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Diana L. Weigmann
Interim Director

Abstract

Nearly 700,000 Virginians depend on septic tanks and other wastewater treatment systems for treatment of household wastes. The Virginia General Assembly's Joint Subcommittee Report HJR 7 (1987) noted that 60% of the state's residential septic systems and drainfields are operating improperly. With the demand for rural and suburban development increasing, a viable alternative to septic systems and drainfields is needed. One alternative is single-family package treatment systems. However, since a majority of these systems discharge directly into surface waters, the effectiveness of such systems is of vital concern. The objective of this study was to evaluate the performance of aerated package treatment systems (APTS).

Five APTS located in southwestern Virginia were chosen for the study. Each site was visited three times during 1990 and 1991, and various parameters were monitored from the primary settling chamber, aeration chamber, and effluent. Systems were sampled in the morning, afternoon, and night. Also, two dye studies were conducted to evaluate hydraulic displacement.

The results indicate that overall field performance was poor due to unreliable maintenance by homeowners, an ineffective chlorinator/dechlorinator system, inadequate biological treatment, and mechanical malfunctions. Eighty-one percent and 62% of the effluent samples were found to have five-day biochemical oxygen demand (BOD_5) and total suspended solid (TSS) concentrations exceeding 30 mg/l, respectively. Effluent dissolved oxygen (DO) values were less than 5 mg/l, the state's standard for small package treatment systems. Sixty-four percent of the effluent samples were found to contain more than 200 fecal coliforms (FC)/100 ml. In five instances where disinfection was evident, chlorine residuals were detected in the effluent, which also violates state standards.

Key Words: Aerated package treatment systems (APTS), onsite wastewater treatment systems, Virginia Pollutant Discharge Elimination System (VPDES) General Permit, National Sanitation Foundation (NSF) Standard 40, dry-feed tube chlorinator/dechlorinator, nutrients, biological data.

1 Introduction

Some situations are unsuitable for septic tank and drainfield use. The soil matrix may be impermeable or too porous, or the subsurface may include fissured rock conditions. The soil's depth to bedrock may be too shallow, or the water table too high. Furthermore, the site's slope may be excessive, or the area may be insufficient for proper treatment.

Soils suitable for a septic tank and drainfield are limited, and rural home construction on these soils can deplete agricultural lands. There are 17-20 million individual waste disposal systems in the United States, and 68% of U.S. land is inappropriate for drainfield systems (Brewer et al., 1978; Glasser, 1975).

In Virginia, approximately 700,000 residents depend on septic tanks and other wastewater treatment systems for treatment of household wastes. The Virginia General Assembly's Joint Subcommittee Report HJR 7 (1987) notes that 60% of Virginia's residential septic systems and drainfields are operating improperly (Weigmann, 1991). A number of these systems are failing due to undersized lots, inadequate system capacity, and/or unsuitable soil conditions.

Usually, it is not economically feasible for rural areas to connect to community water and sewerage systems. With increasing demand for rural and suburban development, a viable alternative to septic systems and drainfields is needed. One proposed alternative is single-family aerated package treatment systems (APTS).

As of June 1991, 1,000 individual Virginia Pollutant Discharge Elimination System (VPDES) permits regulating small package treatment systems had been issued (Weigmann, 1991). With increasing requests for APTS, the potential for point-source pollution is a major consideration. Thus, the objectives of this study were to:

- evaluate APTS field performance,
- relate APTS performance to the system's design, operation, and maintenance, and
- evaluate the suitability of the state's proposed standards regarding APTS.

Five APTS, located in southwestern Virginia and in operation for 2-4 years, were chosen for this study. Four of the systems discharge directly into surface waters; the fifth system discharges into a hillslope soil. To evaluate the systems' performance, parameters such as five-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), suspended solids (SS), and nutrients were monitored throughout each system to determine the level of treatment. Chlorine residuals and coliform bacteria were monitored to determine the effectiveness of the dry-feed tube chlorinator/dechlorinator system. Also, two dye studies were conducted to evaluate hydraulic displacement.

Literature detailing APTS performance for the past 30 years was reviewed, and comparisons of APTS and septic effluent treated by polishing techniques such as sand filters were reviewed. A field study involving soils that failed to treat septic effluent, but effectively treated APTS effluent, also was reviewed. Finally, Virginia's regulations for package treatment systems were compared to those of neighboring states.

2 Literature Review

This chapter reviews literature specifically regarding APTS. First, the National Sanitation Foundation (NSF) Standard 40, which certified the APTS evaluated in this study, is discussed. Next, field studies involving the evaluation of APTS are addressed. Finally, Virginia's regulations governing APTS and other package treatment systems are presented.

2.1 NSF Standard 40

The NSF Standard 40 was created to provide guidance for evaluating the performance of individual aerobic wastewater treatment systems and to quantitatively analyze their bearing on public health and the surrounding environment. Equipment that conforms with the NSF Standard 40 has the NSF seal.

2.1.1 System Description

The APTS evaluated by the NSF is identical to the five systems chosen for this study. As detailed in the 1984 NSF report, *Wastewater Technology*, the APTS has a volumetric capacity of 1300 gal and a flowrate capacity of 500 gal per day (gpd). The precast concrete tank consists of three chambers: a primary settling chamber, an aeration chamber, and a clarification chamber. See figure 1.

All household wastewater enters the primary settling chamber by gravity flow. This chamber has a volumetric capacity of 450 gal. The entire chamber is below grade, and has a sealed circular cover that can be removed for inspection or sludge pumping. The primary settling chamber serves two purposes: anaerobic degradation and settling. The anaerobic environment enables degradation of organic material, while denser solids, both organic and inorganic, settle to the bottom. The primary-treated wastewater is hydraulically displaced through a transfer port to the aeration chamber. A cast-in-place tee baffle is positioned in front of the transfer port to prevent floating scum, sludge, and grease from entering the aeration chamber.

In the 600-gal aeration chamber, wastewater is treated by aerobic degradation of the organic material. Oxygen is introduced into the system by an aeration motor encased in a flood-proof housing that is mounted and centered in an access riser above grade. A stainless-steel air shaft extends below the motor into the wastewater. At the tip of the shaft is an aspirator. A pressure differential between the aspirator and the air intake located on the cover of the access riser forces air into the wastewater from the hollow shaft. Meanwhile, the shaft rotates, mixing the air and the wastewater. The aerated wastewater exits at the bottom of the aeration chamber into the clarification chamber.

The hopper-shaped clarification chamber has a volumetric capacity of 250 gal. As water is hydraulically displaced upward, solids settle to the bottom and are drawn to the aeration chamber by circulation. Water at the top of the chamber exits through a 1.5-ft-long filter consisting of horizontal woven synthetics. An above-grade access riser and cover are located above the filter.

2.1.2 Performance Evaluation

The APTS was operated from November 7, 1977, to May 7, 1978, for general test conditions. The testing required sampling from the three chambers for analysis of various parameters, as shown in table 1. The APTS was dosed with 500 gpd at the following times and flow percentages: 6-9 a.m., 35%; 11 a.m.-2 p.m., 25%; 5-8 p.m., 40%. The wastewater consisted of comminuted raw sewage with a median BOD_5, SS, volatile suspended solids (VSS), and pH of 139 mg/l, 196 mg/l, 68 mg/l, and 7.5, respectively.

The NSF introduced stress testing as a requirement for certification after the APTS passed general test conditions. Stress testing included 24-hr composite sampling of influent and effluent waters immediately before and for 7 days following four different situations. These four situations were 5 days of wash-day loading, 5 days of working-mother loading (no loading 9 a.m.-5 p.m.), 48 hours of equipment/power failure, and return from one week of vacation with shock loading to the system.

The APTS was returned to NSF for stress testing in August 1981 with one addition to the system: a chamber with a submersible pump and filter backwash-discharge system after the clarification chamber. This chamber also had an access riser and cover.

2.1.3 Effluent Requirements

For the general test conditions, the APTS had to meet Class I requirements. Class I requirements are twofold. First, BOD_5 and SS concentrations must be less than or equal to 20 mg/l and 40 mg/l, respectively, for at least 90% of the samples. EPA secondary treatment guidelines also must be met: the BOD_5 and SS arithmetic mean for 30 consecutive days must be less than or equal to 30 mg/l with at least 85% removal, and the

BOD_5 and SS arithmetic mean for 7 consecutive days must be less than or equal to 45 mg/l. The allowable pH range is 6.0-9.0.

The second requirement for Class I is that the effluent be tested 3 times in 6 months at a dilution of 1:1000 for color, threshold odor, oily film, and foam. Color must be less than 15 units, threshold odor must be nonoffensive, oily film nonvisible, and foam nonexistent.

For stress testing, Class II requirements had to be met. All composite samples for BOD_5 and SS, 24 hours after the completion of one of the four situations mentioned previously, had to be less than or equal to 60 mg/l and 100 mg/l, respectively, 90% of the time.

2.1.4 Analytical Results

For general test conditions, the effluent BOD_5 values ranged from 2-31 mg/l with a median of 11 mg/l. Ninety percent of the BOD_5 samples were 20 mg/l or less. The 30-day average was less than 30 mg/l, and the removal efficiency was greater than 85%. The 7-day average was less than 45 mg/l. For effluent SS values, the median was 16 mg/l, and 90.6% of the samples had SS values less than 28 mg/l.

The effluent color was less than 0.5 units, and the threshold odor number was less than 1. Oily film and foam were not detectable. Therefore, requirements for Class I were met.

The median DO reading in the aeration chamber was 8.0 mg/l; the minimum reading was 2.1 mg/l. The median DO reading in the effluent was 4.2 mg/l; the minimum reading was 1.1 mg/l. The mixed liquor suspended solids (MLSS) range was 13-208 mg/l with a median of 41 mg/l.

For all four stress-test cases, effluent BOD_5 values were less than 60 mg/l, and effluent SS values were less than 100 mg/l. Therefore, Class II requirements were met.

Finally, no maintenance was required on the APTS throughout the NSF study. This excellent maintenance record and low BOD_5 and SS effluent values are not representative of the APTS field performance; thus, studies are presented for APTS performance in field conditions.

2.2 Field Studies

Numerous field studies have been performed on APTS in the past 30 years. Mostly, BOD_5 and SS have been monitored, but other parameters, such as nutrients and bacteria, also have been measured. Also, system operation and maintenance have been surveyed, since homeowner interaction, or lack thereof, has been most influential. Furthermore, different polishing techniques for aerobic effluent and its subsequent discharge to the soil and/or surface water have been studied.

The following field studies provide vital information, since they involve the treatment of domestic wastewater from actual households, not flow-proportioned comminuted raw wastewater from the local sewer for simulation of field conditions. These field conditions include variations in the following: wastewater composition, operation and maintenance by the homeowner and/or distributor, hydraulic and organic loadings, and other circumstances difficult to reproduce.

2.2.1 System Operation and Maintenance

Various problems associated with APTS installation, operation, and maintenance are cited in the literature. The Ohio Department of Health (1978) evaluated 61 aerobic units, and reported that 38% were inadequately constructed and 86% did not have appropriate sampling locations. Voell and Vance (1974) cited buried systems with no access. Four of the 5 systems that Glasser (1975) evaluated needed adjustments or repairs within the first 30 days of operation. Glasser recommended that systems be inspected within 10 days of installation.

In terms of operation, Asbury and Hendrickson (1982) inspected 12 APTS and found only 4 systems operating properly; the remaining 8 systems had mechanical malfunctions, 3 of which were due to motor failures. Brewer et al. (1978) also reported mechanical malfunctions: 51 APTS were monitored, and the survey reported that poor effluent, as determined by turbidity, color, and/or odor, was recorded in 21 systems; of those 21 systems, 16 had mechanical malfunctions. Thus, the authors concluded that the poor effluent could be attributed to lack of maintenance and system aging, since 14 of the malfunctioning systems had been operating for 2-4 years.

Hutzler et al. (1978) studied 36 APTS, ranging in age from 6-10 years, for 18 months . Twenty-four percent had mechanical malfunctions, of which 6% were attributed to aerator failure. Twenty-one percent of the systems were mechanically sound, but discharging poor effluent; 18% had no chlorine residual, and 3% had high BOD_5 and SS values.

Voell and Vance (1974) studied 151 APTS, and reported that 57% had high SS values and 75% did not have chlorine tablets in the dry-feed tubes. The authors reported that clogging by hair and lint caused motors to fail. Waldorf (1978) concluded that most mechanical malfunctions were due to electric pump failures.

With high possibilities of mechanical malfunctions and infrequent servicing, homeowner neglect or ignorance can lead to periods in which APTS discharge poor effluent (Bennett et al., 1973; Brewer et al., 1978); thus, the Virginia Water Resources Research Center (VWRRC) surveyed homeowners about system maintenance, installation, repairs, discharges, operation, and overall performance (Weigmann, 1991).

The VWRRC sent surveys to approximately 700 residents having onsite treatment systems. The VWRRC received 152 completed surveys from APTS owners and 82 completed surveys from sand-filter (SF) owners. Eighty-four and 97% of the APTS and SF owners, respectively, reported no system repairs. Eighty-four and 82% of the APTS and SF owners, respectively, reported satisfaction with their systems. Eighty-five and 93% of the APTS and SF owners, respectively, said they were knowledgeable of their systems.

In terms of effluent quality, 21 and 37% of the APTS and SF owners, respectively, reported that the effluent had never been tested. Nearly 80% of APTS and SF owners said the effluent was clear. Voell and Vance (1974) noted that effluent from 66% of the 151 APTS was clear; effluent from the remaining 34% was turbid, mainly due to improper maintenance. They also found chlorine tablets lodged in tubes and, thus, not coming in contact with the water. VWRRC reported that "about 33% of the owners used none or did not know how much chlorine they added, and 40-55% of the owners did not dechlorinate" (Weigmann, 1991). Hutzler et al. (1978) also attributed poor effluent to homeowner neglect. Cases were cited in which homeowners disposed of household hazardous wastes in their systems.

