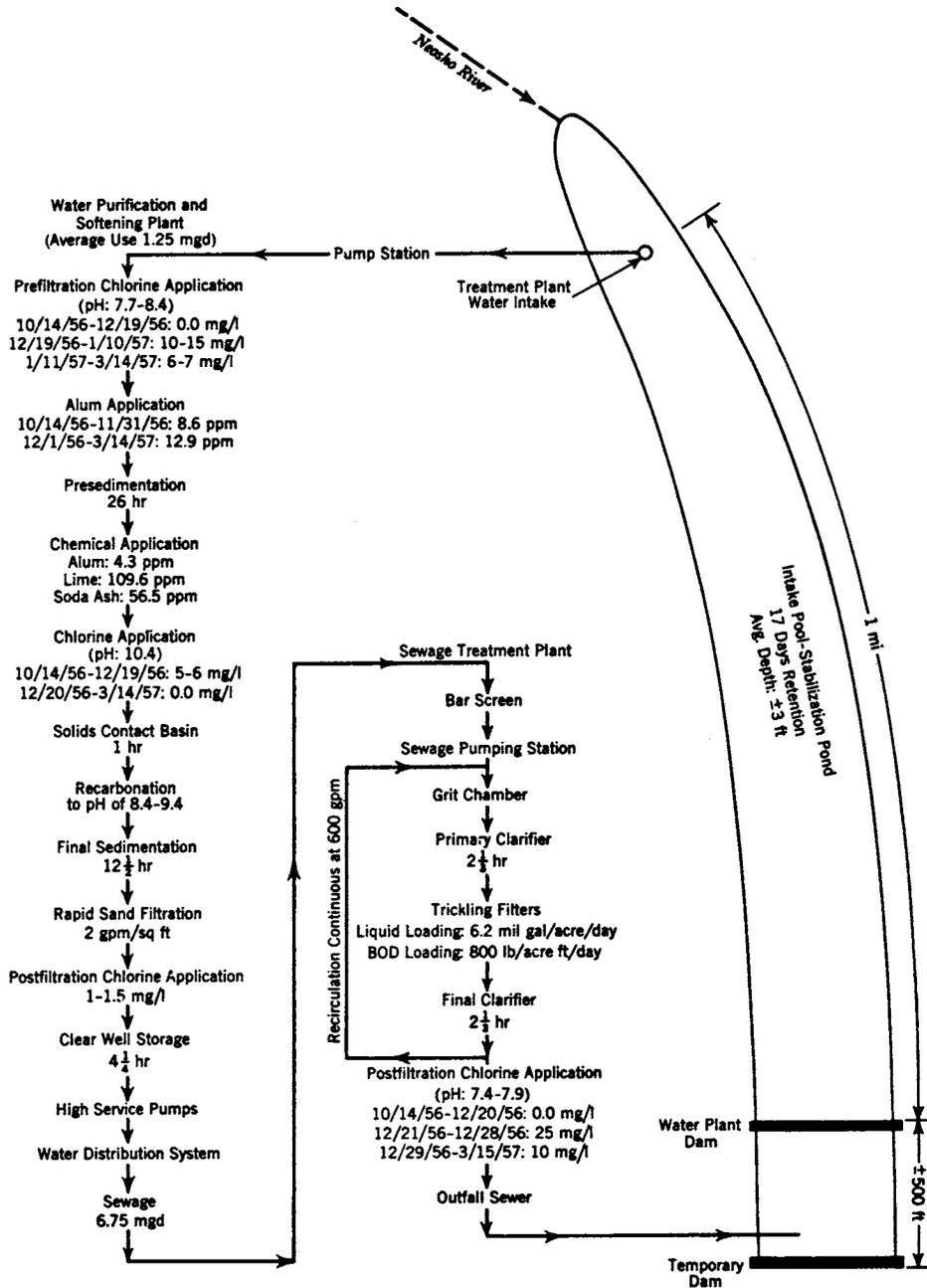


Figure 7. Flow diagram of water recycling system at Chanute, Kansas. (From reference 76.)

Two locations in California reuse municipal wastewater as the main source for recreational lakes. In San Diego County, the municipal wastewater is discharged after treatment to recreational lakes to serve Santee's population of 13,000 people. (82) Following conventional activated sludge treatment, the effluent is improved in a 30-day polishing pond. About half of the .9 mgd effluent is sand filtered and discharged to a series of four lakes. The water separated from the last recreational lake is chlorinated for swimming purposes. Although the additional treatment brings the efficiency of organic removal up to 98%, significant nutrient concentrations exist in the recreational lakes. Nitrogen concentrations in the lake influent average 2.3 mg/l while phosphorus concentrations run about .6 mg/l. Although these concentrations may not seem large, they apparently are high enough to cause significant algal blooms. Not only do these occasional blooms prove a nuisance, but at least two fish kills have occurred due to excessive oxygen depletion because of exorbitant biological activity in the lake. Significant algal growth causes a "nutrient trap" to occur that results in nitrogen and phosphorus buildups in lakes. (83) In this case, much of the influent nutrients are unaccounted for in the outflow, and accelerated eutrophication has resulted.

In contrast, at South Lake Tahoe, California, a reservoir supplied principally by reclaimed wastewater effluent supports a population of rainbow trout and has no algae problem. (84) The difference is that the reclamation plant is one of five full-scale advanced wastewater treatment plants in the United States producing an effluent which nearly meets the drinking water standards. The plant removes 99.4% BOD₅, 99.1% phosphorus, and 100% of suspended solids, color, odor, coliform bacteria, and viruses. Nitrogen concentrations are reduced to .2 mg/l. The processes employed at Lake Tahoe to produce this high quality of water are;

- *Primary settling
- *Conventional activated sludge
- *Lime chemical treatment and coagulation
- *Air stripping of ammonia
- *Mixed bed filtration
- *Activated carbon adsorption
- *Chlorination
- *Reclamation for coagulant recovery
- *Activated carbon regeneration
- *Sludge incineration

The tremendously high cost of the advanced wastewater treatment necessary to produce an effluent comparable to that of Lake Tahoe has been covered in a previous section.

Much work has been done on the closed loop recycle of wastewaters for domestic use by the space industry. (85) Since the late 1950's space researchers have been working on regeneration systems for wastes to prepare for long-term space flights. Although none of the systems have been used on a space craft, many nonbiological systems have been developed. Filtration, distillation, chemical treatment, and combinations of these have been used to recover 85-100% of various domestic wastewaters as drinking water. Most of the units tested can operate on flow rates comparable to that of a single household. (Some researchers (86) feel that a viable alternative to the regional treatment concept would be a recycle system for each home. This would greatly reduce the waste transportation cost, which can amount to one-half the treatment cost.) A system recently developed by the Atomic Energy Commission includes a small nuclear reactor which uses Plutonium 238 to convert domestic wastes to potable water. (87)

A recycle system has proven to be the answer to a domestic wastewater problem at a weather station at Point Barrow, Alaska. (88) Due to the high cost of water (6¢ per gallon), only primitive wastewater collections systems were practical in the remote areas of Alaska. The recycle system installed to relieve this problem includes a 1,500 gpd batch aeration unit, secondary settling, and chlorination. The effluent, which is recycled to the toilets through a heat exchanger to prevent freezing, appears clear and odorless. The cost of the project, designed and built by the National Weather Service, was \$90,000.

A multiple use concept has been tested for use in homes in which water from household uses was stored and reused for toilet flushing. (89) About 45% of the water in a home, which consumed 180-200 gpd, was used for toilets and lavatories. The remaining amount was employed for all other household uses, including drinking, cooking, laundry, and dishwashing. Initially the water was considerably foamy but a switch to low foaming detergents eliminated that problem. The water was grey in color but was unobjectionable in odor.

Public attitudes toward the reuse of municipal wastewater are not well documented. It appears that public acceptance hinges on the acuteness of the water need, the intimacy of use, and degree of education on the subject. Two towns in California were surveyed to evaluate public acceptance toward water reuse. (90) An average of 10% of the people interviewed were opposed to water reuse for lawn irrigation, and 12% opposed toilet flushing with recycled water. Surprisingly, only 28% of the people disliked the idea of using reclaimed water for recreational swimming. Over half (54%) of the people opposed reclaimed water as a potable supply.

THEORY OF RECYCLE

The concept of recycle has been used by engineers to improve yields in chemical production for many years. The theory and mathematics can be quite sophisticated when applied to multicomponent and multiphase reactions. (91) In many cases in chemical production unreacted raw materials are separated from the products and recycled to the reactor. The result is that raw materials are conserved and the reactor feed is enriched. The kinetics of the reaction generally depend on the reactant concentration so the cost savings include increased yields and smaller reactor vessel requirements. A limitation of recycle is that inert materials will inevitably accumulate to high concentrations unless purged from the system. (92) Therefore, a recycle system consisting of raw material supplies, a reactor, and recycle lines, must also include a blow-down line. The blow-down line may contain the desired product, or this product may be withdrawn separately.

Essentially the same concepts apply and the same operations are required when waste treatment effluent is recycled. The bleed-off can be from effluent losses or sludge wastage if biological treatment is employed. The mathematics simplify a great deal when wastewater effluent is the only stream being recycled and organic waste is the limiting raw material. A simplified recycle flow diagram is shown in Figure 8. The differential equation, which can be derived for the accumulation of any reactant or inert material, is set equal to zero when steady state is reached. The equation simplifies to a material balance outside the recycle loop. Using reactant S as an example:

$$\text{accumulation} = (\text{inflow}) - (\text{wastage}) - (\text{amount reacted})$$

$$\frac{ds}{dt} = [S_{\text{makeup}} + S_{\text{added}}] - [S_{\text{wasted}}] - [S_{\text{reacted}}] \quad (2)$$

$$\text{at steady state } \frac{ds}{dt} = 0$$

$$S_{\text{makeup}} + S_{\text{added}} = S_{\text{wasted}} + S_{\text{reacted}} \quad (3)$$

Mass balances for water and wastewater recycle systems which have been reported can be complicated unless simplifications are made. (93, 94) For example, if S represents organic material, the amount in the makeup water should be so small that it may be ignored when potable water is used as the supply.

The inert substances in wastewater will depend upon which unit processes are used to treat the water. Since the major pollutant in domestic waste is organic carbon, biological treatment of some form is generally employed. The inert substances which build up in a recycle system employing bio-treatment are both non-biodegradable organics and inorganic solids.

In aerobic biological waste treatment, the majority of organic conversion is accomplished by heterotrophic bacteria. The biochemical reaction, which was presented in a previous section as equation 1, shows that the prod-

ucts of the reaction are carbon dioxide, water, and ammonia. In addition, bacterial cells use organics and some inorganics as cell material. The bacterial cell has been estimated to be about 80% water and 20% dry material, of which 90% is organic and 10% is inorganic. ⁽⁹⁵⁾ Therefore, while appreciable quantities of inorganic salts are used for cell metabolism, considerably more carbon is required than inorganics. Because domestic wastes normally contain appreciable amounts of inorganic salts, microbial growth in most biological processes which treat domestic waste are limited by the carbon concentration. The salt concentration present is much greater than the amount removed by the cells, so for practical purposes fixed solids are inert to biological processes. (The effects of this buildup during wastewater effluent recycle will be discussed in more detail.)