Some homeowner neglect could be avoided if all systems had alarms. The Ohio Department of Health (1978) found that 6% of the systems had no alarms. Only 54% of APTS owners and 14% of SF owners reported to VWRRC that they had alarms for detecting system malfunctions (Weigmann, 1991). Furthermore, Hutzler et al. (1978) found 3% of the systems not operating because the homeowners had turned off the electricity. VWRRC noted that 9% of APTS owners turned off their system's electricity when they would be gone for at least two days (Weigmann, 1991).

Hutzler et al. (1978) reported that surge flows cause poor effluent. Bennett et al. (1973) noted that surge flows prevent a build-up of biomass in the return sludge, and cause solids washout in the effluent: "under normal home-use conditions, a maximum quantity of about 60 gallons will be surged into the unit in a time period of 7-30 minutes."

For proper operation and maintenance, frequent inspection is imperative. Glasser (1975) stated that APTS should be inspected four times per year, with mandatory inspections within 10 days of installation or major repair. Otis et al. (1975) noted that APTS should be inspected every two months and solids pumped out once per year. Voell and Vance (1974) noted that solids should be removed once every three years and systems should be inspected more than twice per year. Also, legal easement to the system and easy access to all system components and sampling locations is essential (Hutzler et al., 1978; Ohio Department of Health, 1978).

Finally, lifetime maintenance contracts with the distributor are necessary. Most distributors initially offer two-year contracts. However, many homeowners do not renew their contracts (Voell and Vance, 1974). Only 37% of the APTS owners surveyed by VWRRC had maintenance contracts; no SF owners had contracts. This statistic indicates that homeowners are not renewing their contracts, since the APTS and SF median ages were two and four years, respectively (Weigmann, 1991).

2.2.2 APTS Effluent Analysis

Field studies, including effluent analysis of different APTS, both continuous flow and batch flow, have been performed in the past 30 years. Effluent quality was determined mostly by analysis of BOD_5 and SS. Refer to table 2 for BOD_5, SS, and COD results. Systems identified in the literature are listed with their respective authors in table 2.

In only five instances was the BOD_5 reported below 30 mg/l, and no instances showed the SS below 30 mg/l as required by Virginia's Emergency Regulations for APTS (SWCB, 1991). Complete organic and solids degradation was not accomplished (Ohio Department of Health, 1978). Also, variability in effluent values could be attributed to surge flows and lack of maintenance. Otis et al. (1975) reported better treatment with APTS than septic tanks with regard to BOD_5, but the

APTS values had a higher degree of variability; thus, aerobic units were more prone to upsets than septic tanks. Otis et al. (1975) also reported SS effluent values for APTS and septic tanks to be similar.

Total nitrification would be expected with APTS, since hydraulic and solids retention times are usually high (EPA, 1980); but, as shown in table 3, only half of the instances show nitrification. Otis et al. (1975) reported complete nitrification with 50% total nitrogen (TN) removal. Phosphorus results were scarce, as shown in table 3, but the EPA (1980) reported that a total phosphorus (TP) reduction of less than 25% could be expected. However, Glasser (1975) reported that four out of five units had TP reductions of 76%. Nonetheless, additional nutrient removal may be necessary if discharge to surface waters is desired.

Proper disinfection is also necessary for discharge to surface water (Effert et al., 1985; EPA, 1980; Otis et al., 1975; Voell and Vance, 1974; Waldorf, 1978) (see table 4). The Small Scale Waste Management Project (1978), as cited by Hutzler et al. (1978), studied APTS with dry-feed tube chlorinators, and found 75% missing chlorine tablets, and other systems with the tablets stuck in the tubes and not in contact with the wastewater. Otis et al. (1975) compared the results of aerobic and septic effluent without disinfection in terms of bacterial counts. They noted a decrease in fecal coliforms (FC) with aerobic treatment only, but no substantial decrease in fecal *Streptococcus* (FS) with aerobic or septic treatment. Waldorf (1978) noted iodine to be effective as a disinfectant, but initial costs were high.

Table 4 also shows DO and pH effluent readings. All pH readings are within the acceptable range for biological treatment. DO readings fluctuate, with more than half of the instances having DO values below Virginia's Emergency Regulations level of 5 mg/l (SWCB, 1991).

2.2.3 Sand Filtration of APTS Effluent

To further reduce BOD_5 and SS concentrations for discharge to surface water, APTS and septic tank effluents have been applied to sand filters. Waldorf (1978) applied 16 APTS effluents to sand filtration and disinfection, yielding a range of BOD_5 and SS values of 2-11 mg/l and 1-44 mg/l, respectively.

Sauer (1977) applied both APTS and septic tank effluents to sand filters. There was little difference in both effluents after filtration, as shown in table 5. For both cases, a hydraulic loading rate of 5 gpd/ft^2 was recommended to determine the sand filter's surface area. Otis et al.

(1975) recommended loading rates to sand filters of less than 10 gpd/ft^2. The typical sand filter contained 30 in. of sand with 6 in. of pea gravel and 6 in. of coarse gravel below (Sauer, 1977). Sauer (1977) concluded that longer filter runs could be obtained with "larger sand sizes, lower hydraulic loading rates, and lower wastewater organic strengths."

For the septic tank/sand filter system, Sauer (1977) recommended two sand filters operating intermittently, each filter's surface area being determined by a hydraulic loading rate of 5 gpd/ft^2. After operating for three months, the first sand filter would be raked and then allowed to rest for another three months while the second one would be in use. Following the first sand filter's next operation cycle, the crust and 4 in. of sand would be removed and replaced. For the APTS/sand filter case, only one sand filter was recommended. Maintenance would be required every six months, including removal of the crust and approximately 1 in. of sand with replacement of the sand.

Effert et al. (1985) also studied sand filtration of APTS and septic tank effluents. The authors concluded that little difference existed between sand-filtered effluents from APTS or septic tanks: both systems produced complete nitrification, similar DO, BOD_5, SS values, and TP reductions greater than 28%. Also, the sand filters required no maintenance for the 22-month study. Effert et al. (1985) monitored two APTS followed by upflow gravity filters and subsurface gravel beds. Treatment level achieved with gravity filters and subsurface gravel beds was less than the treatment level with sand filters.

In determining which system (APTS or septic tank) to choose for use with a sand filter, a couple of factors must be considered. The septic-tank system costs less than the APTS and has few operational problems; however, the APTS requires only one sand filter (less surface area) and less maintenance. Whether an APTS/sand filter or septic tank/sand-filter system is chosen for discharge to surface water, disinfection is imperative (Sauer, 1977; Effert et al., 1985; Waldorf, 1978).

2.2.4 Soil Absorption of APTS Effluent

A field study by Locker et al. (1981) demonstrated that soils that failed to treat septic tank effluent treated APTS effluent effectively. In fact, the four sites that had previous septic tank/soil absorption failures had been operating with APTS for 2-4 years when the study was conducted. All sites had percolation rates exceeding 60 min/in. and high water tables within 12 in. of the ground surface. Seepage fields receiving the APTS effluent had been reduced in size by at least 50% in each case. Only one site had a couple of inches of ponding for one month in the spring when the ground was completely saturated. By analyzing soil samples, the authors concluded that "the majority of the water was being disposed of in the upper 12 in. of soil or through evaporation and transpiration."

"The use of aerobic systems rather than anaerobic systems prior to a subsurface absorption field increases the efficiency of the field by improving the rate of both soil infiltration and evapotranspiration" (Locker et al., 1981). The aerobic units' effluent has higher DO concentrations, enabling a higher chain of microorganisms to consume bacteria; thus, the formation of a crust layer is prevented (Locker et al., 1981; Glasser, 1975).

Locker et al. (1981) did not mention the possibility of nutrients entering the effluent. Asbury and Hendrickson (1982) favored septic systems over APTS, since APTS can nitrify the waste and, thereby, discharge oxidized forms of nitrogen. Also, the authors pointed out that septic systems have lower operation and maintenance costs and fewer operation and maintenance problems. Thus, septic systems should be used in soils that can treat septic tank effluent effectively; however, APTS should be considered for soils that have failed to treat septic tank effluent, or do not meet standards for soil absorption.

2.3 Regulations Governing APTS Discharge to Surface Waters

Virginia's neighboring states are more stringent with regard to small package treatment systems discharging into surface waters. They require a system's effluent to be directed to a drainfield or monitored by a licensed operator.

For discharge to surface water, Maryland and North Carolina require that systems have a National Pollutant Discharge Elimination System (NPDES) permit and be monitored by a licensed operator. Maryland also requires all discharges to surface waters to be chlorine free; thus, systems must have dechlorinators. Pennsylvania requires an NPDES permit and a second permit for system construction and maintenance only after all other onsite treatment systems have been rejected. Tennessee requires a licensed operator for any system that discharges to surface waters. Delaware and South Carolina require all package systems to discharge to a drainfield (SWCB, 1991).

In Virginia, anyone who discharged pollutants from point sources to surface waters needed an individual Virginia Pollutant Discharge Elimination System (VPDES) permit issued from the State Water Control

Board (SWCB). This law included package treatment systems that discharge to surface waters. As of June 1991, 1,000 individual VPDES permits regulating small package treatment systems were in effect. These systems, which individually discharge 1,000 gpd or less, create a pollution load less than one small town's sewage treatment plant (SWCB, 1991); thus, two recommendations followed: (1) that a VPDES General Permit be created that covers the permitting process of all package treatment systems that discharge less than 1,000 gpd to surface waters, and (2) that the Department of Health assume responsibility for the permitting process and implementation of regulations. This would "allow the Water Control Board to devote more resources to the permitting of pollution sources with greater potential for water quality impacts" (SWCB, 1991).

The EPA approved the VPDES General Permit in June 1991, and the Health Department's responsibilities began upon the SWCB's adoption of the General Permit as a regulation. The General Permit does not take precedence over previous regulations prohibiting discharges to the state's waters. Central sewage facilities must be used if available, or a rejection from the Department of Health for an onsite sewage disposal system must be received. Also, the owner must receive the local government's approval. Finally, the potential permittee must submit a completed VPDES General Permit Registration Statement.

Once a General Permit has been granted, three criteria must be met by the permittee: effluent limitations and monitoring requirements, monitoring and reporting requirements, and management requirements. Refer to table 6 for effluent limitations and monitoring requirements.

The second requirement, monitoring and reporting, includes a description of methods to be used for sampling and analysis, and how results are to be recorded and reported. All records must be retained for five years and given to the SWCB if requested. Any abnormal discharges from a package treatment system should be reported within 24 hours, followed by a written submission within 5 days.

The third requirement, management, outlines the permittee's obligations and rights. The permittee is responsible for taking care of any system malfunctions or upsets. If additional pollutants are to be directed to the system, the SWCB must be notified 180 days prior to any change. The wastewater cannot bypass any section of the system. State and federal authorities have legal easement at reasonable times (any time is deemed reasonable during an emergency).

The permittee can transfer the permit, but must notify the SWCB 30 days in advance; the SWCB has the option of revocation within 30 days. A permit can be terminated only after a public notice and hearing.

The processes for obtaining a VPDES General Permit and following procedures after receiving it are lengthy and involved for the permittee. The permittee must follow all parts of the General Permit, including effluent limitations and monitoring, reporting, and management. These requirements include all costs. Thus, owner involvement with the package treatment system, including inspection of the effluent and operation and maintenance of the system, is necessary, and obligations of the state are mitigated.

3 Methods and Materials

This chapter details the methods of sampling and analysis used to evaluate the performance of five APTS located in southwest Virginia, hereafter referred to as APTS I-V. This chapter also includes a description of the system design and operation.

3.1 System Design and Operation

For overall system design and operation, refer to sections 2.1.1 and 2.1.2. All five APTS have four chambers: a primary settling chamber, an aeration chamber, a clarification chamber, and a submersible pump chamber with chlorination/dechlorination tablet feeders (figure 1). The wastewater travels through the first three chambers by hydraulic displacement. The filtered wastewater from the clarification chamber collects by gravity in the submersible pump chamber until the submersible pump is float-activated; then, the pump discharges approximately 16 gal (5 gal backwash the filter, and 11 gal discharge through the chlorination/dechlorination tablet feeders). The pump activation frequency is proportional to the wastewater flow, so the filter is backwashed frequently during peak flow.

The chlorinator consists of a 5-in. diameter water inlet, which directs the incoming water flow to 2 feed tubes in series (each 24 in. long with outside diameter of 3.5 in.). The bottom of the tubes are slotted, exposing tablets to the flow. The number of chlorine tablets immersed in the water and, thus, dissolved, is proportional to the flowrate. Usually, the second tube in the series has chlorine tablets that should dose a flowrate of 180 gpd, with a maximum dosage of 50 mg/l of available chlorine. If both tubes are full, the maximum dosage of available chlorine would be 70 mg/l (Eltech, 1989).

Two types of chlorine tablets were used in the APTS. Both types are 2.62-in. in diameter and 0.81 in. thick. Tablets recommended by the APTS manufacturer have 70% chlorine content and contain a combination of calcium hypochlorite and 1,3,4,6-tetrachloroglycoluril (Diamond Shamrock, 1979). Competitors' tablets contain 70% calcium hypochlorite (Jet, 1991).

The dechlorinator is similar in design to the chlorinator. These 2.62-in. diameter x 0.81-in.-thick tablets contain 91.5% sodium sulfite as the active ingredient. Two parts of sodium sulfite react with one part of free or combined chlorine, as shown in the following equation (Eltech, 1987):

$Ca(OCl)_2 + 2Na_2SO_3 \dashrightarrow 2Na_2SO_4 + CaCl_2$

Eltech (1987) reports that there is little reduction, if any, in pH or DO. All five APTS used the same dechlorination tablets.

For APTS I-III and V, the 11 gal of treated wastewater flows through the chlorination/dechlorination feeder tubes and then is discharged as effluent. Effluent from APTS III and V discharges into small streams. Effluent from APTS I is stored in a spray irrigation pumping chamber. Effluent from APTS II discharges into a hillslope soil. APTS IV has a baffled chamber to store the chlorinated liquid until the next float activation occurs, which displaces the chlorinated liquid through the dechlorinator and then discharges it into a stream.

Power to the submersible pump is supplied by an underground electrical cable. The aerator is connected by an underground electrical cable to a control panel in the owner's house. The control panel contains the following: manual-reset circuit breaker, on/off switch, audio/visual warning alarm, and distributor's address and telephone number. The warning alarm indicates operational malfunctions or high water when activated by aerator failure.

The aerator has a foam deflector to protect the motor against high water and foam. If water rises to the level of the foam deflector, the aerator shuts off automatically and the alarm is activated. Otherwise, the aerator operates continuously (Stone, 1990).

The aerator consumes approximately 200 W per hour with a 1/6-horsepower General Electric motor operating on 115 V and 60 Hz (Stone, 1990). The motor consumes 1,752 kWh per year; at 6 cents per kWh, the annual operation cost is approximately $105 (Virginia Tech Electric, 1991).

After the liquid is aerated, it travels into the clarification chamber and passes through a filter before entering the submersible pump chamber. The filter assembly consists of a 4-in. diameter by 18-in.-long synthetic filter tube that has a molded polyethylene internal support and a 4.25-in. diameter by 18-in.-long mesh retainer. The filter assembly is clamped onto the clarification chamber's outlet and rests in a horizontal position. By design, only the bottom of the filter is to be submerged in the clarified liquid (Stone, 1990).

Adjacent to the synthetic filter assembly is a plastic alarm extension pipe, which is placed vertically in the clarification chamber's outlet. This pipe's inlet is located higher than the aerator's foam deflector; thus, liquid can bypass the filter only after the alarm has been activated. Liquid would reach the pipe's inlet only if the filter or outfall were clogged.

3.2 Sampling Procedure

Each APTS was visited three times between 1990 and 1991 for an entire day of sampling and monitoring. The dates of each APTS start-up and the three trips are listed in table 7.

Grab samples for analysis of the following parameters were taken three times daily: BOD_5, COD, total suspended solids (TSS), total Kjeldahl nitrogen (TKN), ammonia (NH_4^+-N), nitrate (NO_3^--N), TP, orthophosphate (OP), chlorine residuals, fecal coliforms (FC), fecal *Streptococcus* (FS), DO, pH, and temperature. Samples were taken at 8-10 a.m., 3-5 p.m., and 9-11 p.m. It was assumed that peak flow typically occurred in the morning and at night, while low flow occurred in the afternoon, since Bennet et al. (1973) proved this to be the case. Excluding flowrate and effluent DO and pH, table 8 shows the parameters that were sampled for three times per day and their location. Flowrate analysis is outlined in section 3.8. One grab sample from each site was collected for effluent DO and pH.

All samples were pumped into 500-ml Nalgene square polyethylene bottles (Rochester, N.Y.) with a Peters & Russell hand pump (Springfield, Ohio). Chlorine residuals, DO, temperature, and pH were determined on site. Other samples were stored in ice on site and transferred to a 4°C incubator in the laboratory. Sample preservation was followed as outlined in *Standard Methods for the Examination of Water and Wastewater*, section 1060 B, unless otherwise noted.

Sodium thiosulfate ($Na_2S_2O_3$) was added to FC, FS, and BOD_5 effluent samples to neutralize any residual chlorine and prevent further bactericidal action as outlined in *Standard Methods for the Examination of Water and Wastewater*, section 9060 A. For the first set of trips, .5 ml of 5% $Na_2S_2O_3$ was added to neutralize up to 9 mg/l residual chlorine. Chlorine residuals greater than 9 mg/l were recorded at APTS IV; thus, for subsequent trips, 2 ml of 5% $Na_2S_2O_3$ was added, which could neutralize up to 36 mg/l residual chlorine.

Samples from the primary settling chamber were taken through the inspection cover approximately 2 ft below the water level. If a solids layer was present at this depth, samples were taken just above the solids layer. Samples from the aeration chamber were taken approximately 4 ft below the water level. For the second and third sets of trips, samples also were taken 2 ft below the water level. Samples from the submersible pump chamber were taken a couple of inches below the water surface, ensuring that any solids at the bottom were not disturbed. BOD_5, FC, and FS samples from the submersible pump chamber were taken before chlorination. Chlorine residual samples from the submersible pump chamber were taken after chlorination. After activating the submersible pump, effluent samples were taken from the effluent discharge pipe for APTS II-V (figure 1, item 20). Since the APTS I effluent was stored in a spray-irrigation pumping chamber, effluent samples were taken there.

3.3 Determination of Organic Constituents

The BOD_5 analysis was performed in accordance with *Standard Methods for the Examination of Water and Wastewater*, sections 5210 B and 4500 O G. Three sample dilutions were chosen with reference to table 22-1 in *Chemistry For Environmental Engineering* (Sawyer and McCarty, 1978). Triplicates were performed for each dilution. No seeding or nitrification inhibition was performed.

Analyses for BOD_5 were performed in a 20°C constant-temperature room. For the dilution water, a 20-l glass container was partially filled with 15 l of distilled water and placed in the constant-temperature room at least 2 days before initial BOD_5 readings. Parafilm was placed on the glass container, but not sealed, so that oxygen would be dissolved in the water. A YSI Model 54 ARC meter and a YSI 5720A self-stirring BOD bottle probe (Yellow Springs, Ohio) were used for DO readings. Filled BOD_5 incubation bottles were stored in cabinets to avoid photosynthesis.

The COD analysis was performed following the closed reflux, titrimetric method as described in *Standard Methods for the Examination of Water and Wastewater*, section 5220 C. Nonfiltered samples were digested at 150°C for 2 hours on an aluminum block heated by a Fisher scientific hotplate, Model 11-500-12H (Pittsburgh, Pa.). Duplicates were performed for each sample.

3.4 Solids Determination

All SS analyses were conducted in accordance with *Standard Methods for the Examination of Water and Wastewater*, sections 2540 D and 2540 E. TSS, VSS, MLSS, and mixed liquor volatile suspended solids (MLVSS) were determined. Using a vacuum pump, suspended solids were collected on Whatman 934-AH glass microfibre 5.5-cm filters (Hillsboro, Ore.). For TSS and MLSS determinations, samples were dried at 103-105°C for 1 hour in a Precision Scientific Thelco Model 28 oven (Chicago, Ill.). For VSS and MLVSS determinations, samples were ignited at 550°C for 20 minutes in a Fisher Isotemp Muffle Furnace Model 186A (Pittsburgh, Pa.). Samples were weighed on a Fisher Scientific Mettler H10 scale (Hightstown, N.J.).

3.5 Fecal Coliform and Fecal *Streptococcus* Determination

Analyses were performed by personnel in the Plant Biotechnology Applications Laboratory at Virginia Tech in accordance with *Standard Methods for the Examination of Water and Wastewater*, sections 9222 A and 9230 C. Each sample was shaken well, and serial dilutions of 10^{-1}, 10^{-2}, 10^{-3}, and 10^{-4} were prepared. For FC plating, 100x15-mm petri plates were used. One-tenth ml was pipetted from 10^{-1}, 10^{-2}, and 10^{-3} dilutions and spread on media with a sterilized glass rod to make 10^{-2}, 10^{-3}, and 10^{-4} dilutions, respectively. The glass rod was sterilized by being dipped in ethyl alcohol and flamed. The medium, BBL eosin methylene blue agar (Cockeysville, Md.), was prepared and autoclaved according to label instructions.

For FS plating, 50x9-mm petri plates were used. Dilutions of 10^{-1}, 10^{-2}, 10^{-3}, and 10^{-4} were filtered through a Presterilized Autoclavable Pack (Gelman Sciences, 47 mm, gridded, 0.45-um Metricel membrane filter and pad, Ann Arbor, Mich.). The filter was placed with sterilized forceps on the media, inoculum side up, and then sealed with the other plate. The filtration apparatus was sterilized between filtrations with approximately 75 ml of denatured ethyl alcohol. The medium, BBL M-Enterococcus agar (Cockeysville, Md.), was prepared according to label instructions.

All petri plates were incubated in a Fisher Scientific Isotemp incubator, Model 630 D (Pittsburgh, Pa.), for 48 hours at 35°C. Colonies were counted with a Quebec Darkfield colony counter, Reichert Scientific Instruments, Model 3325 (Buffalo, N.Y.), and a magnifying glass. For FC determinations, only colonies having a metallic sheen were counted. For FS determinations, only red colonies were counted. For both FC and FS analyses, duplicates for each dilution were prepared, and the average recorded.

3.6 Dissolved Oxygen, pH, and Temperature Measurements

A grab sample was taken from the aeration chamber, and measurements were taken promptly. DO was determined using a YSI Model 54 ARC meter and a YSI 5739 submersible probe (Yellow Springs, Ohio). Temperature and pH then were determined using a Corning pH/°C 107 meter with a 476441 Corning electrode (Corning, N.Y.). Both the DO and the pH/temperature instruments were calibrated before measurements were taken.

3.7 Chlorine Measurements

Total residual chlorine (TRC) and free residual chlorine (FRC) were determined with an amperometric titrator, Model 17T1010 (Pittsburgh, Pa.). Before analysis, the titrator was calibrated with a 5×10^{-4}% chlorine solution (bleach with 5.25% sodium hypochlorite was diluted 1:10,000). For the first two sets of trips, this calibration was performed the night before analysis. For the last set of trips, calibration was performed the morning of the site trips. A 200-ml grab sample (or known dilution) was analyzed. For TRC analysis, 1 ml of both pH 4 buffer and 5% potassium iodide solution was added to the sample. The titrator's switch was placed in the TOTAL position, and the sample was titrated with phenylarsene oxide solution until the end point was reached (Fischer and Porter, 1968).

For FRC analysis, 1 ml of pH 7 buffer was added to the sample. The titrator's switch was placed in the FREE position, and titrant was added to the sample until the end point was reached. For both TRC and FRC analysis, the amount of titrant used was equal to the amount of total chlorine or free chlorine in the sample, respectively (ml = mg/l). If the sample were diluted, then the amount of titrant would be multiplied by the dilution factor (Fischer and Porter, 1968). Duplicates were performed and averages recorded.

3.8 Flowrate Analysis

The flowrate was monitored at each site for at least 18 days using a device developed by the Virginia Tech civil engineering department's electrician, C. Brown. This device consists of the following parts: Fluidmaster toilet tank repair valve, Model 200A (Anaheim, Cal.); Micronta Walk-Mate pedometer, Catalogue #63-671 (Fort Worth, Tex.); and a mercury switch. The device was rigidly held by a clamp connected to a ring stand and placed in the submersible pump chamber (figure 2). The mercury switch was placed horizontally on the arm of the toilet tank repair valve. At this resting position, the mercury switch was open. As the water level increased in the submersible pump chamber, the float on the toilet tank repair valve rose, causing the mercury switch to close. The pedometer was wired to the mercury switch so that it would record a closure as one increment. The height of the instrument was adjusted so that the mercury switch would close seconds before the activation of the submersible pump. To protect it from the moist environment, the pedometer was placed in a ziplock bag containing silica gel.

3.9 Dye Study

Two dye studies were performed at APTS I with 50-ml slugs of 0.1% Rhodamine B solution. The primary settling chamber, aeration chamber, and effluent from the clarification chamber were monitored. All samples were analyzed for fluorescence using a Turner fluorometer, Model 111 (Palo Alto, Cal.), and following instructions from the manual by Turner Associates (1974).

The first dye study was performed from May 23 through June 6, 1991. The Rhodamine B solution was poured into the primary settling chamber. For the first two days, samples were analyzed on site and stored at 4°C. Subsequent samples were stored at 4°C and analyzed in the laboratory to avoid extraneous light, which affected the fluorometer.

The second dye study was performed on June 11, 1991. The Rhodamine B solution was poured into the household washer effluent line; then, approximately 1600 gal of water was pumped from a truck to the APTS via the washer effluent line. The flowrate was monitored by a GPI electronic digital meter, Model 1A31GM*5 (Wichita, Kan.). The experiment lasted for approximately 8 hours, and samples were analyzed on site by fluorometry.

3.10 Nutrients Determination

All nutrient analyses were performed by personnel in the Soil Environmental Quality Laboratory at Virginia Tech, unless otherwise noted.

3.10.1 Total Phosphorus

Samples were shaken, and 10 ml pipetted into test tubes. Eight ml of nitric acid was added to each test tube. Samples then were stored at 4°C until one cycle of trips had been completed. Test tubes then were placed in an aluminum block on a GS Lindberg hot plate, Model 53015 (Watertown, Wis.), and 2 ml of concentrated perchloric acid was added to each tube. The tubes were digested in increasing heat increments: first the nitric acid was volatilized, then the perchloric acid was volatilized, and, finally, samples were digested until approximately 1.5 ml remained (Payne et al., 1988). The digested samples were allowed to cool, and then brought to a 25-ml volume with 1.2 N HCl. Samples from the first set of trips were filtered through acid-washed Whatman #42 filter paper (Payne et al., 1988). Samples from the second and third sets of trips were not filtered, since a precipitate was not visible.

Samples then were analyzed for TP by the Soil Testing and Plant Analysis Laboratory with a Jarrell-Ash ICAP 9000 simultaneous spectrometer (Franklin, Mass.). The samples also were simultaneously analyzed for copper, iron, manganese, sulfur, and zinc.

3.10.2 Orthophosphate

All samples were analyzed for OP within 48 hours of returning from a site trip. Samples were filtered through cellulosic, white grid, 0.45 μ, 47 mm, sterile membrane filters (Ann Arbor, Mich.) with a vacuum pump. Five ml of filtrate was collected and diluted to 50 ml with distilled water. The analysis then followed the procedure outlined in *EPA Methods for Chemical Analysis of Water and Wastes*, "Phosphorus, All Forms, Method 365.1 (Colorimetric, Automated, Ascorbic Acid)." The color intensity was determined by analysis with a Hitachi spectrophotometer, Model 100-20 (Danbury, Conn.).