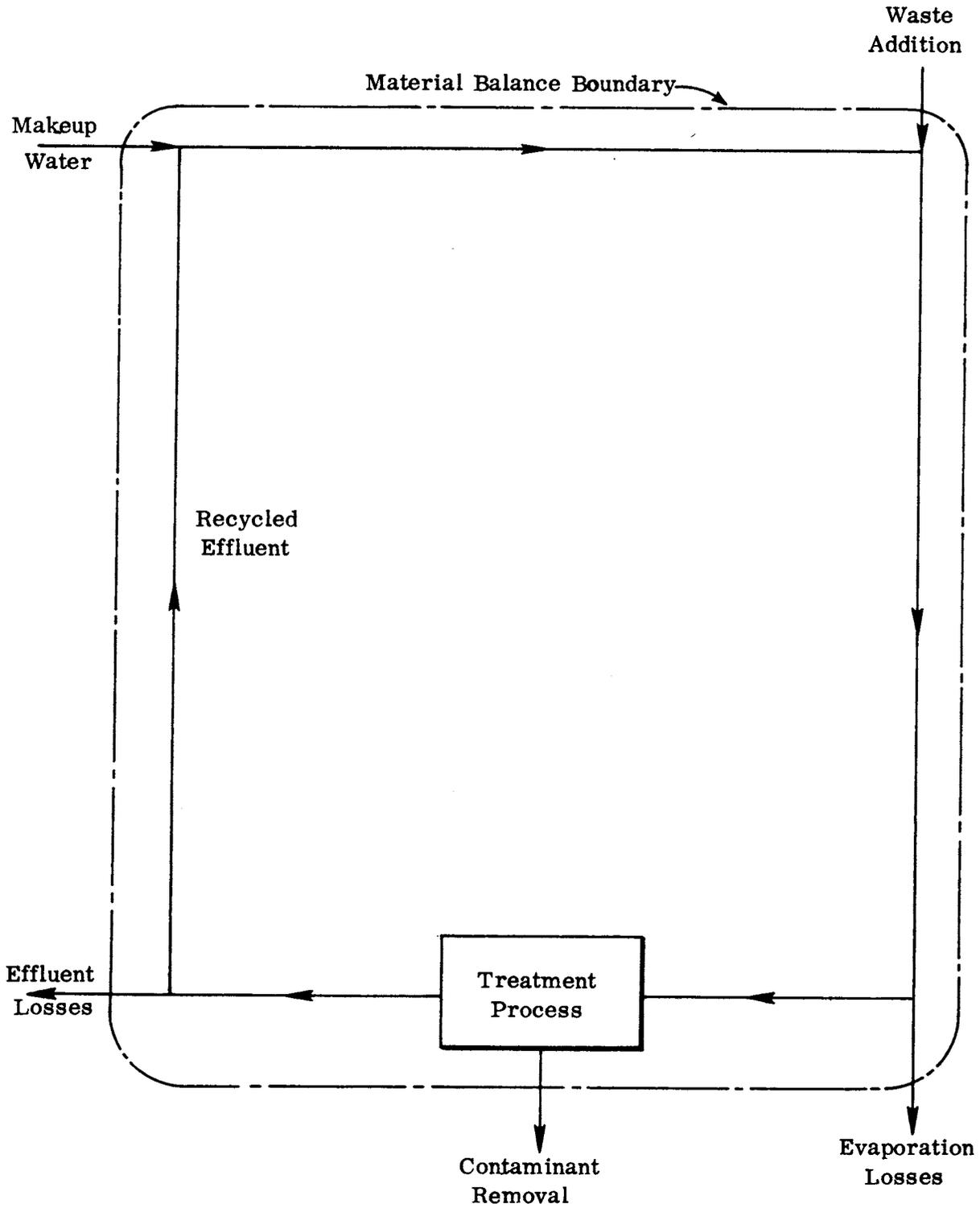


Figure 8. A simplified water recycle flow diagram.
(From reference 110.)

EXTENDED AERATION BIOLOGICAL WASTEWATER TREATMENT

Extended aeration is a modification of the activated sludge biological process that is primarily used for relatively low flow rates in isolated locations to produce a high quality effluent with little operator attention. The conventional activated sludge process is an aerobic biological treatment process in which an activated biomass is maintained through aeration and partial cellular recycle. (86) The wastewater or substrate is mixed with the biological population to form the mixed liquor in which the cells use the oxygen from the supplied air to stabilize the waste material. The aeration, either mechanical or diffused, also serves to suspend the biomass, and thus increase the contact time between the waste, oxygen, and cells. The effluent from the reactor is clarified, and the settled cells or secondary sludge is recycled. Part of the recycled cells are wasted in order to control the balance between the cells and substrate (food-to-mass ratio).

The recycling of cells is employed to maintain a high population of cells in the reactor. Cell wastage keeps the average age of the cells in the proper growth phase, and maintains the proper substrate to micro-organisms ratio. If the average sludge age is too low, the stabilization efficiency will be low. If the sludge age is great, most of the cells will be in the endogenous respiration phase in which the cells may make use of their own biomass for metabolism.

The extended aeration modifications to the activated sludge process can be seen best by comparing Figures 9 and 10. In extended aeration the influent flow rate (Q) and the effluent flow rate are equal since no cells are wasted. ($Q_w = 0$). When total recycle of cells is employed, the sludge age becomes infinite and the cells remain primarily in the endogenous respiration phase. The food to mass ratio is kept low so that the cells will make use of the biomass as food. A 24-hour detention time to oxidize both the cells and substrates is used in extended aeration instead of the conventional 3 to 8 hours. Since little sludge is wasted, extended aeration units are considered easier to operate than conventional activated sludge processes. Disadvantages of the system are higher aeration and power requirements and larger reactor volume requirements. As a result extended aeration units are normally best suited for relatively small flow rates such as housing developments and highway rest areas. Completely mixed units are generally used to dampen fluctuating hydraulic and organic loads.

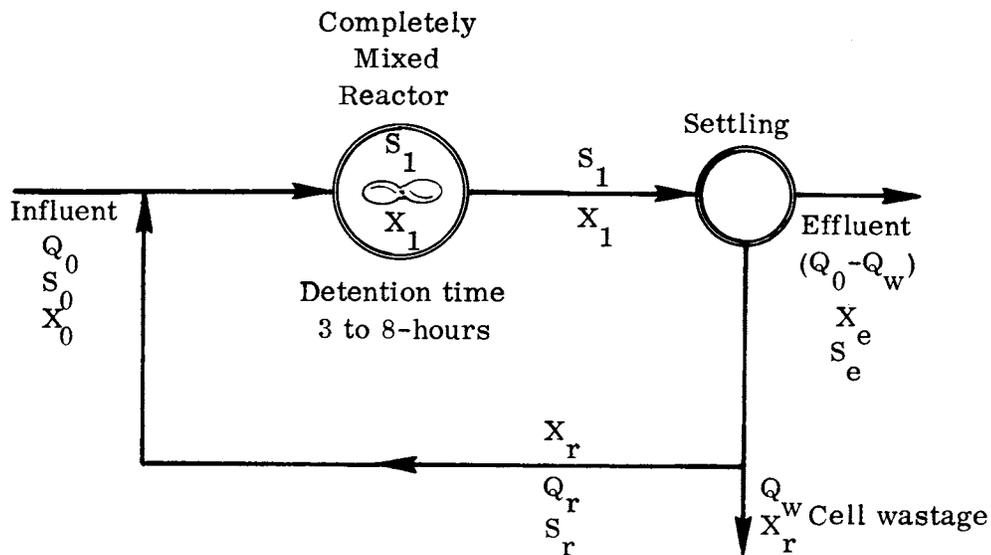


Figure 9. Conventional activated sludge.

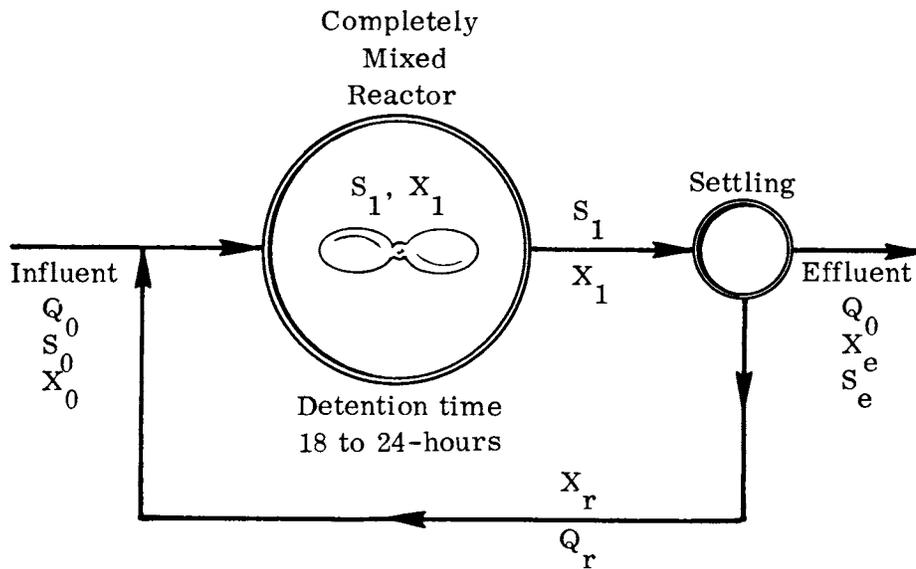


Figure 10. Extended aeration modification

Growth Kinetics of Biological Treatment Systems

The growth kinetics of activated sludge have been extensively reported. (97, 98, 99) Generally the developments involve a cell and substrate balance in terms of growth kinetic parameters. The following derivations with reference to Figures 9 and 10 are intended to illustrate the mathematics of biological treatment and differences between conventional activated sludge and extended aeration.

Definition of Terms

- Q_o - influent volumetric flow rate
- Q_w - wastage volumetric flow rate
- Q_r - recycle volumetric flow rate
- S_o - influent substrate concentration
- S_1 - reactor mixed liquor and effluent substrate concentration
- S_e - clarifier effluent substrate concentration
- X_o - influent biomass concentration
- X_1 - mixed liquor and reactor effluent biomass concentration
- X_e - clarifier effluent biomass concentration
- X_r - recycle biomass concentration
- V - reactor volume
- θ - reactor hydraulic detention time

The material balances make use of the following fundamental bacteriological relationships:

$$\frac{dx}{dt} = \mu X \quad (4)$$

$$\frac{dx}{dt}_{\text{growth}} = Y \frac{ds}{dt} \quad (5)$$

$$\frac{dx}{dt}_{\text{respiration}} = K_e X \quad (6)$$

where;

μ - specific growth rate

Y - yield coefficient, mass of cells produced per mass substrate utilized

K_e - endogenous respiration rate

A cell balance for conventional activated sludge yields;

$$\left[\begin{array}{c} \text{net change in} \\ \text{biomass per unit time} \end{array} \right] = \left[\begin{array}{c} \text{increase from} \\ \text{influent} \end{array} \right] + \left[\begin{array}{c} \text{increase from} \\ \text{growth} \end{array} \right] - \left[\begin{array}{c} \text{decrease due} \\ \text{to wastage} \end{array} \right] - \left[\begin{array}{c} \text{decrease due} \\ \text{to clarifier losses} \end{array} \right]$$

$$V \left(\frac{dx}{dt} \right)_{\text{net}} = Q_o X_o + V \left(\frac{dx}{dt} \right)_{\text{growth}} - V \left(\frac{dx}{dt} \right)_{\text{respiration}} - Q_w X_r - (Q_o - Q_w) X_e \quad (7)$$

substituting from equations 4 and 6 and dividing by V ;

$$\left(\frac{dx}{dt} \right)_{\text{net}} = \frac{Q_o X_o}{V} + \mu X_1 - K_e X_1 - \frac{Q_w X_r}{V} - \frac{Q_o - Q_w}{V} X_e \quad (8)$$

The concentration of cells entering in the influent is generally quite small ($X_o = 0$) and may be neglected.

$$\left(\frac{dx}{dt} \right)_{\text{net}} = (\mu - K_e) X_1 - \frac{Q_w X_r}{V} - \frac{Q_o - Q_w}{V} X_e \quad (9)$$

If the secondary settling is satisfactory, the number of cells lost in the effluent should be insignificant. ($X_e = 0$) At steady state the net change in cells is zero, and

$$\mu - k_e = \frac{Q_w X_r}{V X_1} \quad (10)$$

The product VX_1 represents active biomass while the product $Q_w X_r$ is the wasted biomass. The ratio of the active mass to wasted mass is defined as average cell detention time or sludge age, θ_c .

$$\theta_c = \frac{VX_1}{Q_w X_r} \quad (11)$$

Substituting in equation 10.

$$\mu = \frac{1}{\theta_c} + k_c \quad (12)$$

A similar material balance for the substrate yields;

$$\left[\begin{array}{c} \text{net change in} \\ \text{substrate} \\ \text{per unit time} \end{array} \right] = \left[\begin{array}{c} \text{increase} \\ \text{from} \\ \text{influent} \end{array} \right] - \left[\begin{array}{c} \text{decrease} \\ \text{from} \\ \text{effluent} \end{array} \right] - \left[\begin{array}{c} \text{decrease} \\ \text{from} \\ \text{growth} \end{array} \right] - \left[\begin{array}{c} \text{decrease} \\ \text{from} \\ \text{wastage} \end{array} \right]$$

$$V \frac{ds}{dt}_{\text{net}} = Q_o S_o - (Q_o - Q_w) S_e - \frac{ds}{dt}_{\text{growth}} - Q_w S_r \quad (13)$$

where S_r is the substrate concentration in the recycle stream. Because clarification is a physical operation only, an assumption is made that the settling does not appreciably change the substrate concentration. ($S_e = S_r = S_1$) Simplifying and dividing by V:

$$\left(\frac{ds}{dt} \right)_{\text{net}} = \frac{Q_o S_o}{V} - \frac{Q_o S_1}{V} - \left(\frac{ds}{dt} \right)_{\text{growth}} \quad (14)$$

Substituting equation 5 for $\frac{ds}{dt}_{\text{growth}}$

$$\left(\frac{ds}{dt} \right)_{\text{net}} = \frac{Q_o S_o}{V} - \frac{Q_o S_1}{V} - \frac{dx}{dt}_{\text{growth}} Y \quad (15)$$

substituting for $\left(\frac{dx}{dt} \right)_{\text{growth}}$ from equation 4;

$$\left(\frac{ds}{dt} \right)_{\text{net}} = \frac{Q_o}{V} (S_o - S_1) - \frac{\mu X_1}{Y} \quad (16)$$

$\frac{V}{Q_o}$ is the hydraulic detention time, θ . At steady state there should be no

net change in substrate and $\frac{ds}{dt} = 0$

Simplifying and rearranging equation 16 yields;

$$\frac{S_o - S_1}{X_1} = \frac{\mu \theta}{Y} \quad (17)$$

Substituting for μ from equation 12;

$$\frac{S_o - S_1}{X_1} = \frac{\theta}{Y} \left(\frac{1}{\theta_c} + k_e \right) = \frac{1}{Y} \frac{\theta}{\theta_c} + \theta k_c \quad (18)$$

Over a finite period of time $\frac{S_0 - S_1}{X_1}$ is defined as the food-to-mass ratio, U .

$$YU = \frac{\theta}{\theta_c} + \theta k_e \quad (19)$$

This equation relates food-to-mass ratio and sludge age to the physical parameters of the system and biological characteristics of the waste material. It has been used in the design and operation of the conventional activated sludge process.