3.10.3 Ammonia and Nitrate

Ammonia and nitrate were determined simultaneously on the Orion continuous-flow analysis (M/CFA) system (Hawthorne, N.Y.) consisting of the following modules: autoanalysis colorimeter, AC-100; autoanalysis pump, AP-100; autoanalysis pump, AP-200; and analytical cartridge. Samples were filtered through a 45-μ pore size filter, and 35 ml of filtrate was collected. Samples were not acidified. For ammonia analysis, the procedure outlined in *EPA Methods for Chemical Analysis of Water and Wastes*, "Method 350.1 (Colorimetric, Automated Phenate)" was followed. Alkaline sodium salicylate and hypochlorite were added to react with ammonia, forming an indophenol blue. The ammonia concentration was proportional to the indophenol blue. Sodium nitroprusside was added to intensify this color. The intensities were recorded on a strip chart, and a standard curve was prepared. Standards of 0.2-2.0 mg/l were used. If samples were out of this range, they were diluted using a Hamilton auto-pipetter (Bonaduz, Switzerland). Then, ammonia concentrations were calculated using linear regression.

For nitrate analysis, the procedures as outlined in *EPA Methods for Chemical Analysis of Water and Wastes*, "Method 353.2 (Colorimetric, Automated, Cadmium Reduction)" were followed. Filtered samples were passed through a cadmium reduction column, which reduces nitrate to nitrite. A diazo compound was formed when the nitrite reacted with sulfanilamide under acidic conditions. This compound formed a reddish-purple azo dye as it coupled with N-1-napthylethylenediamine (EPA, 1979). The dye's intensity was recorded on a strip chart, and a standard curve was prepared based on the peak height of each standard, allowing the nitrate concentration to be calculated using linear regression. Standards of 0.2-2.0 mg/l were used, and samples were diluted if found to be out of this range.

A different procedure for ammonia analysis was performed for samples from the second trip to APTS IV, since these samples contained a blue color caused by disinfectants added by the homeowner. Samples were analyzed for ammonia according to the preliminary distillation step, and the titrimetric method as outlined in *Standard Methods for the Examination of Water and Wastewater*, sections 4500-NH_3 B and 4500-NH_3 E, and the Labconco Rapid Distillation Apparatus Instruction Manual.

3.10.4 Total Kjeldahl Nitrogen

For TKN analysis, the procedure outlined in *EPA Methods for Chemical Analysis of Water and Wastes*, Method 351.2 (Colorimetric, Semi-Automated Block Digester, AAII) was followed. Ten ml of unfiltered samples was digested in the presence of 3 ml of sulfuric acid and 1-2 g of catalyst containing potassium sulfate, mercuric oxide, and copper sulfate at 200°C and then 380°C. Samples were analyzed with the Orion continuous-flow analysis system (Hawthorne, N.Y.), as described in section 3.10.3.

3.11 Household Information

For APTS I and II, the households consisted of two adults and one minor. For APTS I, both adults worked at home. The APTS III-V households consisted of two adults. With APTS II-IV, one adult was home most of the time. With APTS V, both adults worked during the weekdays, and they usually washed clothes on Saturdays. With the other households, times for washing clothes varied.

4 Results

In this chapter, field data concerning organic constituents, suspended solids, nutrients, bacterial counts, chlorine residuals, flowrates, and dye studies are presented to illustrate the performance of APTS I-V. APTS problems, malfunctions, and/or violations also are presented.

4.1 Organic Constituents

BOD_5 data are presented in tables 9 and 10 for evaluating the possibility of seasonal and/or daily variations, respectively. Table 9 presents the BOD_5 averages and ranges for three trips to each site. For example, an average BOD_5 of 191 mg/l, with a range of 96-309 mg/l, was determined in the APTS I primary settling chamber from samples taken during the morning (8-10 a.m.), afternoon (2-4 p.m.), and night (9-11 p.m.) of the first trip. To show the possibility of daily variations, table 10 presents the BOD_5 averages and ranges at each site for the morning, afternoon, and night for the three trips combined. For example, the APTS I BOD_5 average and range in the primary settling chamber for the mornings of the three trips were 103 mg/l and 33-181 mg/l, respectively. BOD_5 and COD raw data are listed in Appendix A.

With both perspectives, results from the primary settling tank varied greatly from site to site. In terms of trips, the lowest BOD_5 average of 39 mg/l was reported for the first visit to APTS IV. The highest BOD_5 average of 848 mg/l was reported for the APTS II second trip. At four sites (I, II, IV, V), the highest BOD_5 averages were noted during the second trip; the lowest BOD_5 averages were noted during the first trip at three APTS (III, IV, V). The APTS II primary settling chamber was pumped before the third trip, and its highest BOD_5 average of 848 mg/l, recorded during the second trip, was reduced to 99 mg/l.

For daily variations in the primary settling chamber (table 10), the lowest BOD_5 average of 73 mg/l was reported for APTS IV in the morning. The highest BOD_5 average of 570 mg/l was noted for APTS II at night. In fact, the highest BOD_5 for each site occurred at night for APTS I, II, IV, and V.

For the filtered wastewater sampled from the submersible pump chamber (see table 9), the highest BOD_5 averages were recorded at APTS I, III, and IV during the second trip; the lowest averages were recorded at APTS III, IV, and V during the first trip. The lowest BOD_5 average of 12 mg/l was noted at APTS V during first trip; the highest BOD_5 average of

117 mg/l was noted at APTS III during the second trip. Of the 15 filtered BOD_5 averages in table 9, 5 were less than or equal to 30 mg/l.

In terms of daily fluctuations (table 10), only one average after the filter was less than or equal to 30 mg/l, and that was in the morning for APTS II. The highest BOD_5 average, 88 mg/l, was recorded for APTS III at night.

For seasonal effluent results (table 9), three BOD_5 averages, each from the first trip, were less than or equal to 30 mg/l (I, IV, V). The lowest, 9 mg/l, was recorded at APTS IV; the highest, 158 mg/l, was reported for the third trip to APTS V. For APTS I-IV, the highest BOD_5 averages were reported during the second trip. For daily effluent results (table 10), all 15 daily averages were greater than 30 mg/l. The lowest, 40 mg/l, was recorded in the morning at APTS IV; the highest, 108 mg/l, was recorded at night at APTS V. The highest BOD_5 averages for three sites (II, IV, V) occurred at night; the lowest averages occurred in the morning for the same three sites.

Average COD/BOD_5 ratios for the three trips and morning, afternoon, and night are presented in tables 11 and 12, respectively. A majority of the ratios are near the range of 1.5-3.0, as expected for domestic wastewater. All ratios in the APTS II primary settling chamber greatly exceeded this range, indicating refractory materials that could inhibit the biochemical oxidation process. High ratios were recorded in the APTS III primary settling chamber for the third trip, as shown in table 11, and the afternoon and night, as shown in table 12. A high ratio in the APTS III effluent also was recorded for the first trip, as shown in table 11, and the night, as shown in table 12. For the APTS V third trip, the COD/BOD_5 ratio was 0.93, indicating that the BOD_5 was greater than the COD. Some of the oxygen demand in the BOD_5 test could be attributed to nitrification.

Table 13 presents the overall BOD_5 averages and ranges and COD/BOD_5 averages for each site. The primary settling chamber BOD_5 averages ranged from 84 mg/l (APTS IV) to 535 mg/l (APTS II). For both filtered and effluent waters, all averages exceeded 30 mg/l, with ranges of 44 mg/l (APTS II) to 85 mg/l (APTS III) and 56 mg/l (APTS IV) to 85 mg/l (APTS III), respectively. COD/BOD_5 averages were typical, except for the ratios from the primary settling chamber at APTS II and III.

4.2 Total and Volatile Suspended Solids

Samples from the primary settling chamber and the effluent were analyzed for TSS and VSS. Raw data are listed in Appendix B. TSS averages and ranges for each of the three trips to APTS I-V are presented in table 14. TSS averages and ranges for the morning, afternoon, and night are presented in table 15.

For the primary settling chamber, the lowest TSS average of 26 mg/l occurred during the first trip to APTS V; the highest TSS average of 5570 mg/l occurred during the second trip to APTS II. The APTS II TSS average was reduced to 699 mg/l for the third trip, since sludge was pumped from the chamber. For APTS III, the third trip (2420 mg/l) showed a substantial build-up of solids from the first two trips (154 mg/l, 372 mg/l). The highest TSS averages for APTS IV and V also were recorded during the third trip.

Table 15 shows that the lowest and highest TSS averages occurred in the primary settling chamber at night: 26 mg/l and 4840 mg/l for APTS IV and II, respectively. The highest average for each site occurred at night for APTS I, II, and V; the lowest average for the same sites occurred in the morning.

For effluent waters, the lowest TSS average of 15 mg/l was recorded at night for APTS IV (APTS IV had the lowest primary averages at night, also). The highest TSS average of 263 mg/l was recorded in the afternoon for APTS V. Two other sites (II and IV) produced their highest TSS averages in the afternoon. For the effluent averages in table 15, five values were less than or equal to 30 mg/l.

In terms of trips (table 14), five effluent averages were less than or equal to 30 mg/l. The lowest (8 mg/l) was recorded for the APTS IV second trip. At three sites (II, III, and V), the lowest average was recorded during the third trip. The highest effluent average, 259 mg/l, was recorded for the APTS V second trip. In fact, the APTS V effluent average exceeded the primary average for the first and second trips. The effluent pipe rested in a creek bed, and samples could have been contaminated with sediments in the pipe (Appendix B). For the APTS III first trip, the effluent average exceeded the primary average, probably due to low volumes in the submersible pump chamber when activated in the afternoon and night (Appendix B).

VSS were determined for the second and third trips to APTS I-V; the averaged VSS/TSS ratios are presented in table 16. Both primary and effluent averaged ratios fell within a range of 0.62-0.86, except for the APTS V effluent, which averaged ratios of 0.29 and 0.55 for the second and third trip, respectively. These low ratios were caused by high TSS concentrations, as mentioned in the preceding paragraph.

The overall TSS and VSS/TSS averages for each site are presented in table 17. Effluent averages less than or equal to 30 mg/l were recorded at APTS I and IV, with 30 mg/l and 17 mg/l, respectively. The highest primary averages (3710 mg/l and 983 mg/l) and the highest effluent averages (135 mg/l and 160 mg/l) were recorded at APTS II and III, respectively. APTS V had an effluent average greater than its primary (72 mg/l > 41 mg/l), as mentioned in the preceding paragraphs. VSS/TSS ratios were within a range of 0.63-0.78, excluding the APTS V effluent with a ratio of 0.42 due to the circumstances mentioned previously.

During the third trip to each APTS, measurements were taken to determine the existence of a sludge layer in the primary settling chamber. A sludge layer 4.5 ft below the water surface was found at APTS I. A sludge layer 1 ft below the water surface was found at APTS II—before pumping, the sludge layer had been just below the water surface. Sludge layers 3 ft below the water surface were found at APTS III and V. No sludge layer up to 4.5 ft below the water surface was found at APTS IV.

4.3 Mixed Liquor Suspended Solids

MLSS and MLVSS were measured 4 ft below the water surface in the aeration chamber for all visits to APTS I-V. For the second trip, MLSS and MLVSS also were measured 2 ft below the water surface. No stratification was found. See Appendix C for raw data. The highest MLSS average of 4550 mg/l was recorded for the APTS II second trip (table 18). Even after the sludge was removed from the primary settling chamber, APTS II maintained a higher MLSS (788 mg/l) than any other site.

The lowest MLSS average (8 mg/l) occurred during the first visit to APTS V. A low MLSS average below 20 mg/l was maintained at APTS IV and V through the second trip, but significant increases were noted for the third trip, 160 mg/l and 95 mg/l, respectively. MLVSS/MLSS ratios were typical of activated sludge, with ratios of 0.58-0.91 (table 18).

Differences between averaged results for morning, afternoon, and night are small. Averaged results of MLSS and MLVSS/MLSS ratios for the morning, afternoon, and night are presented in Appendix C.

Overall results of MLSS averages and MLVSS/MLSS ratios are presented in table 19. The lowest MLSS of 39 mg/l and the highest MLVSS/MLSS ratio of 0.74 occurred at APTS V. The highest MLSS average of 3220 mg/l occurred at APTS II. The lowest MLVSS/MLSS ratio of 0.61 occurred at APTS III.

During the third trip to each site, measurements were taken to determine the existence of a sludge layer in the aeration chamber. At each site, measurements were taken up to 4.5 ft below the water surface, and a sludge layer was not found at any site.

4.4 Dissolved Oxygen, pH, and Temperature

For all visits to the five APTS, DO, temperature, and pH were measured from samples taken 4 ft below the water surface in the aeration chamber. For the second set of trips, samples also were taken 2 ft below the water surface. No stratification was found. See Appendix C.

The pH range was 6.5-8.2. For the first, second, and third set of trips, the temperature range was 21.1-29.4°C, 11.1-20.2°C, and 20.5-26.6°C, respectively. The DO range was 2.5-6.5 mg/l, 0.9-8.4 mg/l, and 1.8-5.2 mg/l for the first, second, and third set of trips, respectively. The DO reading of 0.9 mg/l was recorded after the aerator had been unplugged for approximately 24 hours.

pH and DO were measured once from each APTS effluent during the fall of 1991. The effluent pH range was 7.42-7.83. The effluent DO readings at APTS I-V were 3.4 mg/l, 2.8 mg/l, 1.9 mg/l, 3.8 mg/l, and 2.8 mg/l, respectively.

4.5 Nutrients

For APTS I-V, the overall averages and ranges for nitrate, ammonia, and TKN are presented in table 20; the overall averages and ranges for OP and TP are presented in table 21. Raw data and averages and ranges for the three trips and morning, afternoon, and night are presented in Appendix D.

For the primary settling chamber (table 20), the highest nitrate average of 35.3 mg/l was recorded at APTS I; the lowest nitrate average of 1.3 mg/l was recorded at APTS IV. The highest ammonia average of 39.9 mg/l was reported at APTS III; the lowest, 3.9 mg/l, was reported at APTS V. For TKN averages, the highest, 256 mg/l, was recorded at APTS II; the lowest, 19.0 mg/l, was recorded at APTS I.

For the effluent, the highest nitrate average of 15.9 mg/l was noted at APTS II; the lowest nitrate average of 1.8 mg/l was noted at APTS IV. The highest ammonia average of 37.7 mg/l was recorded at APTS III; the lowest, 2.3 mg/l, was recorded at APTS V. For TKN averages, the highest, 46.1 mg/l, was reported at APTS III; the lowest, 6.4 mg/l, was reported at APTS V.

Increases in effluent nitrate averages and reductions in effluent TKN averages, as compared to their respective primary averages, were noted at APTS II, III, and V. Reductions in effluent ammonia averages, as compared to their respective primary averages, were noted at APTS I-III and V.

For the primary settling chamber (table 21), the highest OP average of 6.6 mg/l was recorded at APTS II; the lowest, 3.1 mg/l, was recorded at APTS I. The highest TP average of 200 mg/l was recorded at APTS II; the lowest, 5.3 mg/l, was recorded at APTS V.

For the effluent, the highest OP average of 5.7 mg/l occurred at APTS II; the lowest, 2.7 mg/l, occurred at APTS III. The highest TP average of 8.9 mg/l was noted at APTS III; the lowest, 5.2 mg/l, was noted at APTS V.

Significant reductions in TP averages were recorded at APTS I-III, unlike APTS IV and V. High TP averages in the primary settling chambers were noted for APTS I-III; low averages were noted in APTS IV and V. The TP averages recorded at APTS V consisted mostly of OP.

Overall reductions in OP averages less than or equal to 0.2 mg/l were recorded at APTS I, IV, and V. Overall reductions of 0.9 mg/l and 0.7 mg/l were recorded at APTS II and III, respectively.

4.6 Fecal Coliform and Fecal *Streptococcus*

FC and FS ranges for each trip to the five APTS are presented in table 22. An asterisk indicates values determined from colony densities less than 20. All other values were determined with colony densities of 20-200. Raw data are presented in Appendix E.

For APTS I, none of the filtered wastewater samples had FC or FS ranges less than 200 colonies/100 ml, the state's requirement. For the first and third trip, the effluent samples contained no FC colonies. The second trip's effluent samples contained FC ranges that exceeded the state's limit by a minimum of 2 log values. The third trip's effluent samples contained an FS range less than 200 colonies/100 ml.

For the APTS II third trip, both filtered and effluent samples contained no FC colonies. The remaining FC ranges and all FS ranges for both filtered and effluent samples exceeded 200 colonies/100 ml.

For APTS III, all FC and FS ranges for both filtered and effluent samples exceeded 200 colonies/100 ml. In fact, no significant reductions from the primary settling chamber to the effluent were apparent.

For APTS IV, all effluent samples for each trip were clean, with no FC or FS colonies detected. For the first trip, no FS colonies were detected in the filtered water, but the filtered water for the second and third trip contained FC and FS levels that exceeded 200 colonies/100 ml.

For APTS V, the second trip's effluent samples contained no FC or FS colonies, and, before chlorination, the FC count was zero. For the third trip, the FS values were less than 200 colonies/100 ml for both the filtered water and the effluent. All other FC and FS ranges exceeded 200 colonies/100 ml.

With a total of 45 effluent samples (3 samples per APTS per trip—Appendix E), 29 had FC counts of less than 200 colonies/100 ml. Twenty-three effluent samples had FS counts of less than 200 colonies/100 ml. In terms of filtered samples, 16 had FC counts of less than 200 colonies/100 ml, and 13 had FS counts of less than 200 colonies/100 ml.

4.7 Total and Free Chlorine Residuals

Total and free chlorine residual (TRC and FRC) averages for the three trips to each site are reported in table 23. See Appendix F for raw data. After chlorination or dechlorination, no chlorine residuals were found at APTS II or III during any of the three visits. For the APTS I initial trip, an average TRC and FRC of 0.9 mg/l and 0.2 mg/l, respectively, was recorded in the submersible pump chamber after chlorination. The effluent yielded an average TRC and FRC of 0.1 mg/l and 0.0 mg/l, respectively. The second and third trips yielded no chlorine residuals after chlorination or dechlorination.

APTS V had no chlorine residuals for the first or third trip, but the second trip yielded an average TRC and FRC of 1.9 mg/l and 0.5 mg/l, respectively, after chlorination. After dechlorination, the effluent yielded an average TRC and FRC of 0.3 mg/l and 0.0 mg/l, respectively.

Chlorine residuals were recorded at APTS IV after chlorination and dechlorination for all three trips. At APTS IV, the baffled chamber was *between the chlorinator and dechlorinator. See section 3.1. For the first* trip, the average FRC after chlorination was more than 9.0 mg/l; the titrator broke during the second FRC titration after chlorination. The TRC after chlorination was not determined. The effluent had an average TRC of 13.0 mg/l and an average FRC of 8.0 mg/l. Tablets were in one of the dechlorinator's tubes, but lodged so that a 2-in. gap existed between the tablets and the bottom of the tube.

For the second trip, an average TRC of more than 16.3 mg/l and an average FRC of 0.2 mg/l were recorded after chlorination. The titrator ran out of titrant during the second TRC titration. An average TRC and FRC of 0.2 mg/l and 0.0 mg/l, respectively, were found in the effluent. Both tubes in the chlorinator and dechlorinator had tablets. The system had been checked by the distributor the day before this visit.

For the third visit, an average TRC of 13.2 mg/l and an average FRC of 0.0 mg/l after chlorination were recorded. The effluent had an average TRC of 10.8 mg/l and an average FRC of 0.0 mg/l. The chlorinator had one tube full of tablets, and caking had occurred at the bottom. The dechlorinator had tablets in both tubes, with one tube having lodged tablets and an open space of 1.5 in. to the bottom. The other tube had caked tablets at the bottom.

Various problems were noted with both the chlorinator and dechlorinator dry-feed tubes, whether they were system or homeowner related. APTS I and III did not have any dechlorination tablets on any of the three trips. APTS V did not have any chlorine tablets on the first trip, and APTS III did not have any chlorine tablets on the third trip. Four instances were noted in which tablets were lodged in the tube and a gap existed between the tablets and the bottom of the tube, preventing contact between the tablets and the wastewater. Three of these instances involved the dechlorinator on the first trips to APTS IV and V and the third trip to APTS V. The fourth involved the chlorinator on the first trip to APTS III.

Tablets were found caked together in all instances where they were exposed to the air. Tablets oozing out of the openings at the bottom of the tubes also were found. Furthermore, in the four instances where gaps existed, the bottom tablets were caked together.

4.8 APTS Malfunctions and Violations

Mechanical malfunctions and violations were noted throughout the field study by observations and/or conversations with the homeowners. The aeration motor was replaced once at APTS II, III, and IV, and the motor was replaced six times at APTS I due to failures caused by cotton gauze wrapping around the shaft. Only APTS V did not need a new aeration motor.

The submersible pump was not operating during the morning of the first trip to APTS II—a cut in the electrical cord had caused a short (the cord was not underground, as required by permit regulations, due to landscaping). Similarly, on the second trip to APTS I, the aerator was found unplugged, and had been so for two days, due to landscaping.

For all trips to APTS I, the filter was found covered with 3-5 in. of wastewater. The homeowner had removed the plastic alarm extension pipe due to frequent alarms. Thus, wastewater was bypassing the filter to the submersible pump chamber. For the APTS IV second trip, the filter was found covered with 5 in. of wastewater. The filter was found missing for the APTS II first trip. The distributor searched the clarification chamber, but did not find the filter, and another filter was placed in the system.

4.9 Flowrate

The flowrate was monitored by a device that measured the number of submersible pump activations, as described in section 3.8. Knowing that 11 gal were discharged as effluent for each activation, the average flowrate was determined for each APTS (table 24). APTS I was monitored for 18 days, the minimum time, and APTS II was monitored for 26 days, the maximum time.

The highest average flowrates were recorded at APTS I and II, 182 gpd and 180 gpd, respectively. The lowest average flowrates were recorded at APTS III and V, 139 gpd and 135 gpd, respectively. An average flowrate of 166 gpd was recorded at APTS IV.

4.10 Dye Studies

For the first dye study, which was conducted from May 23 through June 6, 1991, 50 ml of 0.1% Rhodamine B solution was poured into the primary settling chamber (see section 3.9). The primary settling chamber, aeration chamber, and clarification chamber were monitored, with the flowrate being a function of homeowner use. See Appendix G for raw data.

Fluorescence was plotted versus time for each chamber, as shown in figures 3-5. Using the plot and a baseline as borders, the center of mass was calculated for each figure; thus, the actual detention time was determined (Osborne/McGraw-Hill, 1981). For figures 3-5, a complete mix dye pattern was plotted, based on the design detention time, using the following equation (Grady and Lim, 1980):

$$C \backslash C_o = e^{-\theta}$$

C = fluorescence at specified time (10x)
C_o = initial fluorescence (10x)
θ = detention time (hrs)

For figure 5, a complete mix dye pattern also was plotted, based on the actual detention time.

For figure 3, the actual detention time in the primary settling chamber was determined to be 76.7 hours (3.2 days). Dividing the chamber's volume (450 gal) by the average flowrate of 182 gpd (table 25) yielded a shorter design detention time of 59.3 hours (2.5 days).

For figure 4, the actual detention time in the aeration chamber was determined to be 75.2 hours (3.2 days). A slightly longer design detention time of 79.1 hours (3.3 days) was calculated by dividing the chamber's volume (600 gal) by the average flowrate of 182 gpd.

For figure 5, the actual detention time in the clarification chamber was determined to be 80.0 hours (3.3 days). However, a much shorter design detention time of 33.0 hours (1.4 days) was calculated with the ratio of the chamber's volume (250 gal) to the average flowrate (182 gpd).

The second dye study was performed on June 11, 1991 (see section 3.9). Fifty ml of Rhodamine B was poured into the washer effluent line followed by water at a controlled, average flowrate of 3.4 gal per minute (gpm), approximately 4900 gpd. Fluorescence versus time was plotted for the aeration chamber and the clarification chamber, as shown in figures 6 and 7, respectively. See Appendix G for raw data.

Once again, using the plots and baselines as borders, the center of mass was calculated for figures 6 and 7. For figure 6, the complete mix dye pattern, as determined by the design detention time, was plotted. For figure 7, the complete mix dye patterns, as determined by both the design and actual detention times, were plotted.

An actual detention time of 2.86 hours was determined for the aeration chamber (figure 6). Dividing the chamber's volume of 600 gal by the controlled, average flowrate of 3.4 gpm yielded a slightly longer design detention time of 2.94 hours.

For figure 7, an actual detention time of 3.78 hours was determined for the clarification chamber. However, a much shorter detention time of 1.23 hours was calculated from the ratio of the chamber's volume (250 gal) to the controlled, average flowrate (3.4 gpm).

5 Discussion

5.1 Wastewater Characterization in the Primary Settling Chamber

Wastewater characteristics in the primary settling chamber from APTS I-V and residential and municipal influent ranges are presented in table 25 for comparison. Residential influents consisted of wastewater from rural households; municipal influents consisted of domestic wastewater.

For all APTS parameters, the standard deviation was large, due to wide ranges exceeding the expected ranges for both residential and municipal wastewaters. This variability was expected to some extent, since individual household wastewater concentrations and loadings fluctuate constantly, depending on wastewater quantity and type (e.g., toilet, shower, washer). Also, samples from the primary settling chamber were probably influenced by material build-up within the chamber.

The upper limit of each range for BOD_5, COD, SS, TP, and TKN was influenced by high concentrations recorded at APTS II and III. For APTS II, high concentrations of each parameter were found during the first two trips. Significant reductions were noted during the third trip, after sludge had been pumped from the chamber. These reductions for BOD_5, COD, SS, TP, and TKN were 87%, 82%, 87%, 89%, and 84%, respectively. For APTS III, high concentrations of each parameter were noted on the third trip, unlike the first two trips. BOD_5, COD, SS, TP, and TKN levels for the third trip were 42%, 90%, 89%, 90%, and 80%, respectively, higher than the average values of the first two trips.

Ranging from 1.7 mg/l to 8.8 mg/l, OP was the only parameter that did not exceed the upper limit of either the residential or municipal range. In fact, the OP averages at each APTS fell below the residential range, except for APTS II, with an OP average of 6.6 mg/l (table 21).

The overall nitrate average and range of 12.3 mg/l and 0.0-180 mg/l, respectively, exceeded both residential and municipal values, as shown in table 25. The overall nitrate average was significantly increased by two values recorded during the first visit to APTS I, 180 mg/l and 115 mg/l. If those values were disregarded, the average would be 5.7 mg/l, with the highest value in the range being 24.2 mg/l. High nitrate concentrations could be attributed to household influent, fertilizer infiltration through the sampling port, nitrification within the primary settling chamber, or erroneous readings. High nitrate levels were probably in the household influent, since the sampling port was epoxy-sealed to the inspection cover. Also, nitrification could not account for such high nitrate concentrations, and the primary settling chamber would not provide the proper environment for nitrification. The overall ammonia average of 19.6 mg/l was within the municipal range, but exceeded the residential range (table 25).