Kinetics and material balances restricted to extended aeration have also been reported. ^(100, 101) Since no sludge is intentionally wasted in extended aeration ($Q_w = 0$) a cell balance similar to that presented for conventional activated sludge yields;

$$\left(\frac{dx}{dt}\right)_{\text{net}} = (\mu - k_e) X_1 - \frac{Q_0}{V} k_e \quad (20)$$

If X_e is negligible, then at steady state, $\frac{dx}{dt}_{\text{net}} = 0$; $\mu = k_e$ (21)

This equation states that the rate of growth is equal to the rate of endogenous respiration and that in the extended aeration process biological cell growth extends from acclimation to death.

Neglecting X_e may not be a valid assumption in extended aeration, however. If X_e is not negligible, there appears to be at least two mathematical methods for handling it. One method which has been presented consists of substituting another variable, b' , for the ratio X_1/X_e . ⁽¹⁰²⁾ At steady state, equation 21 becomes;

$$\mu - k_e = \frac{X_e}{X_1} \frac{1}{\theta} = \frac{1}{b'\theta} \quad (22)$$

b' then becomes a measureable variable based solely on settling efficiency. An alternative to this is an application of the definition of sludge age, θ_c , which is defined as the active cells divided by wasted cells. Modifying equation 11 for extended aeration;

$$\theta_c = \frac{VX_1}{Q_0X_e} \quad (23)$$

Rearranging equation 20 and substituting θ_c at the steady state condition results in a relationship identical to equation 12 for conventional activated sludge.

$$\mu - k_e = \frac{Q_0X_e}{VX_1} = \frac{1}{\theta_c}$$

A substrate balance produces equations identical to 18 and 19. Theoretically in the extended aeration process the wasted cells represent a relatively inactive cell biomass. It must be remembered, however, that θ_c for extended aeration is a function of settling efficiency alone, and is no longer an operational parameter which may be changed to control the process.

Assuming that 100% solids return is technically feasible, there exists much controversy as to whether total oxidation of the biological cells is possible. It has been reported that up to 25% of the cells cannot be oxidized. Cells will continue to build up when total sludge recycle is attempted until intentional or unintentional cell wastage allows the system to reach equilibrium. (103, 104, 105) In contrast, results of a three-year study in which an extended aeration pilot plant was operated tend to support the total oxidation theory. (106) A centrifuge was used to ensure 100% sludge return with the result that the buildup of suspended solids reached a stable equilibrium state, fluctuating between finite levels. The conclusions from the research were that the total oxidation of cells is possible, and that sludge wastage in extended aeration treatment is unnecessary.

Regardless of the total oxidation capabilities of extended aeration, it has been well documented that treatment efficiency is greatly dependent upon the ability of the system to retain solids. (107, 108, 109, 110) Solids retention is disturbed mainly by hydraulic shock loads and denitrification in the secondary sludge. In one application where extended aeration was used to treat an industrial waste, a strain of bacteria which was produced by the wastewater settled very poorly due to trapped air bubbles, and the efficiency of removal dropped below 30%. (111)

Salinity and Biological Treatment

One of the factors which must be taken into consideration when biological treatment is employed in a recycle system is the effect of high salt concentrations on the metabolism of the biological cells. The salt buildup occurs because salts are inert to biological activity and tend to build up to abnormally high levels. In one study, while high salinity had no effect on treatment efficiency, the rate of change in salinity had a profound adverse effect on an extended aeration system. (112) The gradual change from fresh water to sea water which contained up to 20,000 mg/l chlorides and 38,000 mg/l total dissolved salts had little effect on biological efficiency. Shock salinity dosages caused drastic reductions in efficiency. The research was done to evaluate extended aeration as a treatment method for large ships which must pass from fresh water to sea water. In a separate study, similar results were obtained at salt concentrations up to 30,000 mg/l. (113) After acclimation substrate removal was quite adequate, but when shock loaded by high salinity, a time span of nearly four detention times was required for complete recovery.

RESEARCH PROCEDURE

The general procedure for this research was as follows:

1. A literature search of recycle applications, extended aeration usage, and waste treatment practices at highway rest areas.
2. Design and construction of the laboratory wastewater treatment system, including the extended aeration biological treatment unit.
3. Creation of a biodegradable synthetic wastewater similar in chemical composition to the wastewater at highway rest areas.
4. Operation of the pilot plant with the synthetic wastewater to ensure comparable performance to field operation.
5. Variation of the recycle ratio to determine effects on the system and the water produced.

The Pilot Plant

In order to properly represent the field facilities, the laboratory plant had to include the same unit processes and be readily adaptable to the proposed recycle system through additions and modifications. Extended aeration systems now used at rest areas in Virginia consist of aeration with secondary settling, only occasional cell wastage, a polishing lagoon, and chlorination (see Figure 4). One possible recycle system would eliminate usage of the lagoon, recycle the secondary effluent through a rapid sand filter, and store for flushing water.

The pilot biological treatment unit used in this work was a plexi-glass extended aeration unit, Figure 11. To eliminate sludge pumping, the settling chamber was separated from the aeration unit by adjustable weirs. The aeration chamber was 14" x 9" x 9" with a volume of .7 gallon. An inclined plane served to concentrate the secondary sludge near the recycle port.

Air for the aeration unit was supplied by four diffused aerators that provided oxygen for the bacteria and turbulence to mix the contents. In addition, the diffusers provided a current through the settling chamber that caused the biomass to recycle. Weirs in the settling chamber directed the current away from the effluent discharge, which provided a "tortuous path effect" and increased the settling efficiency of the unit. The weirs between the aeration chamber and settler were independently adjustable to provide flexibility in controlling the sludge recycle and minimizing aerator effects on settling. A sludge wastage line was included in the settling chamber because the field units normally have such capabilities.

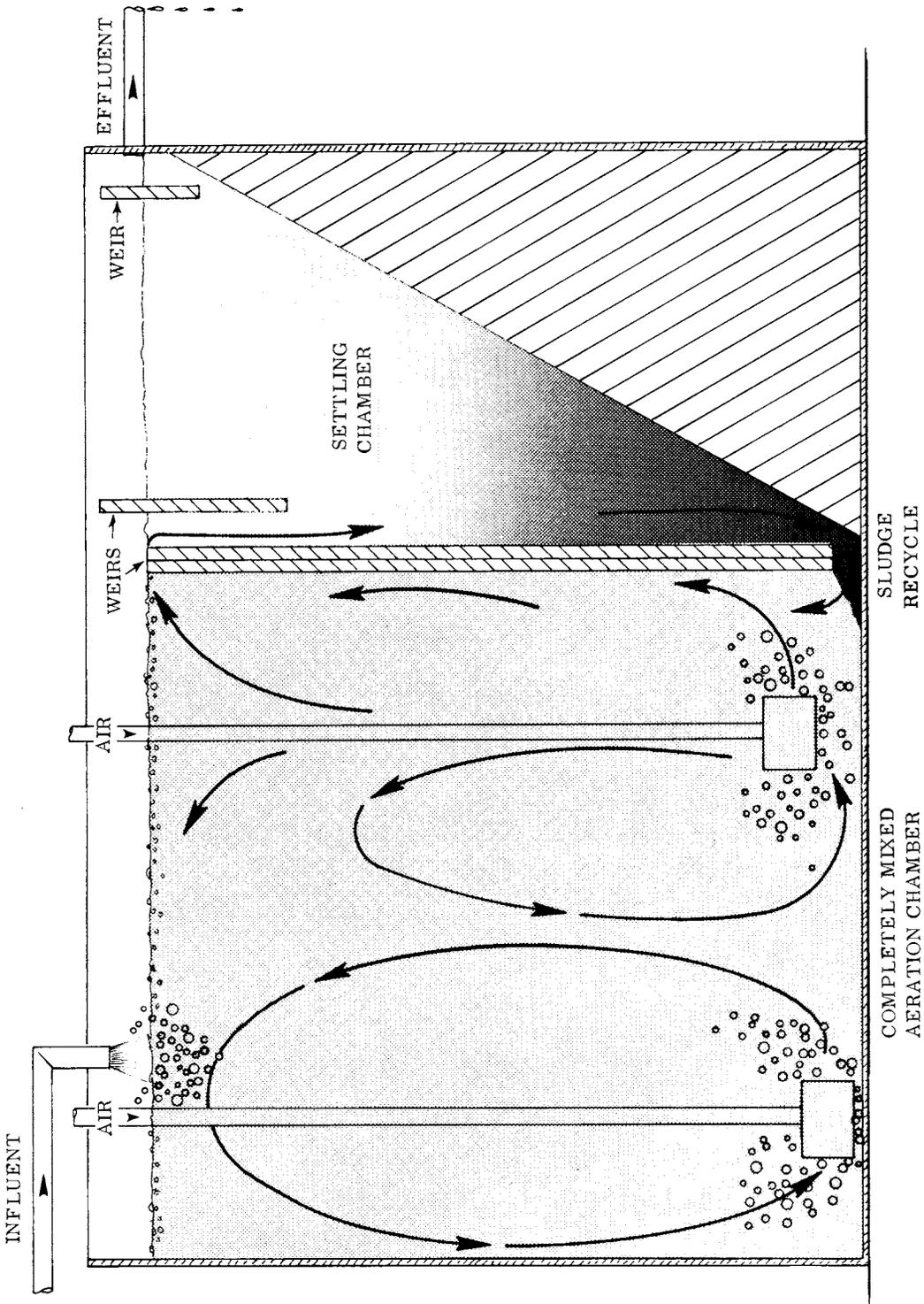


Figure 11. Laboratory extended aeration unit.

In addition to the biological unit, the research apparatus consisted of 2 storage containers, 2 pumps, an effluent discharge basin, Tygon tubing, and a laboratory sand filter. The effluent and influent storage containers were calibrated 5-gallon polyethylene containers with spigots for drainage. The containers were stored in a refrigerator to minimize bacterial activity in the influent and recycled effluent. To transport influent and recycled effluent, variable speed, peristaltic (varistaltic) pumps with a variable pumping rate of 15 ml/min. to 4,500 ml/min. were used. To further increase the flexibility of the pumps, one-hour cycle time switches were installed. The time switches allowed the pumps to operate only a fraction of every hour at mid-range instantaneous flow rates. This procedure proved to be easier on the pumping equipment, and the on-off flow rate closely simulated field operation, where the waste flow is rarely continuous.

The laboratory sand filter consists of a 2-inch inside diameter cylinder, 3-feet high, open to the atmosphere at the top. Approximately 9 inches of gravel were used to support another 9 inches of sand in the cylinder. Near the bottom of the cylinder a port was located for effluent drainage and filter backwashing. The sand was comparable to that normally used at water treatment plants.

The tubing used in conjunction with the pumps was Tygon tubing with a 1/8-inch inside diameter and 1/16-inch wall thickness. This tubing proved to be the best size for maintaining the desired flow rates. A .3 gallon (1.1 liters) cylinder was used to collect the secondary effluent which provided a supply for pumping the recycle. The 5-inch inside diameter cylinder was 7 inches high with an effluent discharge port near the top.

Synthetic Waste

Since the amount of wastewater required for the laboratory pilot plant was too great to make daily collection and storage from a rest area practical, a synthetic waste comparable to rest area influent was developed. In addition, the synthetic waste was required because it was necessary to obtain a concentrated waste similar to bodily wastes so that the varying quality of the flushing water could be analyzed. Both influent and effluent rest area wastewater samples were collected and analyzed. Using results previously obtained to supplement the collected data, ranges of values were obtained for field waste and desired values for the synthetic waste were chosen. (114) A wastewater with the desired characteristics was obtained by modifying a recipe for a synthetic wastewater used in bacterial growth kinetics studies. (115) The synthetic wastewater consisted of three categories of ingredients: organics, inorganic nutrients, and inorganic salts. The biodegradable organics produced the desired COD and the organic fraction of the Kjeldahl nitrogen. The inorganic nutrients supplied the desired alkalinity, pH, calcium, chlorides, ammonia, and phosphorus. The remaining inorganic compounds were added to bring the inorganic salt concentration in the wastewater up to the desired level.