With regard to pumping sludge from the primary settling chamber, it is recommended that the solids be removed once per year or once every three years (Otis et al., 1975; Voell and Vance, 1974). In this study, solids removal was recommended after the second visit to APTS II, and was performed before the third trip, approximately 2.5 years after start-up (table 7). After the third visit to APTS III, solids removal was recommended, approximately three years after start-up. The sludge layer should be measured during each inspection and pumped when necessary, since solids loading and consequential build-up is a function of homeowner use and can be determined only on an individual site basis.

With wide ranges and large standard deviations for all parameters, fluctuations in loading and concentrations were apparent and directly related to homeowner use. The primary settling chamber (450 gal) functioned as a settling basin, with a detention time of 2.5-3.3 days, depending on the flowrate (table 24). This detention time would be shortened as solids accumulate, and short circuiting could occur, causing increased variability in terms of loading and concentration for the wastewater entering the aeration chamber. Equalization should be considered to handle fluctuations from households and reduce the possibility of shock loadings and washout. Research in this area is ongoing at Virginia Tech.

5.2 Characterization of Effluent Organic Constituents, Suspended Solids, and Nutrients

Overall averages, ranges, and standard deviations of organic constituents, SS, and nutrients from APTS I-V effluents are presented in table 26. For all APTS parameters, the standard deviation was quite large, due to poor system performance caused by influent variability in terms of loading and concentrations, lack of maintenance, and system design.

The overall effluent BOD_5 average was 70 mg/l, well above the state's limit of 30 mg/l for an annual grab sample from any package treatment system (SWCB, 1991). In fact, BOD_5 concentrations higher than 30 mg/l were found in 35 of the 43 samples analyzed, as shown in figure 8 (2 of the 43 effluent values were not plotted, since corresponding values from the primary settling chamber were unavailable—see Appendix A).

The overall effluent SS average was 99 mg/l, well above the state's limit of 30 mg/l (table 26). In fact, SS concentrations higher than 30 mg/l were noted for 28 of the 45 samples analyzed, as shown in figure 9 (2 of the 45 effluent values were not plotted, since corresponding values from the primary settling chamber were unavailable—see Appendix B).

The SS effluent range (6-465 mg/l) varied significantly. There was a question of sample contamination with five SS values: two samples from the first trip to APTS III, one sample from the first trip to APTS V, and two samples from the second trip to APTS V. Disregarding these values, the overall average was still 64 mg/l. Similar results were found in the literature, and are presented in table 2.

Effluent BOD_5 averages ranged from 13 mg/l to 279 mg/l. All effluent SS averages exceeded 30 mg/l. Effluent COD averages ranged from 76 mg/l to 456 mg/l. It can be concluded from the literature and this study that a high degree of variability in effluent values exists, which probably can be attributed to surge flows, lack of maintenance, and poor system performance.

With such variability in the effluent, the state's effluent limitations and monitoring requirements, as shown in table 6, seem futile. A grab sample taken once per year will not be indicative of APTS performance, and, thus, is not a good basis for acceptance or rejection. Energies should be spent modifying the system of this study for better performance (i.e., polishing techniques) and studying the performance of other APTS.

The APTS did not perform effectively as a biological reactor. Referring to figure 10, biodegradation seemed to occur with adequate BOD_5 reductions, especially at MLSS greater than 3000 mg/l. However, figure 11 shows that the MLSS concentration was directly related to the SS concentration in the primary settling chamber (SS_{PSC}). For example, the first two trips to APTS II yielded an average SS_{PSC} and MLSS of 5220 mg/l and 4440 mg/l, respectively (tables 14 and 18). After the primary settling chamber was pumped, SS_{PSC} and MLSS averages of 480 mg/l and 788 mg/l, respectively were noted. Referring to tables 17 and 19, differences between SS_{PSC} and MLSS averages were minimal for APTS I, IV, and V. TSS averages in the primary settling chamber and MLSS averages of 142 mg/l and 152 mg/l, 55 mg/l and 65 mg/l, and 41 mg/l and 39 mg/l were noted for APTS I, IV, and V, respectively. Typically, biomass growth did not occur, and biomass was not maintained in the reactor.

The aeration chamber could be oversized. Referring to Benefield and Randall (1980), the volume (gal) of a reactor using extended aeration can be determined with the following formula:

$$V = [Y_T Q(S_o - S_e)]/(X k_d)$$

Y_T = 0.5, typical growth yield value
Q = flowrate (gal/d)
S_o = influent BOD_5 (mg/l)
S_e = effluent BOD_5 (mg/l)
X = MLSS (mg/l)
k_d = 0.02 d^{-1}, typical decay coefficient

A range of 1500-2500 mg/l was chosen for the MLSS. The overall averages for both the flowrate and the influent BOD_5, 160 gpd and 218 mg/l, respectively, were chosen. The effluent BOD_5 was chosen to be 30 mg/l, the state's proposed standard. With these assumptions, the required volume would be 500-300 gal, 100-200 gal less than the actual volume. The growth yield and decay coefficient are typical values for domestic sewage, and would need to be determined experimentally for individual household wastewater. Reducing the aeration chamber size should be investigated to improve biological degradation.

BOD_5 and SS reductions in the APTS were achieved due to settling and filtration. This was also true for TP, OP, and TKN removal. The overall effluent TP average and range was 7.1 mg/l and 2.7-24 mg/l (table 26), similar to the literature, with TP averages ranging from 5 mg/l to 26 mg/l (table 3). Plotting TP_{PSC} versus effluent TP shows effluent TP values from APTS I-V were typically less than 12 mg/l (figure 12), even with a TP_{PSC} concentration of 540 mg/l. Thus, one would expect effluent TP concentrations to be less than 12 mg/l consistently, with settling being the key removal operation.

For OP, the overall average was 4.2 mg/l, with a range of 0.0-6.1 mg/l (table 26); this was less than the averages reported in the literature ranging from 12 mg/l to 39 mg/l (table 3). Referring to figure 13, reductions in OP were slight, with greater reductions occurring for higher OP_{PSC} concentrations.

The overall effluent TKN average and range were 22 mg/l and 3.1-94 mg/l, respectively (table 26). Referring to the raw data in Appendix D, typical TKN effluent values were less than 35 mg/l, except for the second and third trips to APTS III, where high TKN concentrations in the effluent were noted. As shown in table 20, effluent TKN averages of 6.4-46.1

mg/l were maintained, regardless of the concentration in the primary settling chamber. Similar values were reported in the literature, with effluent total nitrogen averages ranging from 17 mg/l to 40 mg/l (table 3).

For nitrate, the overall effluent average and range were 8.4 mg/l and 0.2-30 mg/l, respectively (table 26). Similar nitrate averages were reported in the literature (table 3, 0.8-70 mg/l). Effluent nitrate averages of 16 mg/l and 13 mg/l at APTS II and V, respectively, should raise concern, since a majority of APTS discharge to surface waters (table 20). However, stream dilution should be considered, since an APTS discharges approximately 11 gal per float activation (section 4.9).

For ammonia, the overall average and range were 17 mg/l and 0.1-56 mg/l, respectively. Ammonia averages in the literature ranged from 0.0 mg/l to 73 mg/l (table 3). High effluent ammonia averages of 38 mg/l and 21 mg/l were noted at APTS II and III.

As shown in figures 14 and 15, the least square lines would indicate that little nitrification occurred. A linear regression of the ammonia data (figure 15) shows slight, consistent overall ammonia reductions occurring, with the slope approximately 1. These reductions might be attributed to nitrification and/or volatilization. In fact, data above the least square line in figure 14 indicate that nitrification occurred. However, high nitrate concentrations in the household influent could have influenced these values (section 5.1). In any case, occurrences were inconsistent.

5.3 Seasonal and/or Daily Fluctuations

Daily fluctuations in BOD_5 and SS from the primary settling chamber and the effluent were noticed. For APTS I, II, IV, and V, the highest daily BOD_5 average from the primary settling chamber was recorded at night. For three of the same sites (II, IV, V), the highest daily effluent BOD_5 average was recorded at night. At APTS II, IV, and V, the lowest daily effluent BOD_5 average was recorded in the morning. No overall trends were noticed with seasonal variations.

For APTS I, II, and V, the highest daily SS average from the primary settling chamber was noted at night; the lowest daily SS average occurred in the morning. The highest daily effluent SS average was noted in the afternoon for APTS II, IV, and V, and at night for APTS I and III. The lowest daily effluent SS average was noted in the morning for APTS I, II, and III. No trends were noticed with seasonal variations.

Sample collection apparently should be conducted at night to determine system performance during worst conditions. Also, samples should be collected on weekends, when household activity normally is increased.

5.4 Dissolved Oxygen, pH, and Temperature

In the aeration chamber, all ranges for DO, pH, and temperature were adequate for bacterial growth and biological degradation. The DO range was 0.9-8.4 mg/l. A concentration of 0.5 mg/l is reported to be the critical DO value for aeration chambers (Viessman and Hammer, 1985). All pH values fell within a range of 6.5-9.0, which is recommended for the activated sludge process; all temperature values were within a range of 10-45°C, which is acceptable for mesophilic microbes (Reynolds, 1982).

The effluent pH range of 7.4-7.8 was within Virginia's regulation, a range of 6.0-9.0 (SWCB, 1991). Similar effluent pH averages of 6.8-7.6 were reported by other investigators (Brewer et al., 1978; Glasser, 1975), as shown in table 4.

The effluent DO at APTS I-V (all $\leq$ 3.8 mg/l) did not meet Virginia's regulation, $\geq$ 5.0 mg/l (SWCB). The NSF (1984) reported an effluent DO median of 4.2 mg/l, which would not have complied with Virginia's regulation. Effert et al. (1985) reported an effluent DO range of 2.7-3.4 mg/l (table 4). Glasser (1975) reported an effluent DO range of 4.4-7.8 mg/l and an average DO $\geq$ 5.0 mg/l in studies with two systems (table 4). An effluent DO level of 5.0 mg/l was not found consistently by investigators, as was also the case in this study.

One method to increase DO levels is to follow APTS treatment with a sand filter (section 2.2.3). Effert et al. (1985) increased an average DO of 3.4-7.1 mg/l (5.0-8.2 mg/l range) with this addition. The authors also reported a DO average and range of 6.7 mg/l and 4.0-9.5 mg/l, respectively, with a septic tank/sand filter system.

5.5 Comparison of Bacterial Counts and Chlorine Residuals

Virginia's regulations require that effluent grab samples contain no more than 200 FC colonies/100 ml and nondetectable TRC readings (SWCB, 1991). In a total of 45 effluent grab samples from APTS I-V, 29 samples contained more than 200 FC colonies/100 ml. Seven of the 43 effluent grab samples analyzed for TRC contained detectable TRC readings.

The dry-feed tube chlorinator/dechlorinator system was not effective. This system is situated in a humid environment, causing tablets to cake and lodge in the tubes, which may prevent them from contacting the wastewater. Homeowners had been told to knock the tubes against the ground periodically to dislodge and break up caked tablets. Instances where bacterial counts met regulations occurred when detectable TRC concentrations were being discharged; at those times when bacterial counts exceeded regulations, little to no chlorine was present.

Effective chlorination was apparent on all trips to APTS IV; all FC and FS counts in the effluent were zero (table 22). APTS IV had a baffled chamber following chlorination, unlike the other four APTS. However, TRC values exceeded 10 mg/l in the APTS IV effluent on the first and third trips, indicating inadequate dechlorination (table 23). Effective chlorination was also apparent for the second trip to APTS V; all FC and FS counts in the effluent were zero (table 22).

There was one instance where the FS count was less than 200 colonies/100 ml when the FC count exceeded this limit (the APTS V third trip). However, there were two instances where the FC count was less than 200 colonies/100 ml when the FS count exceeded this limit (APTS I first trip, APTS II third trip). Thus, monitoring FS along with FC should be considered to evaluate disinfection methods.

No bacterial counts were noted with APTS IV, which had the baffled chamber following chlorination. The other four APTS should have baffled chambers to provide for longer contact times. It also might be worthwhile to add a baffled chamber following dechlorination. However, longer contact times will, of course, not help if the tubes are empty or if the tablets are lodged.

Voell and Vance (1974) visited 151 APTS and found 75% without tablets; in the systems with tablets, the tablets were lodged in the tubes. Hutzler et al. (1978) visited 36 APTS with chlorinators only, and discovered 6 with no TRC. The VWRRC reported that 33% of the owners used no chlorine or did not know how much chlorine they added; 40-55% of the owners did not dechlorinate (Weigmann, 1991).

5.6 APTS Malfunctions and Violations

Various malfunctions and violations were encountered in this study, as discussed in section 4.8, and these occurrences were similar to those presented in the literature.

Mechanical malfunctions, especially with the aeration motor, were seen in this study. Enclosed in the aeration chamber, the motor operates continuously in a humid and stressful environment. At APTS I, the aeration motor failed six times due to cotton gauze wrapping around the shaft. At APTS II-IV, the aeration motor failed once.

Mechanical failures are reported throughout the literature (see section 2.2.1). Voell and Vance (1974) reported that hair and lint caused motors to fail. Sixteen percent of surveyed APTS owners reported the need for system repairs (Weigmann, 1991). A better warranty for the aeration motor is needed, as well as maintenance contracts and frequent inspections. In addition, homeowners need to aid system performance by keeping cotton gauze, hair, etc., out of the waste stream.

Many homeowners do not renew their system contracts and warranties (Voell and Vance, 1975). For systems 2-4 years old, only 37% APTS and no SF owners surveyed by the VWRRC had maintenance contracts (Weigmann, 1991). Lifetime maintenance contracts with inspections 4-6 times per year were recommended by Glasser (1975) and Otis et al. (1975). Glasser (1975) also recommended that the first visit occur within the first 10 days of operation.

Homeowners have violated operational standards, causing system malfunctions and/or poor effluent. The VWRRC discovered that 9% of APTS homeowners turned off the system's electricity if they were gone for at least two days (Weigmann, 1991). Hutzler et al. (1978) visited 36 systems and found one with the electricity turned off. In this study, the aerator was found unplugged during the second trip to APTS I, and had been unplugged for two days due to landscaping. On the first trip to APTS II, an electrical cord to the submersible pump was found severed and above ground, which is a violation. Also, the filter was missing during the first trip to APTS II. The APTS I plastic alarm extension pipe (figure 1, item 13) was removed by the homeowner because he was tired of frequent alarms; this violation allowed wastewater to bypass the filter. One homeowner did not know the location of the system in the yard.

Homeowners' knowledge of the system is essential, since they are the only ones to witness daily operation. With proper education, homeowners can assist in maintenance; e.g., dislodge tablets and advise distributors of system malfunctions.

An alarm system, as required by this APTS manufacturer, is needed for all package treatment systems, since alarm activation is the only warning to a homeowner that the system is malfunctioning. APTS I-V had functioning alarm systems, but only 54% of the APTS owners and 14% of the SF owners surveyed by the VWRRC reported having alarm systems (Weigmann, 1991).

5.7 Flowrate and Dye Studies

With household information from section 3.11 and flowrate data from table 24, the gallons of wastewater discharged as effluent per capita per day (gpcd) were as follows for APTS I-V: 61, 60, 70, 83, and 68 gpcd, respectively. At the time the flowrate was determined at APTS IV, which had the highest per-capita flowrate, both occupants were home most of the time. For APTS I, where the highest flowrate of 182 gpd was noted, both adults worked at home. Both adults were absent from the home during the weekdays where the lowest flowrate of 135 gpd was recorded (APTS V).

In the literature, Hammer (1975), as cited by Benefield and Randall (1980), reported that the per-capita wastewater flow for single-family houses in residential areas was 75 gpcd. Also, Chien (1975), as cited by Benefield and Randall (1980), reported a 58-gpcd production of domestic wastewater. Thus, the per-capita flowrates determined in this study were similar to those found in the literature.

From the dye study results, it seemed that short circuiting occurred in the primary settling chamber. Referring to figure 3, the plot shows a discrepancy between the actual fluorescence and the complete mix dye pattern during the first 90 hours. Short circuiting could be attributed to materials build-up within the chamber. However, the actual detention time of 76.7 hours, as determined from the center of mass (figure 3), exceeded the design detention time (volume/flowrate) of 59.3 hours by 17.4 hours (Osborne/McGraw-Hill, 1981).

In the aeration chamber, the actual hydraulic detention times for both dye studies were found to be close to the design detention times. In the first dye study (figure 4), the actual detention time was determined to be 75.2 hours, 3.9 hours shorter than the design detention time of 79.1 hours. For the second dye study (figure 6), the actual detention time was determined to be 2.86 hours, 5 minutes shorter than the design detention time of 2.94 hours. Adequate mixing in the aeration chamber was evident, as shown by similarities with the actual fluorescence curve and the complete mix dye pattern for both figures 4 and 6.

In the clarification chamber, the actual hydraulic detention times for both dye studies were found to greatly exceed their corresponding design detention times. In the first dye study (figure 5), the actual detention time was determined to be 80.0 hours, 47 hours longer than the design detention time of 33.0 hours. For the second dye study (figure 7), the actual detention time was determined to be 3.78 hours, 2.55 hours longer than the design detention time of 1.23 hours. Actual fluorescence seemed to follow the complete mix dye pattern for the actual detention time rather than the design detention time, indicating excessive retention and possibly backmixing of wastewater through the sludge return port. These traits differ from plug flow characteristics that are expected for a secondary clarifier.

5.8 Summary

Substantial variation in APTS effluent quality was evident from this study, and was related to influent variability in terms of loading and concentrations, build-up of materials within the primary settling chamber, lack of maintenance, and poor system performance. The system's design provided good retention of wastewater, and there seemed to be minimal short circuiting throughout APTS chambers. However, short circuiting appeared to occur in the primary settling chamber. The need for sludge removal from the primary settling chamber should be determined on an individual case basis. During an inspection, the sludge layer should be measured.

The aeration chamber did not perform effectively as a biological reactor, but the aeration motor controlled septic odors well. BOD_5, COD, SS, TP, OP, and TKN removals were mostly a function of settling and filtration. The MLSS concentration reflected the SS_{PSC} concentration; biomass was not growing and being maintained in the aeration chamber. The chamber seemed to be too large to function properly as a biological reactor, and further studies are needed to enhance biological removal. If the chamber size is reduced, equalization should be considered to lessen the effects of influent variability. The flowrates of events that produce surges in wastewater (e.g., washing machine, shower) should be controlled so that they do not upset the system.

The dry-feed, chlorinator/dechlorinator tubes performed poorly. The humid environment caused tablets to cake and lodge in the tubes. When bacterial counts exceeded regulations, little to no chlorine was present. It is recommended that APTS have baffled chambers following chlorination and dechlorination to ensure contact times. It is also recommended that FS counts be monitored along with FC counts, since FC counts were at times less than 200 colonies/100 ml when FS counts exceeded this standard. Furthermore, FS counts are another indication of disinfection performance.

APTS effluent was generally of poor quality. Eighty-one percent of the effluent BOD_5 samples exceeded 30 mg/l, and 62% of the effluent SS samples exceeded 30 mg/l. No effluent DO values were $\geq$ 5.0 mg/l. Sixty-four percent of the FC samples exceeded 200 colonies/100 ml. High nitrate concentrations were noted in APTS II and V effluents, and high ammonia concentrations were noted in APTS II and III effluents. However, effluent pHs were acceptable, and ranged from 7.4 to 7.8.

Even with a majority of the effluent being considered of poor quality, it is still possible that APTS effluents could have been acceptable in terms of state standards. Since effluent variability is so great, the state's proposed monitoring technique of one grab sample per year will not be a good indicator of system performance.

Worst conditions, in terms of effluent quality, occurred at night, while best conditions occurred generally in the morning, and most household activities occurred during the weekends. Therefore, a sample collected during a weekday morning will overestimate effective system performance.

6 Conclusions and Recommendations

An alternative to septic systems and drainfields is needed as rural and suburban development increases with limited suitable soils. APTS are a practical choice; however, modifications are needed since overall field performance of APTS I-V in this study was unreliable and poor. Effluent BOD_5, SS, and FC samples exceeded the state's proposed standards 60-80% of the time. The poor field performance was a function of improper operation by homeowners, an ineffective chlorinator/dechlorinator system, inadequate biological treatment, and mechanical malfunctions. Studies are ongoing at Virginia Tech to improve APTS performance and reliability.

State standards appear to be reasonable, but results of this study show that one grab sample per year is not representative of effluent quality due to the variability in effluent samples. However, the process for obtaining a VPDES General Permit to install a package treatment system is well conceived, ensuring that all other alternatives are considered first.

Energies should be spent modifying these systems to improve performance and studying other APTS. Polishing techniques, such as sand filtration, should be considered for systems currently in the field. Sand filtration following an APTS or septic tank will provide better BOD_5, COD, and SS removal and greater DO concentrations; however, nitrate concentrations may increase.

Inspections should be made at least four times per year for the system's lifetime, and all mechanical parts should be covered by a warranty. To minimize APTS malfunctions and violations, homeowners should be properly educated, since they are the only ones that can monitor their system daily. They can assist in maintenance, such as checking on the chlorinator/dechlorinator and dislodging caked tablets. They also can advise distributors of system malfunctions. All package treatment systems with mechanical parts should have alarms to notify the homeowner of malfunctions. With proper homeowner interaction, APTS performance can be enhanced, and violations of operational standards, as mentioned in section 5.6, can be avoided.

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Tables

Table 1.
Sampling procedure for NSF Standard 40.

	Sample Location		
Parameter	Influent[1]	Aerator[2]	Effluent[1]
D.O.[3] (mg/L)		x	x
BOD_5 (mg/L)	x		x
SS (mg/L)	x	x	x
VSS (mg/L)	x	x	x
Settleable Solids [mL/(L*30 min]		x	
Temperature (°C)	x	x	x
pH	x	x	x

[1]24 hr. composite sample, daily
[2]grab sample, daily
[3]dissolved oxygen

Table 2.
Field data of five-day biochemical oxygen demand (BOD_5), suspended solids (SS), and chemical oxygen demand (COD) effluent results.

Description	# of Systems	BOD_5 (mg/L) mean	SS (mg/L) mean	COD (mg/L) mean
Bernhart 1967[1]	-	47 (86)[7]	94 (74)	-
Bennett *et al.* 1973	-	150 (16)	150 (16)	-
Glasser 1975				
Bi-A-Robi[2]	1	47 (31)	75 (31)	-
Chromaglass[2]	1	52 (23)	83 (23)	-
Flygt[2]	1	27 (21)	56 (21)	-
Jet[2]	1	45 (29)	83 (29)	-
Nayadic[2]	1	70 (20)	104 (20)	-
Otis *et al.* 1975	1	55 (19)	38 (20)	158 (20)
	1	55 (19)	65 (20)	159 (20)
	1	36 (24)	59 (28)	107 (28)
Tipton 1974				
Chromaglass[2]	8	207 (9)	139 (9)	456 (9)
CT86[2]	21	150 (26)	204 (26)	423 (26)
Jet[2]	1	33 (2)	41 (2)	-
PCD[2]	6	83 (9)	100 (9)	249 (9)
Sanicell[2]	1	279 (1)	126 (1)	376 (1)
Voell and Vance 1974	-	92(146)	94(146)	-
McClelland 1976[3]	8	13	57	-
Sauer 1977	1	26	48	-
ARC[4]	-	37(116)	62(116)	-
Brewer *et al.* 1978	10	31	49	-
ODH 1978[5]				
Roll-Aer[2]	3	194	70	-
Coate-Aer[2]	10	177	12372	-
Jet[2]	15	143	263	-
Multiflow[2]	14	97	1145	-
Oldham[2]	19	51	46	-
SSWMP[6]	-	37(112)	39(117)	108(117)
Effert *et al.* 1985	1	28	38	76
	1	27	39	95
	1	31	62	121

[1]Bernhart 1967 as reported by Hutzler *et al.* 1978
[2]systems' name as reported by author
[3]McClelland 1976 as reported by EPA 1978
[4]Appalachian Regional Commission as reported by Hutzler *et al.* 1978
[5]Ohio Department of Health 1978
[6]Small Scale Waste Management Project as reported by Hutzler *et al.* 1978
[7]number of samples in parentheses

Table 3.
Field data of nitrate (NO_3^-), ammonia (NH_4^+), total nitrogen (TN), orthophosphate (OP), and total phosphate (TP) effluent results.

Description	NO_3^- (mg/L) mean	NH_4^+ (mg/L) mean	TN (mg/L) mean	OP (mg/L) mean	TP (mg/L) mean
Glasser 1975					
Bi-A-Robi[1]	1.06(29)[3]	50(29)	-	-	-
Chromaglass[1]	12(11)	27(11)	-	-	-
Flygt[1]	69(19)	10(19)	-	-	-
Jet[1]	0.73(26)	31(26)	-	-	-
Nayadic[1]	4.4(26)	73(26)	-	-	-
Otis *et al.* 1975	19.2(13)	0.74(12)	32.2(11)	16.7(8)	-
	29.8(12)	0.02(13)	39.11(10)	22.8(9)	-
	37.1(21)	0.00(19)	40.2(17)	39.0(15)	-
Sauer 1977	33.8	0.4	-	28.1	-
Brewer *et al.* 1978	8.9	40.6	-	11.8	-
SSWMP[2]	30(95)	0.9(92)	36(87)	21(78)	26(80)
Effert *et al.* 1985	7.4	-	17.8	-	5.3
	9.3	-	17.3	-	10.6
	3.7	-	33.3	-	10.4

[1] systems' name as reported by author
[2] Small Scale Waste Management Project as reported by Hutzler *et al.* 1978
[3] number of samples in parentheses

Table 4.
Field data of dissolved oxygen (DO), pH, fecal coliforms (FC), total coliforms (TC), and fecal *Streptococcus* (FS) effluent results.

Description	D.O. (mg/L) mean	pH mean	FC #/100mL mean	TC #/100mL mean	FS #/100mL mean
Glasser 1975					
Bi-A-Robi[1]	3.8	7.5	-	-	-
Chromaglass[1]	7.8	6.8	-	-	-
Flygt[1]	6.6	6.9	-	-	-
Jet[1]	4.6	7.6	-	-	-
Nayadic[1]	4.4	7.5	-	-	-
Otis *et al.* 1975	-	-	105(20)[3]	-	39(19)
	-	-	68(21)	-	41(19)
	-	-	26(29)	-	144(29)
Sauer 1977	-	-	19000	$1.5x10^5$	-
Brewer *et al.* 1978	-	7.57	100.6	2400(10)	-
SSWMP[2]	-	-	$1x10^5$(115)	-	19953(113)
Effert *et al.* 1985	3.4	-	589	-	-
	3.4	-	32000	-	-
	2.7	-	7900	-	-

[1]systems' name as reported by author
[2]Small Scale Waste Management Project as reported by Hutzler *et al.* 1978
[3]number of samples in parentheses

Table 5.
Field data of septic tank/sand filter effluent and aerobic unit/sand filter effluent.[1,2]

Parameter	Septic Tank Effluent	Sand Filter Effluent[3]	Aerobic Unit Effluent	Sand Filter Effluent[4]
BOD_5 (mg/L)	123	9	26	2-4
TSS (mg/L)	48	6-9	48	9-11
Ammonia-N (mg/L)	19.2	0.8-1.1	0.4	0.3
Nitrate-N (mg/L)	0.3	19.6-20.4	33.8	36.8
Orthophosphate (mg/L)	8.7	6.7-7.1	28.1	22.6
Fecal Coliform (#/100mL)	$5.9x10^5$	$(0.5-0.8)x10^3$	$1.9x10^4$	$1.3x10^3$
Total Coliform (#/100mL)	$9.0x10^5$	$1.3x10^3$	$1.5x10^5$	$1.3x10^4$

[1]Sauer 1977 (Compiled from Table VI and VII)
[2]numbers are mean values
[3]Average loading rate of 5 gal/day/ft^2 dosed from septic tank
[4]Average loading rate of 3.8 gal/day/ft^2 dosed from aerobic unit

Table 6.
Effluent limitations and monitoring requirements.[1,2]

Parameter	Limit	Frequency	Sample Type
BOD_5	≤ 30 mg/L	1/year	grab
Suspended Solids	≤ 30 mg/L	1/year	grab
Fecal Coliform	≤ 200/100 mL	1/year	grab
Total Residual Chlorine	Non-detectable	1/year	grab
pH	6.0 - 9.0	1/year	grab
Dissolved Oxygen	≥ 5 mg/L	1/year	grab
Flow	≤ 1,000 gal/day	1/year	estimate

[1]SWCB 1991 (Part 1: "Emergency Regulations")
[2]"There shall be no discharge of floating solids or visible foam in other than trace amounts" (SWCB 1991).