Operating Procedure

The laboratory pilot plant was assembled as shown in Figure 12. The influent, which was stored at 8-10°C, was created by adding the proper dosage of waste materials to 20 liters of tap water. The procedure for storing and dosing of the synthetic waste consisted of dividing the materials into three stock areas. The organics and the calcium compounds were mixed together and stored dry. A 20-day supply was normally prepared and mixed so that the dosage of 10 g/day of the mixture was as homogeneous as possible. The ammonia and phosphorus compounds were combined with the sodium bicarbonate and mixed in a concentrated aqueous nutrient solution so that 25 ml/20 l of water provided the proper dosage of the constituents. The remaining four salts were combined in a similar concentrated aqueous solution that provided the proper salt dosage when 25 ml. were used. There were primarily two reasons for separating the synthetic waste materials: (1) If all of the inorganics were combined in one concentrated solution, precipitation would likely occur, and (2) if the organics were stored in an aqueous solution, extensive bacterial activity would occur, which would result in variable influent characteristics.

The influent pump was calibrated and set to operate at an average flow rate between 12.9 - 15.5 ml/min. to provide a detention time in the aeration chamber of 20-24 hours. Compressed air was metered through the four diffusers using a manual valve and a rotameter. The air was controlled by visually checking to ensure that enough turbulence was present for completely mixed conditions in the chamber without a great hinderance to the settling in the settling chamber. In addition, periodic dissolved oxygen determinations were made to ensure that the air flow rate was adequate. The weirs between the two chambers were also adjusted to assist in obtaining the proper balance between turbulence and quiescence.

The effluent from the second settler overflowed to the discharge basin. The desired amount of effluent was recycled by pumping the effluent to the laboratory sand filter, which discharged by gravity into the refrigerated effluent storage tank. Each day the effluent was manually drained into the influent storage tank and makeup water and synthetic waste were added. The effluent was sampled periodically for dissolved solids and mixed liquor suspended solids to determine when steady state conditions had been reached.

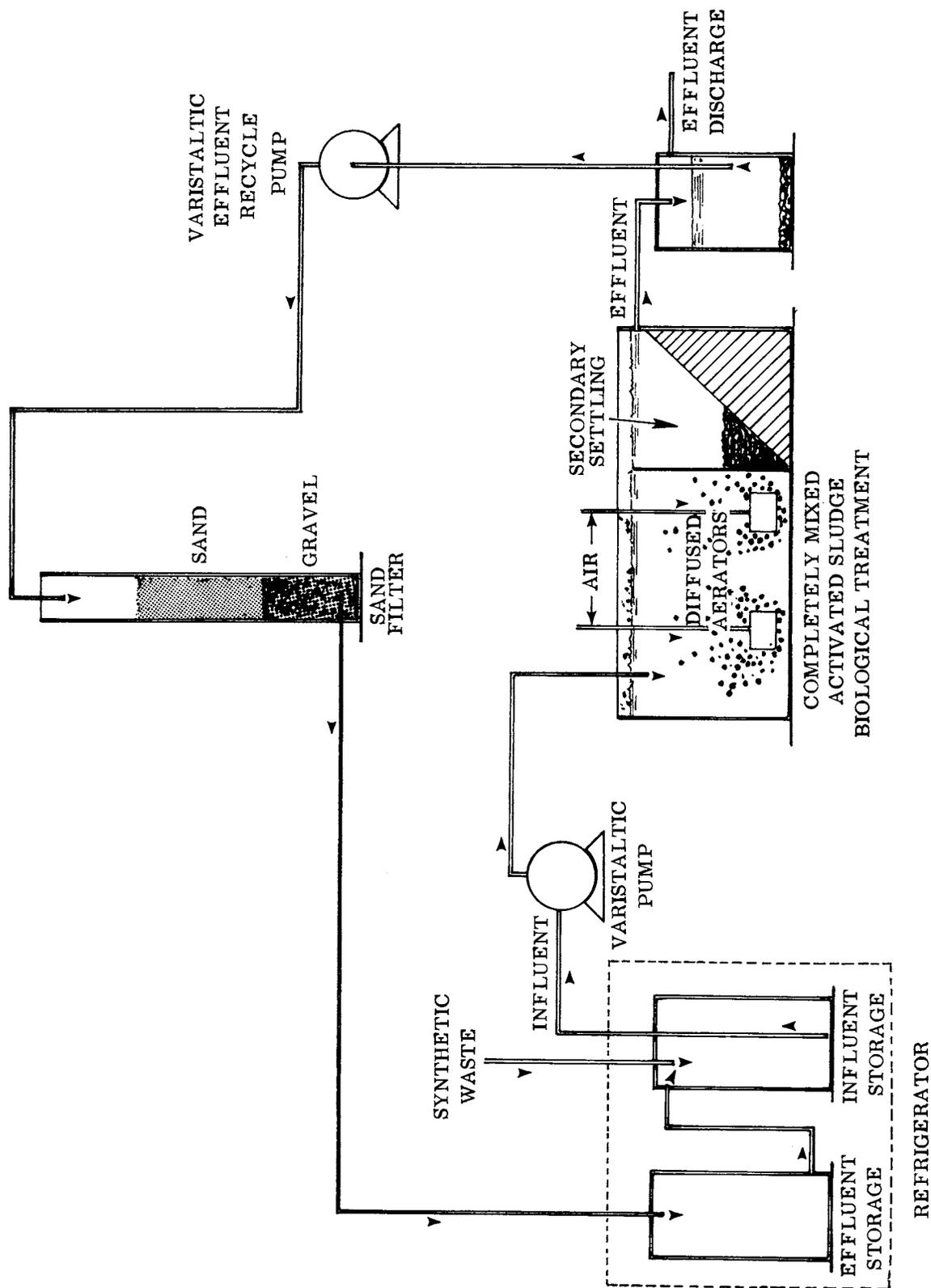


Figure 12. Laboratory recycle treatment plant.

After design and construction of the pilot plant and calibration of the pumps, the plant was started up without recycle to check the biodegradability of the synthetic waste and the performance of the extended aeration unit. Initially without effluent recycle, the synthetic waste was pumped through the extended aeration unit, which was seeded to provide bacteria, and the effluent was discharged to a drain. Mixed liquor suspended solids and effluent suspended solids were monitored until steady state was reached. At that point, removals of COD, BOD₅, and Kjeldahl nitrogen were obtained and compared with those from the field plant operation.

Recycling operation began after data was collected at zero recycle. The plant was operated first at 50% effluent recycle and later increased to 70% and 90% recycle. In initial recycle attempts, the effluent recycle pump was set to pump the proper recycle ratio through the sand filter to the effluent storage. Due to operational difficulties in maintaining the proper recycle ratio, this procedure was modified. The recycle pump was set to recycle nearly 100% of the effluent through the sand filter and the ratio adjustment was accomplished by manually wasting from the effluent storage.

The laboratory sand filter required backwashing periodically to remove the trapped suspended solids. Tap water was pumped into the discharge of the sand filter, which expanded the bed, and the backwash overflowed the filter to a drain. A procedure in which the filter backwash was returned to the extended aeration unit was attempted. Since the backwash flow rate was significant enough to cause severe hydraulic load increases, the bacterial settling efficiency deteriorated due to the reduced detention time, and the procedure was abandoned.

For both 50% and 70% recycle the influent wastewater was created by mixing appropriate volumes of filtered effluent and tap water with the synthetic waste. This procedure proved inadequate at 90% recycle because as the dissolved solids concentration increased, not all the organic solids would dissolve, and the pumps proved incapable of pumping the suspended solids.

At 90% recycle, the synthetic waste materials were added directly to the biological treatment unit to ensure that the waste reached the treatment system. Initially the waste was added to the extended aeration unit in an instantaneous dose once a day. To prevent organic shock loading, the procedure was modified to extend the dosage period over several hours. The waste was mixed in one liter of tap water, which was kept well stirred, and the mixture was dripped into the extended aeration unit by gravity.

Alterations to the extended aeration unit were made during 90% recycle operation to improve the ability of the system to handle the high suspended solids concentration at the high recycle rate. The modifications became necessary because higher aeration rates were required to provide the necessary oxygen for the large biological population, and more turbulence was

required to keep the cells suspended. These additional air requirements greatly hindered the settling efficiency. Essentially, the modification made to improve the system was to change the settler to an upflow clarifier, as shown in Figure 13. The weirs that separated the settling chamber from the aeration chamber were adjusted so that the aeration chamber discharged through the sludge return. The aerators could then be adjusted to provide the adequate mixing without sacrificing the settling efficiency.

All laboratory quantitative analyses were done in accordance with Standard Methods for the Examination of Water and Wastewater, except the Kjeldahl nitrogen determination, which was made following a procedure presented by McKenzie. (116)

LABORATORY EXTENDED AERATION UNIT
(Modified for High Sludge Concentrations)

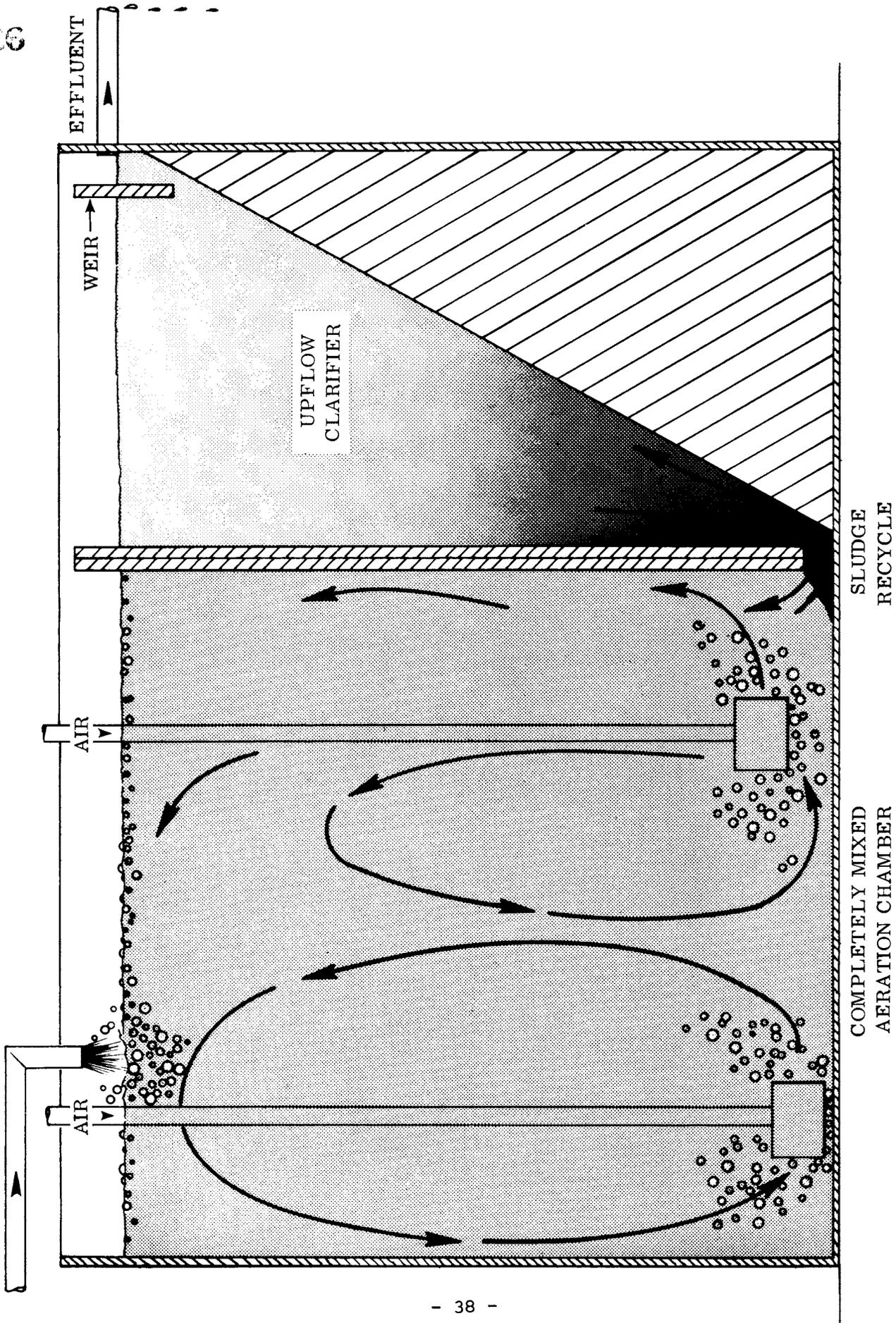


Figure 13. Modified laboratory extended aeration unit with upflow clarifier.

PRESENTATION OF RESULTS

Samples were collected and analyzed from the influent and effluent of the extended aeration wastewater treatment process at the Fairfield rest area to determine the influent characteristics and the treatment efficiency. The results obtained from these analyses are summarized in Table 1. The composite sample results were compared with previous Virginia rest area results and characteristic ranges of values for the wastewater were obtained. The ranges of values for rest area influent and values of the synthetic wastewater are shown in Table 2. The chemicals and dosages used to produce the synthetic wastewater are presented in Table 3.

Table 1

ANALYSES OF REST AREA WASTEWATER

(All analyses are expressed in mg/l except pH, and are results of composite samples from the inflow to the extended aeration unit and overflow to the secondary settler at Fairfield rest area, Rockbridge County, Virginia.)

<u>Parameter</u>	<u>Symbol</u>	<u>Influent</u>	<u>Effluent</u>
pH		8.2	
Biochemical Oxygen Demand	BOD ₅	175	8
Total Chemical Oxygen Demand	COD _T	440	73
Soluble Chemical Oxygen Demand	COD _S	180	
Total Kjeldahl Nitrogen	TKN	93	3
Total Solids	TS	650	542
Total Volatile Solids	TVS	360	174
Total Fixed Solids	TFS	290	368
Total Suspended Solids	TSS	140	24
Volatile Suspended Solids	VSS	56	23
Fixed Suspended Solids	FSS	84	1
Total Dissolved Solids	TDS	510	518
Volatile Dissolved Solids	VDS	304	151

Table 1 (continued)

Fixed Dissolved Solids	FDS	206	367
Phosphorus (as P)	P	8	9
Alkalinity (as CaCO ₃)	Alk.	83.5	
Calcium	Ca	60	
Chlorides	Cl	58	

Table 2

CHARACTERISTIC ANALYSES RANGES FOR REST AREA WASTEWATER

(All analyses except pH expressed in mg/l.)

<u>Parameter</u>	<u>Symbol</u>	Field Wastewater (range of analyses)	Synthetic Wastewater (selected value)
Chemical Oxygen Demand	COD	320-440	340
Biochemical Oxygen Demand	BOD ₅	130-175	340
pH		77-83	77
Total Solids	TS	620-688	892
Total Fixed Solids	TFS	290-426	492
Total Volatile Solids	TVS	234-360	400
Total Dissolved Solids	TDS	480-530	892
Fixed Dissolved Solids	FDS	279-342	492
Volatile Dissolved Solids	VDS	188-213	400
Total Suspended Solids	TSS	140-158	0
Fixed Suspended Solids	FSS	11-84	0
Volatile Suspended Solids	VSS	56-147	0
Alkalinity	Alk.	58-83.5	70

Total Kjeldahl Nitrogen	TKN	80-92.5	100
Chlorides	Cl	50-58	60
Calcium	Ca	56-60	60
Phosphorus	P	1.8-9	8

Table 3

RECIPE FOR SYNTHETIC WASTEWATER

Ingredient	Formula	Synthetic Wastewater Dosage (mg/L)
SUCROSE		160
PEPTONE		160
MONOSODIUM GLUTAMATE		15
UREA		32.5
YEAST EXTRACT		32.5
CALCIUM HYDROXIDE	$\text{Ca}(\text{OH})_2$	50
CALCIUM SULFATE	CaSO_4	50
SODIUM BICARBONATE	NaHCO_3	5
AMMONIUM CHLORIDE	NH_4Cl	100
AMMONIUM NITRATE	NH_4NO_3	37.5
POTASSIUM PHOSPHATE MONOBASIC	KH_2PO_4	5
POTASSIUM PHOSPHATE DIBASIC	K_2HPO_4	20
DIBASIC SODIUM PHOSPHATE	$\text{Na}_2\text{HPO}_4 \cdot 7\text{H}_2\text{O}$	25
POTASSIUM NITRATE	KNO_3	100
SODIUM NITRITE	NaNO_2	50
SODIUM SULFITE	Na_2SO_3	25
MAGNESIUM SULFATE	MgSO_4	25

When the laboratory pilot treatment plant began treating the synthetic wastewater, mixed liquor suspended solids were monitored to determine when steady state had been reached (Figure 14). A monitoring procedure similar to the one presented was employed at each recycle rate. To compare the pilot plant operation with field operation, the pilot plant was operated initially without employing effluent recycle and the results of the comparison are summarized in Table 4.

Table 5 includes a summary of the effluent quality produced by the pilot plant at several recycle rates. As previously mentioned, it became increasingly apparent that the pilot plant had a problem retaining suspended solids, especially at the higher aeration rates required at higher recycle rates. At 90% recycle, after results were obtained using a conventional settling unit, the pilot plant was modified to include upflow clarification (see Figure 13). The comparison of results from these two treatment processes is summarized in Table 6.

Table 4

COMPARISON OF PILOT PLANT AND REST AREA
WASTEWATER TREATMENT SYSTEMS

(Laboratory pilot plant was used to treat a synthetic wastewater while rest area wastewater was treated with the field package plant.)

Fairfield Rest Area

Parameter	Symbol	Influent mg/l	Effluent mg/l	% removal
Chemical Oxygen Demand	COD	310	73	76.4
Biochemical Oxygen Demand	BOD ₅	175	8	95.5
Total Kjeldahl Nitrogen	TKN	92	3	96.4

Laboratory Pilot Plant

Parameter	Symbol	Influent mg/l	Effluent mg/l	% removal
Chemical Oxygen Demand	1 COD	340	37	89.0
Biochemical Oxygen Demand	BOD ₅	340	26	92.4
Total Kjeldahl Nitrogen	TKN	100	54	46.0

Table 5

LABORATORY PILOT PLANT EFFLUENT QUALITY AT
VARIOUS RECYCLE RATES

(All results except pH expressed in mg/l.)

Parameter	Symbol	0	50	70	90	90*
pH		7.4	7.1	7.1	7.1	5.4
Chemical Oxygen Demand	COD	37	110	212	335	155
Biochemical Oxygen Demand	BOD ₅	26				14
Mixed Liquor Suspended Solids	MLSS	1040	1975	2350	2725	7100
Mixed Liquor						
Volatile Suspended Solids	MLVSS	885	1580	1974	1980	5900
Total Dissolved Solids	TDS	658	1220	2126	6520	5920
Total Fixed Dissolved Solids	TFDS	460	820	1638	2684	3860
Total Kjeldahl Nitrogen	TKN	54	39	75	240	128
Alkalinity	Alk.	95	218	172		10

*Results obtained after conversion of pilot plant to include an upflow clarifier.

Table 6

A COMPARISON OF TREATMENT EFFICIENCIES EMPLOYING THE
CONVENTIONAL SETTLER AND THE UPFLOW CLARIFIER

(Results obtained using a 4.8 gallon extended aeration unit and synthetic wastewater.)

Parameter	Symbol	Effluent Quality at 90% Recycle	
		Conventional Settler	Upflow Clarifier
Chemical Oxygen Demand	COD	335	155
Biochemical Oxygen Demand	BOD		14
Mixed Liquor Suspended Solids	MLSS	2725	7100
Mixed Liquor Volatile Suspended Solids	MLVSS	1980	5900
Percent Volatile Suspended Solids	%VSS	71.6	83.0
Total Dissolved Solids	TDS	6520	5920
Total Fixed Dissolved Solids	TFDS	2684	3860
Total Kjeldahl Nitrogen	TKN	240	128
Percent COD Removed		48	68
Percent BOD Removed			96
Percent TKN Removed		10	22

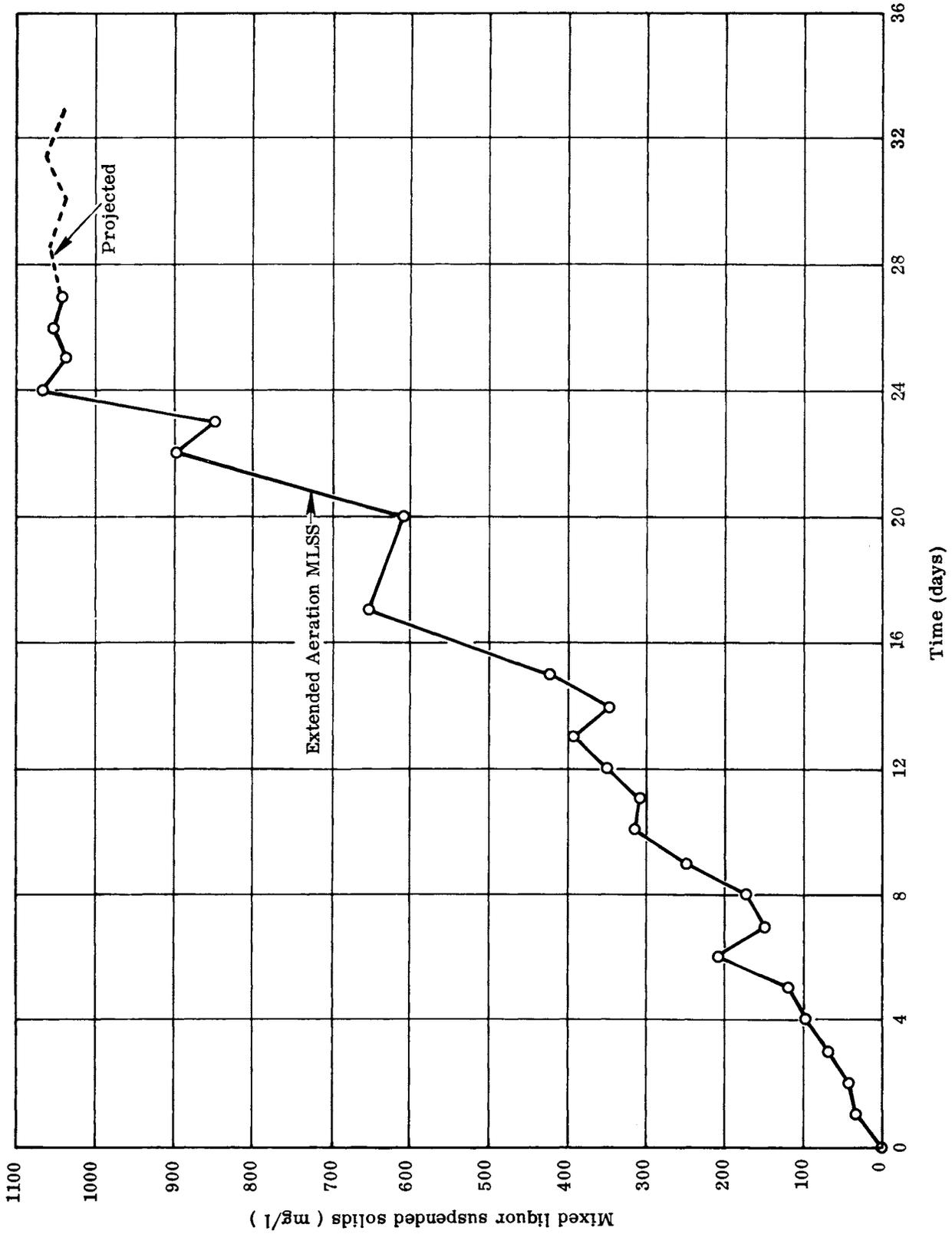


Figure 14. Determining steady state by monitoring MLSS.

DISCUSSION OF RESULTS

Rest Area Wastewater Characteristics

Although rest area wastewater does not contain the significant volume of storm drainage, laundry, dishwashing, and industrial wastewaters which greatly affect the strength of municipal wastewaters, it appears that rest area wastewater has a BOD₅ comparable to that of municipal wastewaters. It should also be pointed out that rest area wastewater is not analogous to turnpike wastewaters, since rest areas do not include restaurants and gasoline stations. Turnpike wastewaters that have been reported have a much higher BOD₅ than rest area wastewater and contain significant quantities of grease, while the rest area wastewater visually appeared void of grease. (117, 118) The COD of rest area wastewater was nearly three times as great as the BOD₅, apparently the result of the high paper content. The Kjeldahl nitrogen was relatively high, probably due to the prevalence of urine. A comparison of many of the parameters measured at the Fairfield rest area with values obtained from several rest areas (see Table 7) indicate that rest area wastewater characteristics do not vary greatly from location to location. (119, 120)

The effluent values obtained indicate quite satisfactory treatment by the extended aeration process as shown by the high removals of BOD₅ and Kjeldahl nitrogen. The nitrogen conversion also indicates that nitrification is prominent and the majority of Kjeldahl nitrogen is converted to nitrites and nitrates. The fact that the Fairfield rest area is presently operating significantly below design capacity is supported by all the results, especially the very low suspended solids carryover.

Table 7

REST AREA INFLUENT CHARACTERISTICS

(All analyses except pH expressed in mg/l.)

Parameter	Symbol	Commonwealth of Virginia		State of Washington
		Fairfield Rest Area	Montgomery Co. Rest Area 21 *	Average of Four Rest Areas **
pH		8.2	8.6	8.3
Total Kjeldahl Nitrogen	TKN	93.	84.	140.
Total Suspended Solids	TSS	140.	192.	175.
Chemical Oxygen Demand	COD	440.	580.	405.
Biochemical Oxygen Demand	BOD ₅	175.	177.	165.
Phosphorus (as P)	P	8.	1.	9.5

*From a study prepared by the Virginia Highway Research Council (reference 120).

**From a study prepared for the Washington State Highway Commission by the University of Washington in January 1972 (reference 119).

Synthetic Wastewater

Previous results from rest areas were combined with results obtained in this study, and a range of values for each measured parameter was determined. From these, values for the synthetic wastewater were chosen. As can be seen from Table 2, not all of the synthetic wastewater values were selected in the determined range of field analyses. There were basically two reasons for this procedure. (1) It would have been extremely difficult, using laboratory chemicals, to obtain a wastewater which contained all values in the given range. It was felt that the time and effort required to achieve this goal were impractical since an adequate synthetic waste could be designed in much less time. (2) Several of the values of the synthetic wastewater were much higher than the field results so that the synthetic wastewater would be at least as difficult to treat as in the field.

It was decided that the synthetic wastewater should be similar to the field wastewater in pH, alkalinity, total Kjeldahl nitrogen, chlorides, calcium, and phosphorus concentrations. The synthetic wastewater was designed to have a COD similar to that of field wastewater, but since most of the compounds used to produce the COD were biodegradable organics, which is not the case in rest area wastewater, the BOD₅ of the synthetic was much greater than field wastewater BOD₅. The synthetic wastewater was designed to be

totally soluble to prevent the need for pumping suspended solids. In this manner, the suspended solids in the biological reactor and settling chamber were a good estimate of the biological cell mass present. Since the effects of the appreciable fixed solids buildups on biological activity were of primary importance, the total fixed solids in the synthetic were similar to that in field waste. Because the organics which determine the BOD₅ and COD also provide the volatile solids, the total solids were significantly higher in the synthetic wastewater.

Pilot Plant Operation

In order to compare the similarity of the synthetic wastewater and the extended aeration pilot plant to field operation, the laboratory unit was operated initially without recycle. The results, as shown in Table 4, indicated that the biodegradabilities of the two wastewaters were similar since the percentages of BOD₅ removal were nearly the same. The higher COD removal and Kjeldahl nitrogen conversion in the laboratory were expected due to the absence of a significant non-biodegradable COD, and because nearly 50% of the Kjeldahl nitrogen in the synthetic was provided by the organic compounds. The Kjeldahl nitrogen in the field wastewater contained a more significant ammonia concentration.

From this comparison it can be speculated that it might have been better for the BOD₅ of the field wastewater and synthetic wastewater to be similar. In addition, a more significant non-biodegradable COD should have been included to obtain a synthetic wastewater which more closely resembled the field wastewater. Furthermore, if the ammonia and organic nitrogen fractions of the Kjeldahl nitrogen for each waste were more similar, the Kjeldahl nitrogen removals would have been closer for the unit without recycle, and the buildups in Kjeldahl nitrogen during recycle would have predicted field operation more closely.

When secondary effluent was recycled and reused, dissolved salts and untreated organics increased in concentration in the influent, which increased the salinity and organic load without affecting the hydraulic load. The organic load increase initially caused the food-to-mass ratio to increase so that the bacteria were surrounded by an excess of substrate for growth and metabolism. The biomass no longer needed to make use of its own cell material and shifted from the endogenous respiration phase to a more accelerated growth phase. The result was a significant growth in the biomass (represented by MLSS) until the proper biomass was available for utilization of the substrate present. Even though this population increase occurred, the effluent quality worsened with increased recycle as long as the conventional settler was used with the pilot plant as indicated by the increased COD and both volatile and fixed dissolved solids. This reduction in removal apparently was the result of increased unintentional cell wastage.

The change to the upflow clarifier greatly reduced suspended solids carryover, which increased the mixed liquor suspended solids. The effluent quality which resulted, discounting the inevitable increase in salts, was comparable to that produced without recycle. Much higher aeration rates were required to provide the oxygen and turbulence to the extended aeration system. Although the Kjeldahl nitrogen removal was not as good as usually desired, it should be remembered that the high amine concentration in the synthetic is uncharacteristic of rest area wastewater and much better conversion in the field would be expected. Although the salt buildups may have caused inhibition to biological activity, results which support previous investigation indicate that biological treatment can be effective at high salinities.

From these results, it appears that the ability of the recycle system to produce an effluent of acceptable quality hinges primarily on the ability of the system to retain the high suspended solids concentrations required. Hydraulic upsets would not only have a detrimental effect on the biological treatment system but would likely inhibit sand filter operation due to the high solids carryover. Equalization and excellent settling efficiency seem to be the keys to success of the proposed system. Since filter backwash will be recycled in the field by returning the washed out biomass to the aeration chamber, adequate cell retention is guaranteed and satisfactory performance is expected.

As with any reuse system, the operation and control of the biological treatment system is of critical importance. Increased operator training and more frequent parameter monitoring may be necessary. In addition, the mechanical aerators and circulation pumps which are generally connected to timers to prevent wastage of electricity should be left on continuously to provide the needed oxygen and prevent turbulence surges from an on-off operation.

A subject which was not dealt with was a study of the possible biological system control methods. The field operation could be operated similarly to the laboratory pilot plant in which buildups were controlled by wasting a fraction of the effluent. It should be considered, however, that if settling efficiency is high, non-biodegradable suspended material will build up to very high levels without sludge wastage. An alternative to the operating procedure employed is to recycle greater than 90% of the effluent and waste suspended solids from the secondary settler. The effect of such a control procedure would be to convert the extended aeration process to a more conventional activated sludge process. It may even be possible to return 100% of the effluent for reuse if control is accomplished totally through sludge wastage. The results of such action can only be speculated upon and should be investigated.

CONCLUSIONS

1. Based on the use of a synthetic wastewater, it is possible to produce a water which is of sufficient quality for toilet flushing purposes by recycling 90% of the effluent from rest area wastewater treated by the extended aeration process.
2. The degree of treatment for the extended aeration process is primarily dependent on the ability of the system to retain solids.
3. Because provisions have been made in the field design to return the washed out biomass to the extended aeration unit, proper food-to-mass ratios are possible and satisfactory effluent quality for flushing toilets is expected.
4. Biological processes, such as extended aeration, can operate effectively at dissolved solids concentrations over 6000 mg/l, which are produced by recycle and reuse of effluent.
5. When recycle is employed, a biological population increase of up to eight times that required without recycle may be necessary to produce a satisfactory effluent. Much higher aeration rates are required to support the increased biomass.
6. The BOD₅ of rest area wastewater is comparable to that of municipal wastewater, but the COD is much greater than that of normal municipal wastewater, probably due to the high paper content.

RECOMMENDATIONS

1. Every effort should be made for equalization of flow to the extended aeration unit in the field when recycle is employed. Hydraulic upsets cause reduced settling efficiency that adversely effect effluent quality and hinder sand filter operation.
2. Further research is required to determine the most economical operating procedure and best control method for the field recycle system. An investigation of intentional sludge wastage and sludge handling is recommended.
3. The effects of chlorination and dye addition should be determined.
4. Field test operation, when recycle is employed, should be monitored for a reasonable time period during start up and early operation to determine optimum operating conditions.

5. It should be determined if higher than 90% recycle rates can be employed in the recycle system.
6. The BOD₅, COD, and organic nitrogen concentrations in the synthetic wastewater should be modified to be more similar to those in rest area wastewater.
7. In field operation, the entire effluent should be filtered before discharge or recycle to recover the biomass.

REFERENCES

1. NCHRP Synthesis of Highway Practice, "20-Rest Areas," Highway Research Board, Division of Engineering, National Research Council, 1973, p. 1.
2. Standard Methods for the Examination of Water and Wastewater, 13th ed., American Public Health Association, 1971, p. 489.
3. Sawyer, C. N. and P. L. McCarty, Chemistry for Sanitary Engineers, McGraw-Hill, New York, 1967, p. 396.
4. Ibid., p. 384.
5. Metcalf and Eddy, Incorporated, Wastewater Engineering, McGraw-Hill, 1972, Appendix C.
6. Streeter, N. W. and E. B. Phelps, Public Health Bulletin 146, U. S. Public Health Service, 1925.
7. Metcalf and Eddy, Incorporated, op. cit.
8. Rich, L. G., Unit Processes of Sanitary Engineering, Wiley and Sons, 1963.
9. Moores, C. W., "Wastewater Biotreatment: What It Can and Cannot Do," Chemical Engineering, pp. 63-66, December 25, 1972.
10. "How Fast Are U. S. Lakes Aging and Why?," Environmental Science and Technology, vol. 7, pp. 198-199, March 1973.
11. Sawyer, C., "ABC's of Cultural Eutrophication and Its Control," Water and Sewage Works, vol. 118, 1971, p. 278.
12. Ibid., p. 322.
13. Nesbitt, J. B., "Phosphorus Removal; the State of the Art," Water Pollution Control Federation Journal, vol. 41, pp. 701-713, May 1969.
14. Miller, W. E. and T. E. Maloney, "Effects of Secondary and Tertiary Wastewater Effluents on Algal Growth in a Lake-River System." Water Pollution Control Federation Journal, vol. 43, pp. 2361-2365, December 1971.
15. Metcalf and Eddy, Incorporated, op. cit., pp. 633-669.
16. Goodman, B. L. and K. A. Mikkelson, "Advanced Wastewater Treatment; Removing Phosphorus and Suspended Solids," Chemical Engineering, vol. 77, pp. 75-83, April 27, 1970.
17. Shindala, A., "Nitrogen and Phosphorus Removal from Wastewater," Water and Sewage Works, vol. 119, pp. 66-71, June 1972.

18. Sawyer, G. A., "New Trends in Wastewater Treatment and Recycle," Chemical Engineering, vol. 79, July 24, 1972, p. 122.
19. Ibid., p. 122.
20. Suhr, L. G., "Some Notes on Reuse," American Water Works Association Journal, vol. 63, October 1971, p. 631.
21. Sawyer, G. A., op. cit., p. 124.
22. NCHRP Synthesis of Highway Practice, op. cit., p. 15.
23. "Short Cut Rest Area Sanitary Facility," Better Roads, 1973, p. 22.
24. Sylvester, R. O. and R. W. Seabloom, Rest Area Wastewater Disposal, Washington State Highway Commission, January 1972, p. 40.
25. Ibid., p. 2.
26. NCHRP Synthesis of Highway Practice, op. cit., p. 17.
27. Marston, T. B., Jr., Virginia State Highway Department, Landscape Architect, Environmental Quality, personal communication, February 7, 1974.
28. Federal Water Pollution Control Act of 1972, Section 101, 92nd Congress, October 18, 1972.
29. Lawson, Larry, Virginia State Water Pollution Control Board, personal communication, February 7, 1974.
30. "How Florida Keeps Water Untainted from Rest Stop Waste," Rural and Urban Roads, vol. 11, p. 24, July 1973.
31. Sylvester, R. O. and R. W. Seabloom, op. cit., p. 54.
32. Sherrod, A. J., Texas Highway Department, Chief Engineer of Maintenance Operations, personal communication, February 11, 1974.
33. Anderson, Charles, Maryland State Highway Administration, Assistant Chief Engineer, Maintenance, personal communication, February 11, 1974.
34. Parker, C. E., "Water Reuse at Highway Rest Stations," Virginia Highway Research Council, Working Plan, 1972.
35. Bott, W. B., "Feasibility of Recycling Grey Water at Highway Rest Stations," Virginia Highway Research Council, in publication.

36. Metzler, D. F., et al., "Emergency Use of Reclaimed Water for Potable Supply at Chanute, Kansas," American Water Works Association Journal, pp. 1021-1060, August 1958.
37. Brezina, E. R., R. S. Campbell, and J. R. Whitley, "Thermal Discharges and Water Quality in a 1500-Acre Reservoir." Water Pollution Control Federation Journal, vol. 42, pp. 24-32, June 1970.
38. Ibid.
39. Stevens, D. B., "Wastewater Reuse," Water Pollution Control Federation Journal, vol. 40, April 1968, p. 677.
40. Love, J. A., "Water: The need for Action Now," American Water Works Association Journal, vol. 63, October 1971, p. 660.
41. Linstedt, K. D., K. J. Miller, and E. R. Bennett, "Metropolitan Successive Use of Available Water," American Water Works Association Journal, vol. 63, October 1971, p. 613.
42. NCHRP Synthesis of Highway Practice, op. cit., p. 13.
43. Sylvester, R. O. and R. W. Seabloom, op. cit., p. 19-28.
44. Ferris, H. G., Virginia Highway Department, Resident Engineer, personal communication, February 4, 1974.
45. Howard, H. L., Virginia Highway Department, Resident Engineer, personal communication, February 6, 1974.
46. Long, W. N. and F. A. Bell, "Health Factors and Reused Water," American Water Works Association Journal, vol. 64, April 1972, p. 224.
47. Sawyer, C. N. and P. L. McCarty, op. cit., p. 31.
48. Sienko, M. J. and R. A. Plane, Chemistry, 3rd. ed., McGraw-Hill, New York, 1966, p. 287.
49. Rich, L. G., op. cit., p. 89.
50. Suhr, L. G., op. cit.
51. NCHRP Synthesis of Highway Practice, op. cit., Appendix B.
52. Rey, G., W. S. Lacy and C. Allen, "Industrial Water Reuse: Future Pollution Solution," Environmental Science and Technology, vol. 5, September, 1971, p. 762.
53. Middleton, F. M., "Concepts of Wastewater Reuse," Water and Sewage Works, vol. 118, pp. R 59-62, August 31, 1971.

54. Rey, G., W. J. Lacy, and C. Allen, op. cit., p. 760.
55. Aberbach, R. J., "Water Reclamation and Reuse Team up to Combat Water Pollution," Power, vol. 113, pp. 57-59, October 1969.
56. "Avoid Pollution by Total Water Recycle" Canadian Chemical Processing, vol. 56, pp. 25-26, April 1972.
57. Eller, J., "Water Reuse and Recycling in Industry," American Water Works Association Journal, vol. 62, pp. 149-154, March 1970.
58. "Reuse Water Instead of Dumping It," Manufacturing Engineering and Management, vol. 67, p. 18, July 1971.
59. Barber, J. C., "Waste Effluent; Treatment and Reuse," Chemical Engineering Progress, vol. 65, pp. 70-73, June 1969.
60. Shannon, E. S., and A. Maas, "Michigan-Industry Reuse of Treated Waste," American Water Works Association Journal, vol. 63, p. 154, March 1971.
61. Norman, A. D. and Busch, A. W., "Biological Processes for Water Reuse," Chemical Engineering Symposium Series, vol. 63, pp. 178-182, 1967.
62. Shannon, E. S. and A. Maas, op. cit.
63. "Sewage Wastewater to be Used Industrially," Civil Engineering, vol. 42, p. 93, April 1972.
64. Smyth, F., "Multiple Water Reuse," American Water Works Association Journal, vol. 63, pp. 623-625, October 1971.
65. Scherer, C. H. and J. L. Terry, "Reclamation and Industrial Reuse of Amarillo's Wastewater," American Water Works Association Journal, vol. 63, pp. 159-164, March 1971.
66. Jopling, W. F., D. G. Deaner, and H. J. Ongerth, "Fitness Needs for Wastewater Reclamation Plants," American Water Works Association Journal, vol. 63, pp. 626-627, October 1971.
67. Deaner, D. G., "Public Health and Water Reclamation," Water and Sewage Works, vol. 117, pp. R 7-13, November 28, 1970.
68. Suhr, L. G., op. cit.
69. Weismantel, G. E., "Denver Aims at Total Reuse," Chemical Engineering, vol. 78, pp. 82-83, May 17, 1971.
70. Linstedt, K. D., K. J. Miller, and E. R. Bennett, op. cit.

71. Amiamy, A., "Reuse of Municipal Wastewater," Civil Engineering, vol. 38, pp. 58-61, May 1968.
72. Sopper, W. E., "Wastewater Renovation for Reuse Key to Optimum Use of Water Resources," Water Research, vol. 2, pp. 471-480, September 1968.
73. "How Florida Keeps Water Untainted From Rest Stop Waste," op. cit.
74. Garthe, E. C. and W. C. Gilbert, "Wastewater Reuse at the Grand Canyon," Water Pollution Control Federation Journal, vol. 40, pp. 1582-1583, September 1968.
75. Metzler, D. F., F. M. Middleton and others, op. cit.
76. Ibid., p. 1024.
77. Suhr, L. G., op. cit., p. 630.
78. Clayton, A. J. and P. J. Pybus, "Windhoek Reclaiming Sewage for Drinking Water," Civil Engineering, vol. 42, pp. 103-106, September 1972.
79. Stander, G. J. and L. R. J. Van Vuuren, "Reclamation of Potable Water From Sewage," Public Works, vol. 101, pp. 132-133, May 1970.
80. Suhr, L. G., op. cit., p. 630.
81. "Water Reuse on Pikes Peak," Public Works, vol. 101, p. 83, November 1970.
82. Merrill, J. C. and A. Katko, "Reclaimed Wastewater for Santee Recreational Lakes," Water Pollution Control Federation Journal, vol. 38, pp. 1310-1318, August 1966.
83. Ruttner, F., Fundamentals of Limnology, 3rd ed., Translated by D. G. Frey and F. E. J. Fry, Toronto Press, 1963, p. 91.
84. Suhr, L. G., op. cit.
85. Weinstein, R. H., "Water Recycling for Domestic Use," Astronautics and Aeronautics, vol. 10, pp. 44-51, March 1972.
86. Ibid., p. 44.
87. "Potable Water From Human Wastes," Mechanical Engineering, vol. 94, p. 37, 1972.
88. Buchanan, R. D. "Partial Recycle: A New Sewerage System," Water and Sewage Works, pp. 46-47, January 1972.
89. McLaughlin, E. R., "Recycle System for Conservation of Water in Residences," Water and Sewage Works, vol. 115, pp. 175-176, April 1968.

90. Bruvold, W. H. and P. C. Ward, "Public Attitudes Toward Use of Reclaimed Wastewater," Water and Sewage Works, vol. 117, pp. 120-122, April 1970.
91. Nagiev, M. F., The Theory or Recycle Processes in Chemical Engineering, Translated by R. Hardbottle, Macmillan Company, 1964.
92. Westrick, J. J., J. M. Morand, and D. J. Eye, "A Field Study of the Extended Aeration Process," Proceedings 21st Industrial Waste Conference, Purdue University, p. 424, 1966.
93. Steward, J., H. F. Ludwig and W. H. Kearns, "Effects of Varying Salinity on the Extended Aeration Process," Water Pollution Control Federation Journal, vol. 34, pp. 1161-1177, November 1962.
94. Kincannon, D. F. and A. F. Gaudy, "Responses of Biological Waste Treatment Systems to Changes in Salt Concentrations," Biotechnology and Bioengineering, vol. 10, pp. 483-496, 1968.
95. Bott, W. B., op. cit.
96. Reynolds, T. D., and J. T. Yang, op. cit.
97. McKinney, R. E., "Mathematics of Completely-Mixed Activated Sludge," Journal of ASCE Proceedings (EE), vol. 88, p. 87, 1962.
98. Reynolds, T. D. and J. T. Yang, "Model of the Completely-Mixed Activated Sludge Process," Proceedings 21st Industrial Waste Conference, Purdue University, pp. 696-713, 1966.
99. Metcalf and Eddy, Incorporated, op. cit., pp. 391-394.
100. McCarty, P. L. and C. F. Brodersen, "Theory of Extended Aeration Activated Sludge," Water Pollution Control Federation Journal, vol. 34, pp. 1095-1103, November 1962.
101. Middlebrooks, E. J. and C. F. Garland, "Kinetics of Model and Field Extended Aeration Wastewater Treatment Units," Water Pollution Control Federation Journal, vol. 40, p. 586, April 1968.
102. Ibid., p. 590.
103. Kountz, R. R. and C. Forney, "Metabolic Energy Balance in a Total Oxidation Activated Sludge System," Sewage and Industrial Wastes, vol. 31, p. 819, July 1959.
104. Eye, D. J., et. al., "Field Evaluation of the Performance of Extended Aeration Plants," Water Pollution Control Federation Journal, vol. 41, pp. 1299-1318, July 1969.

105. Morris, G. L., et. al., "Study of an Extended Aeration Plant and Effluent Effect on the Receiving Watercourse," Proceedings 18th Industrial Waste Conference, Purdue University, pp. 331-347, 1963.
106. Gaudy, A. F., P. Y. Yang, and A. W. Oboyashi, "Studies on the Total Oxidation of Activated Sludge With and Without Hydrolytic Pretreatment," Proceedings 25th Industrial Waste Conference, Purdue University, p. 342, 1970.
107. Baker, R. J., Jr. "Package Aeration Plants in Florida," Journal of ASCE Proceedings (EE), vol. 88, p. 75, 1962.
108. Eye, D. J., et. al, op. cit.
109. Morris, G. L., et. al., op. cit.
110. Westrick, J. J., et. al., op. cit.
111. Andersen, D. R., "Pharmaceutical Wastewater; Characteristics and Treatment," Water and Sewage Works, vol. 118, pp. IW 2-6, March 1971.
112. Stewart, J., et. al., op. cit.
113. Kincannon, D. F. and A. F. Gaudy, op. cit.
114. Bott, W. B., op. cit.
115. Reynolds, T. D. and J. T. Yang, op. cit.
116. McKenzie, H. A. and H. S. Wallace, "The Kjeldahl Determination of Nitrogen: A Critical Study of Digestion Conditions - Temperature, Catalyst, and Oxidizing Agent," Australian Journal of Chemistry, vol. 7, p. 55. 1954.
117. Dixson, G. G. and H. L. Kaufman, "Turnpike Sewage Treatment Plants," Sewage and Industrial Wastes, vol. 28, pp. 245-254, March 1956.
118. Finn, R. H., "Plant Operation on the Ohio Turnpike," Water Pollution Control Federation Journal, vol. 34, pp. 1156-1160, November 1962.
119. Sylvester, R. O. and R. W. Seabloom, op. cit. p. 30.
120. Bott, W. B., op. cit.

BIBLIOGRAPHY

- Aberbach, R. J., "Water Reclamation and Reuse Team Up to Combat Water Pollution." Power, Vol. 113, pp. 57-9 October, 1969.
- Amiomy, A., "Reuse of Municipal Wastewater," Civil Engineering, Vol. 38, pp. 58-61, May 1968.
- Andersen, D. R., "Pharmaceutical Wastewater; Characteristics and Treatment." Water and Sewage Works, Vol. 118, pp. IW 2-6, March, 1971.
- "Avoid Pollution by Total Water Recycle" Canadian Chemical Processing, Vol. 56, pp. 25-6, April, 1972.
- Baker, R. H., Jr., "Package Aeration Plants in Florida," Journal of ASCE Proceedings (EE), Vol. 88, p. 75, 1972.
- Barber, J. C., "Waste Effluent; Treatment and Reuse," Chemical Engineering Progress, Vol. 65, pp. 70-3, June, 1969.
- Bott, W. B., "Feasibility of Recycling Grey Water at Highway Rest Stations," Virginia Highway Research Council, Charlottesville, Virginia, in publication.
- Brezina, E. R., R. S. Campbell, and J. R. Whitley, "Therman Discharges and Water Quality in a 1500-Acre Reservoir," Water Pollution Control Federation Journal, Vol. 42, pp. 24-32, June, 1970.
- Bruvold, W. H. and P. C. Ward, "Public Attitudes Toward Use of Reclaimed Wastewater," Water and Sewage Works, Vol. 117, pp. 120-2, April, 1970.
- Buchanan, R. D. "Partial Recycle: A New Sewerage System," Water and Sewage Works, pp. 46-7, January, 1972.
- Clayton, A. S. and P. J. Pybus, "Windhoek Reclaiming Sewage for Drinking Water," Civil Engineering, Vol. 42, pp. 103-6, September, 1972.
- Deaner, D. G., "Public Health and Water Reclamation," Water and Sewage Works, Vol. 117, pp. R 7-13, November 28, 1970.
- Dixson, G. G., and H. L. Kaufman. "Turnpike Sewage Treatment Plants," Sewage and Industrial Wastes, Vol. 28, pp. 245-54, March, 1956.
- Eller, J. "Water Reuse and Recycling in Industry," American Water Works Association Journal, Vol. 62, pp. 149-54, March, 1970.
- Eye, D. J., D. P. Eastwood, F. Requena, and D. P. Spath, "Field Evaluation of the Performance of Extended Aeration Plants," Water Pollution Control Federation Journal, Vol. 41, pp. 1299-1318, July, 1969.

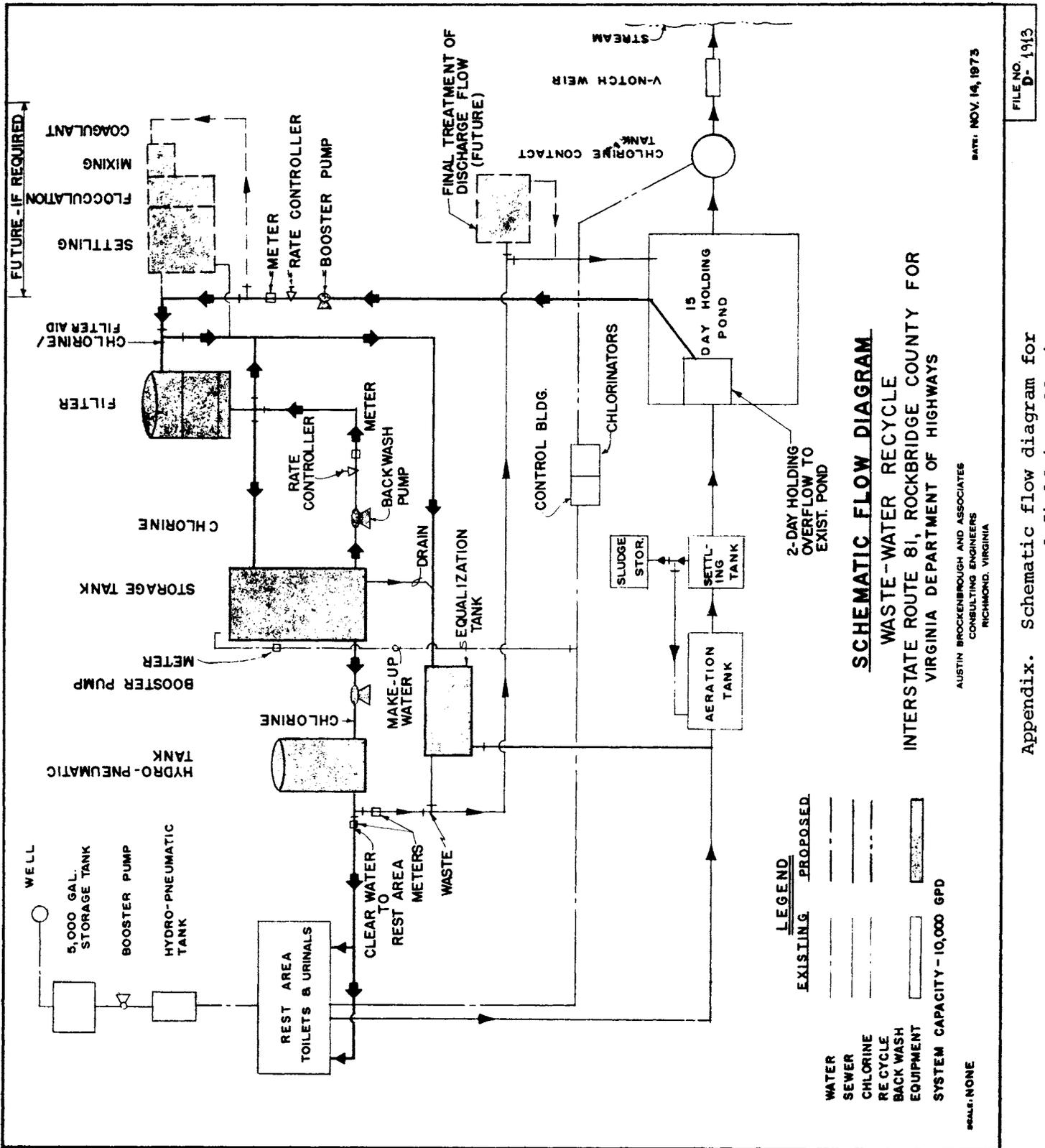
- Fair, G. M., J. C. Geyer, and D. A. Okun, Water and Wastewater Engineering, Vol. 2, Wiley and Sons, Inc., New York, 1968.
- Federal Water Pollution Control Act of 1972, Section 101, 92nd Congress, October 18, 1972.
- Finn, R. H., "Plant Operation on the Ohio Turnpike," Water Pollution Control Federation Journal, Vol. 34, pp. 1156-1160, November, 1962.
- Garthe, E. C. and W. C. Gilbert, "Wastewater Reuse at the Grand Canyon," Water Pollution Control Federation Journal, Vol. 40, pp. 1582-85, September, 1968.
- Gaudy, A. F., Jr., P. Y. Yang, and A. W. Oboyashi, "Studies on the Total Oxidation of Activated Sludge With and Without Hydrolytic Pretreatment," Proceedings 25th Industrial Waste Conference, Purdue University, p. 342, 1970.
- Garmhausen, W. J. "Rest Area Sanitary Disposal Systems," Highway Research Record, Number 161, p. 58-70, 1967.
- Goodman, B. L. and K. A. Mikkelson, "Advanced Wastewater Treatment; Removing Phosphorus and Suspended Solids," Chemical Engineering, Vol. 77, pp. 75-83, April 27, 1970.
- Heaton, R. "It's Reuse in the Rockies," Water and Waste Engineering, Vol. 9, pp. 32-4, June, 1972.
- Hougen, O. A., K. M. Watson, and R. A. Ragatz, Chemical Process Principles, Part I, 2nd Ed., Wiley and Sons, Incorporated, 1967.
- "How Fast Are U. S. Lakes Aging and Why?" Environmental Science and Technology, Vol. 7, pp. 198-9, March, 1973.
- "How Florida Keeps Water Untainted from Rest Stop Waste," Rural and Urban Roads, Vol. II, p. 24, July, 1973.
- Johnson, R. L. "Water Systems for Interstate Safety Rest Areas: Quantity and Quality Aspects," Highway Research Record, Number 280, pp. 39-52, 1969.
- Jopling, W. F., D. G. Deaner, and H. J. Ongerth, "Fitness Needs for Wastewater Reclamation Plants," American Water Works Association Journal.
- Keinath, T. M., "Water Reclamation and Reuse," Water Pollution Control Federation Journal, Vol. 44, pp. 981-6, June, 1972.
- Kincannon, D. F., and A. F. Gaudy, "Responses of Biological Waste Treatment Systems to Changes in Salt Concentrations," Biotechnology and Bioengineering, Vol. 10, pp. 483-496, 1968.
- Kountz, R. R. and C. Forney, "Metabolic Energy Balance in a Total Oxidation Activated Sludge System," Sewage and Industrial Wastes, Vol. 31, p. 819, July, 1959.

- Linstedt, K. D. "Quality Considerations in Successive Water Use," Water Pollution Control Federation Journal, Vol. 43, pp. 1681-94, August, 1971.
- Linstedt, K. D., K. J. Miller, and E. R. Bennett, "Metropolitan Successive Use of Available Water," American Water Works Association Journal, Vol. 63, pp. 610-15, October, 1971.
- Long, W. N. and F. A. Bell, "Health Factors and Reused Waters," American Water Works Association Journal, Vol. 64, pp. 220-5, April, 1972.
- Love, J. A. "Water: The Need for Action Now," American Water Works Association Journal, Vol. 63, pp. 658-60, October, 1971.
- McCarty, P. L. and C. F. Brodersen, "Theory of Extended Aeration Activated Sludge," Water Pollution Control Federation Journal, Vol. 34, pp. 1095-1103, November, 1962.
- McKenzie, H. A. and H. S. Wallace, "The Kjeldahl Determination of Nitrogen: A critical Study of Digestion Conditions - Temperature, Catalyst, and Oxidizing Agent," Australian Journal of Chemistry, Vol. 7, p. 55, 1954.
- McKinney, R. E., "Mathematics of Completely-Mixing Activated Sludge," Journal of ASCE Proceeding (EE), Vol. 88, p. 87, 1962.
- McLaughlin, E. R., "Recycle System for Conservation of Water in Residences," Water and Sewage Works, Vol. 115, pp. 175-6, April, 1968.
- Merrell, J. C. And A. Katko, "Reclaimed Wastewater for Santee Recreational Lakes," Water Pollution Control Federation Journal, Vol. 38, pp. 1310-1318, August, 1966.
- Metcalf and Eddy, Incorporated, Wastewater Engineering, McGraw-Hill, 1972.
- Metzler, D. F., F. M. Middleton, and others, "Emergency Use of Reclaimed Water for Potable Supply at Chanute, Kansas," American Water Works Association Journal, pp. 1021-1060, August 1958.
- Middlebrooks, E. J. and C. F. Garland, "Kinetics of Model and Field Extended Aeration Wastewater Treatment Units," Water Pollution Control Federation Journal, Vol. 40, p. 586, April, 1968.
- Middleton, F. M., "Concepts of Wastewater Reuse," Water and Sewage Works, Vol. 118, pp. R 59-62, August 31, 1971.
- Miller, D. G. and D. H. Newsome, "Conservation of Water by Reuse in the United Kingdom," Chemical Engineering Progress Symposium Series, Vol. 63, pp. 13-31, 1967.

- Miller, W. E. and T. E. Maloney, "Effects of Secondary and Tertiary Wastewater Effluents on Algal Growth in a Lake-River System," Water Pollution Control Federation Journal, Vol. 43, pp. 2361-5, December, 1971.
- Moore, C. W., "Wastewater Biotreatment: What It Can and Cannot Do," Chemical Engineering, pp. 63-66, December 25, 1972.
- Morris, G. L., L. A. Vandenberg, G. L. Culp, J. R. Geckler, and R. Porges, "Study of an Extended Aeration Plant and Effluent Effect on the Receiving Watercourse," Proceedings 18th Industrial Waste Conference, Purdue University, pp. 331-347, 1963.
- Nagiev, M. F., The Theory of Recycle Processes in Chemical Engineering, Translated by R. Hardbottle, MacMillan Company, 1964.
- NCHRP Synthesis of Highway Practice, "20-Rest Areas," Highway Research Board, Division of Engineering, National Research Council, 1973.
- Nesbitt, J. B. "Phosphorus Removal; the State of the Art," Water Pollution Control Federation Journal, Vol. 41, pp. 701-13, May, 1969.
- Norman, A. D., and A. W. Busch, "Biological Processes for Water Reuse," Chemical Engineering Symposium Series, Vol. 63, pp. 178-82, 1967.
- Ongerth, H. J. and S. A. Harmon, "Sanitary Engineering Appraisal of Wastewater Reuse," American Water Works Association Journal, Vol. 51, pp. 647-58, May 1969.
- Parker, C. E., "Water Reuse at Highway Rest Stations," Virginia Highway Research Council, Working Plan, 1972.
- "Potable Water from Human Wastes," Mechanical Engineering, Vol. 94, p. 37, July, 1972.
- "Reuse and Treatment of Wastewater; Solution Proposed," Mechanical Engineering, Vol. 94, pp. 88-90, May, 1972.
- "Reuse Water Instead of Dumping It," Manufacturing Engineering and Management, Vol. 67, p. 18, July, 1971.
- Rey, G., W. S. Lacy, and C. Allen, "Industrial Water Reuse: Future Pollution Solution," Environmental Science and Technology, Vol. 5, pp. 760-65, September, 1971.
- Reynolds, T. D., and J. T. Yang, "Model of the Completely-Mixed Activated Sludge Process," Proceedings 21st Industrial Waste Conference, Purdue University, pp. 696-713, 1966.
- Rich, L. G., Unit Processes of Sanitary Engineering, Wiley and Sons, 1963.

- Ritz, M. A., "Effects of Recycling on the Quality of Water and the Treatment System at Highway Rest Stations," Research Proposal, Virginia Highway Research Council, Charlottesville, Virginia, March, 1973.
- Ruttner, F., "Fundamentals of Limnology," 3rd Ed., Translated by D. G. Frey and F. E. J. Fry, Toronto Press, 1963.
- Sabastian, F. P., "Wastewater Reclamation and Reuse," Water and Wastes Engineering, Vol. 7, pp. 46-7, July 1970.
- Sawyer, C. "ABC's of Cultural Eutrophication and Its Control," Water and Sewage Works, Vol. 118, Part I, p. 278, Part II, p. 322, 1971.
- Sawyer, C. N. and P. L. McCarty, Chemistry for Sanitary Engineers, McGraw-Hill, New York, 1967.
- Sawyer, G. A., "New Trends in Wastewater Treatment and Recycle," Chemical Engineering, Vol. 79, pp. 120-8, July 24, 1972.
- Scherer, C. H. and J. L. Terry, "Reclamation and Industrial Reuse of Amarillo's Wastewater," American Water Works Association Journal, Vol. 63, pp. 159-64, March, 1971.
- "Sewage Wastewater to be Used Industrially," Civil Engineering, Vol. 42, p. 93, April, 1972.
- Shannon, E. S. and A. Maas, "Michigan - Industry Reuse of Treated Waste," American Water Works Association Journal, Vol. 63, p. 154, March 1971.
- Shindala, A., "Nitrogen and Phosphorus Removal from Wastewater," Water and Sewage Works, Vol. 119, pp. 66-71, June, 1972.
- "Short-Cut Rest Area Sanitary Facility," Better Roads, p. 22-3, January, 1973.
- Sienko, M. J. and R. A. Plane, Chemistry, 3rd Ed., McGraw-Hill, New York, 1966.
- Smyth, F., "Multiple Water Reuse," American Water Works Association Journal, Vol. 63, pp. 623-5, October, 1971.
- Sopper, W. E., "Wastewater Renovation for Reuse Key to Optimum Use of Water Resources," Water Research, Vol. 2, pp. 471-80, September, 1968.
- Standard Methods for the Examination of Water and Wastewater, 13th Ed., American Public Health Association, 1971.
- Stander, G. S. and L. R. S. Van Vuuren, "Reclamation of Potable Water from Sewage," Public Works, Vol. 101, pp. 132-3, May, 1970.
- Stevens, D. B. "Wastewater Reuse," Water Pollution Control Federation Journal, Vol. 40, pp. 677-83, April 1968.

- Stewart, J., H. F. Ludwig, and W. H. Kearns, "Effects of Varying Salinity on the Extended Aeration Process," Water Pollution Control Federation Journal, Vol. 34, pp. 1161, 1177, November, 1962.
- Streeter, N. W. and E. B. Phelps, Public Health Bulletin 146, U. S. Public Health Service, 1925.
- Suhr, L. G., "Some Notes on Reuse," American Water Works Association Journal, Vol. 63, pp. 630-3, October, 1971.
- Sylvester, R. O., and R. W. Seabloom, Rest Area Wastewater Disposal, Washington State Highway Commission, January, 1972.
- "Water Reuse on Pikes Peak," Public Works, Vol. 101, p. 83, November, 1970.
- Weinstein, R. H. "Water Recycling for Domestic Use," Astronautics and Aeronautics, Vol. 10, pp. 44-51, March, 1972.
- Weismantel, G. E., "Denver Aims at Total Reuse," Chemical Engineering, Vol. 78, pp. 82-3, May 17, 1971.
- Westrick, J. J., J. M. Morand, and D. J. Eye, "A Field Study of the Extended Aeration Process," Proceedings 21st Industrial Waste Conference, Purdue University, p. 424, 1966.
- Wolf, H. M., "Biological Problems with Reused Water," American Water Works Association Journal, Vol. 63, pp. 181-5, March, 1971.



Appendix. Schematic flow diagram for proposed field installation