Table 7.
Listing of dates for APTS start-up and visits.

APTS	Start-up	Trip 1	Trip 2	Trip 3
I	10/26/88	7/12/90	12/01/90	5/12/91
II	6/13/88	9/02/90	2/04/91	5/30/91
III	4/12/88	9/23/90	1/05/91	5/11/91
IV	1/18/90	10/21/90	1/18/91	5/26/91
V	11/25/88	10/06/90	2/27/91	6/05/91

Table 8.
Listing of parameters and sampling points.

Parameters	Primary Settling	Aeration	Submersible Pump Chamber	Effluent
BOD_5	x		x	x
COD	x			x
TSS	x	x		x
TKN	x			x
Ammonia	x			x
Nitrate	x			x
TP	x			x
Ortho-P	x			x
Chlorine Residuals			x	x
Fecal Coliform	x		x	x
Fecal Streptococcus	x		x	x
D.O.		x		x
pH		x		x
Temperature		x		
Flowrate			x	

Table 9.
BOD_5 averages and ranges of three trips to APTS I-V.

SITE AND LOCATION	TRIP 1 (mg/L) AVE	RANGE	TRIP 2 (mg/L) AVE	RANGE	TRIP 3 (mg/L) AVE	RANGE
PRIMARY	191	96-309	217	171-300	74	33-102
I FIL.[1,2]	28	19-36	111	103-115	15	6-20
EFFL.[2]	28	24-32	119	114-124	34	26-40
PRIMARY	657	590-714	848	795-906	99	88-119
II FILTER	62	16-115	48	36-64	23	11-37
EFFL.[3]	56	33-81	99	69-121	36	29-40
PRIMARY	136	119-145	153	140-167	249	186-352
III FILTER	44	42-47	117	103-130	92	86-96
EFFL.	64	36-110	99	89-108	92	83-103
PRIMARY	39	34-44	119	65-187	116	-
IV FILTER	17	15-21	82	68-89	52	47-58
EFFL.[4]	9	-	72	58-96	56	53-58
PRIMARY	46	33-65	132	118-159	116	95-130
V FILTER	12	9-17	57	42-76	71	61-79
EFFL.	19	15-22	70	49-82	158	103-222

[1]filter: filtered water from submersible pump chamber prior to chlorination/dechlorination
[2]For trip 2, the residual D.O. was less than 0.5 mg/L; thus, BOD_5 was calculated using the dilution with the least sample volume.
[3]For trip 3, an initial D.O. value of 7.0 mg/L was used in calculations since problems with the probe occurred.
[4]For trip 1, BOD_5 could have been influenced by residual chlorine; not enough sodium thiosulfate was present to neutralize residual chlorine.

Table 10.
Morning, afternoon, and night BOD_5 averages and ranges for APTS I-V.

SITE AND LOCATION		8-10 AM (mg/L) AVE	RANGE	2-4 PM (mg/L) AVE	RANGE	9-11 PM (mg/L) AVE	RANGE
I	PRIMARY	103	33-181	142	87-171	237	102-309
	FIL.[1,2]	43	6-103	57	19-115	54	20-114
	EFFL.[2]	62	24-124	63	32-118	56	26-114
II	PRIMARY	543	119-843	491	88-795	570	91-906
	FILTER	30	16-37	36	11-55	67	22-115
	EFFL.[3]	61	29-121	63	40-81	67	40-107
III	PRIMARY	216	145-352	165	119-208	157	140-186
	FILTER	80	44-103	86	42-119	88	47-130
	EFFL.	79	46-108	101	89-110	75	36-100
IV	PRIMARY	73	38-116	74	44-104	110	34-187
	FILTER	54	16-89	45	15-68	52	21-88
	EFFL.[4]	40	9-58	60	58-62	76	56-96
V	PRIMARY	94	33-130	84	39-118	115	65-159
	FILTER	52	9-76	44	10-79	44	17-61
	EFFL.	56	15-103	84	22-150	108	20-222

[1]filter: filtered water from submersible pump chamber prior to chlorination/dechlorination
[2]For trip 2, the residual D.O. was less than 0.5 mg/L; thus, BOD_5 was calculated using the dilution with the least sample volume.
[3]For trip 3, an initial D.O. value of 7.0 mg/L was used in calculations since problems with the probe occurred.
[4]For trip 1, BOD_5 could have been influenced by residual chlorine; not enough sodium thiosulfate was present to neutralize residual chlorine.

Table 11.
Average COD/BOD_5 ratios of three trips to APTS I-V.

SITE AND LOCATION		TRIP 1	TRIP 2	TRIP 3
I	PRIMARY	1.90	1.58	4.16
	EFFLUENT	2.22	2.21	3.74
II	PRIMARY	7.56	6.55	9.86
	EFFLUENT	2.97	1.90	4.17
III	PRIMARY	1.65	2.75	14.84
	EFFLUENT	5.13	2.52	2.29
IV	PRIMARY	3.39	2.43	2.97
	EFFLUENT	-	1.81	2.91
V	PRIMARY	2.33	1.07	1.23
	EFFLUENT	3.41	1.52	0.93

Table 12.
Average COD/BOD_6 ratios for the morning, afternoon, and night for APTS I-V.

SITE AND LOCATION		8-10 AM	2-4 PM	9-11 PM
I	PRIMARY	2.67	2.12	2.47
	EFFLUENT	2.82	2.11	3.24
II	PRIMARY	5.57	8.35	10.05
	EFFLUENT	2.79	3.50	2.76
III	PRIMARY	3.74	8.38	7.13
	EFFLUENT	1.86	2.80	5.28
IV	PRIMARY	2.87	2.96	2.96
	EFFLUENT	4.80	2.29	2.20
V	PRIMARY	1.62	1.76	1.23
	EFFLUENT	2.24	2.95	1.29

Table 13.
Overall results for BOD_5 and COD/BOD_5 ratios.

SITE AND LOCATION		BOD_5 OVERALL (mg/L) AVERAGE	RANGE	COD/BOD_5 OVERALL AVERAGE
	PRIMARY	161	33-309	2.55
I	FILTER[1]	51	6-115	-
	EFFLUENT	60	24-124	2.72
	PRIMARY	535	88-906	7.99
II	FILTER	44	11-115	-
	EFFLUENT	64	29-121	3.01
	PRIMARY	179	119-352	6.42
III	FILTER	85	42-130	-
	EFFLUENT	85	36-110	3.31
	PRIMARY	84	34-187	2.92
IV	FILTER	50	15-89	-
	EFFLUENT	56	9-96	3.34
	PRIMARY	98	33-159	1.54
V	FILTER	47	9-79	-
	EFFLUENT	82	15-222	1.96

[1]filter: filtered water from submersible pump chamber prior to chlorination/dechlorination

Table 14.
TSS results for three trips to APTS I-V.

SITE AND LOCATION		TRIP 1 (mg/L) AVE	RANGE	TRIP 2 (mg/L) AVE	RANGE	TRIP 3 (mg/L) AVE	RANGE
I	PRIMARY	275	104-620	40	34-51	112	92-127
	EFFLUENT	11	8-17	27	26-30	53	50-60
II	PRIMARY	4870	4160-6200	5570	4470-7580	699	530-820
	EFFLUENT	181	77-336	161	138-188	64	47-74
III	PRIMARY	154	134-182	372	243-625	2420	1770-3500
	EFFLUENT	252	46-465	144	138-188	85	71-94
IV	PRIMARY	47	21-83	27	20-32	164	-
	EFFLUENT	16	11-20	8	6-12	28	22-36
V	PRIMARY	26	20-34	45	14-81	53	46-61
	EFFLUENT	148	6-426	259	27-445	51	41-59

Table 15.
Morning, afternoon, and night averages and ranges of TSS for APTS I-V.

SITE AND LOCATION		8-10 AM (mg/L) AVE	RANGE	2-4 PM (mg/L) AVE	RANGE	9-11 PM (mg/L) AVE	RANGE
I	PRIMARY	77	34-104	87	34-127	262	51-620
	EFFLUENT	28	8-50	29	8-48	34	17-60
II	PRIMARY	3080	530-4470	3210	820-4650	4840	746-7580
	EFFLUENT	104	47-188	183	74-336	119	71-157
III	PRIMARY	808	182-2000	1420	146-3500	717	134-1770
	EFFLUENT	67	46-71	174	94-244	240	91-465
IV	PRIMARY	74	20-164	56	29-83	26	21-32
	EFFLUENT	16	7-25	21	6-36	15	11-22
V	PRIMARY	32	14-61	40	34-46	52	24-81
	EFFLUENT	164	6-445	263	59-426	31	12-53

Table 16.
Average VSS/TSS ratios of two trips to APTS I-V.

SITE AND LOCATION		TRIP 2	TRIP 3
I	PRIMARY	0.63	0.71
	EFFLUENT	0.76	0.72
II	PRIMARY	0.68	0.69
	EFFLUENT	0.65	0.70
III	PRIMARY	0.64	0.62
	EFFLUENT	0.65	0.85
IV	PRIMARY	0.68	0.64
	EFFLUENT	0.71	0.86
V	PRIMARY	0.73	0.78
	EFFLUENT	0.29	0.55

Table 17.
Overall results for TSS and VSS/TSS ratios for APTS I-V.

SITE AND LOCATION		OVERALL TSS AVERAGE (mg/L)	OVERALL TSS RANGE (mg/L)	OVERALL VSS/TSS AVERAGE
I	PRIMARY	142	34-620	0.67
	EFFLUENT	30	8-60	0.74
II	PRIMARY	3710	530-7580	0.68
	EFFLUENT	135	47-336	0.68
III	PRIMARY	983	134-3500	0.63
	EFFLUENT	160	46-465	0.75
IV	PRIMARY	55	20-164	0.67
	EFFLUENT	17	6-36	0.78
V	PRIMARY	41	14-81	0.76
	EFFLUENT	72	6-426	0.42

Table 18.
Results of MLSS averages and MLVSS/MLSS ratios for three trips to APTS I-V.

SITE AND PARAMETER		TRIP 1 AVE	TRIP 1 RANGE	TRIP 2 AVE	TRIP 2 RANGE	TRIP 3 AVE	TRIP 3 RANGE
I	MLSS (mg/L)	205	167-243	61	36-71	197	192-200
	MLVSS/MLSS	0.71	-	0.60	-	0.62	-
II	MLSS (mg/L)	4290	4070-4590	4550	4350-4860	788	715-833
	MLVSS/MLSS	0.64	-	0.67	-	0.69	-
III	MLSS (mg/L)	202	182-220	328	247-420	468	380-565
	MLVSS/MLSS	0.65	-	0.58	-	0.62	-
IV	MLSS (mg/L)	15	14-16	19	10-27	160	148-167
	MLVSS/MLSS	0.91	-	0.60	-	0.72	-
V	MLSS (mg/L)	8	5-9	18	12-36	95	82-113
	MLVSS/MLSS	0.89	-	0.68	-	0.72	-

Table 19.
Overall results for MLSS and MLVSS/MLSS ratios.

SITE AND PARAMETER		OVERALL AVERAGE	OVERALL RANGE
I	MLSS (mg/L)	152	36-243
	MLVSS/MLSS	0.63	-
II	MLSS (mg/L)	3225	715-4860
	MLVSS/MLSS	0.67	-
III	MLSS (mg/L)	331	182-565
	MLVSS/MLSS	0.61	-
IV	MLSS (mg/L)	65	10-167
	MLVSS/MLSS	0.71	-
V	MLSS (mg/L)	39	5-113
	MLVSS/MLSS	0.74	-

Table 20.
Overall results for nitrate, ammonia, and TKN at APTS I-V.

SITE AND LOCATION		OVERALL NITRATE (mg/L)		OVERALL AMMONIA (mg/L)		OVERALL TKN (mg/L)	
		AVE	RANGE	AVE	RANGE	AVE	RANGE
I	PRIMARY	35.3	0.0-180	15.5	6.3-25.5	19.0	7.1-29.3
	EFFLUENT	3.2	0.3-9.8	10.4	2.2-17.5	19.1	3.9-54.3
II	PRIMARY	6.9	0.0-20.4	20.3	4.1-43.9	256	34.0-970
	EFFLUENT	15.9	0.3-30.1	6.9	0.5-21.4	15.1	4.5-22.3
III	PRIMARY	4.9	0.1-15.6	39.9	5.1-60.0	125	9.9-430
	EFFLUENT	8.1	1.8-20.4	37.7	3.3-56.3	46.1	4.5-93.4
IV	PRIMARY	1.3	0.0-4.2	18.4	1.7-34.9	23.0	4.5-45.5
	EFFLUENT	1.8	0.2-3.7	20.6	0.1-34.9	24.9	3.1-43.0
V	PRIMARY	10.7	1.1-24.2	3.9	0.5-9.5	38.2	10.0-111
	EFFLUENT	13.0	4.1-20.0	2.3	0.1-6.6	6.4	4.3-9.0

Table 21.
Overall results for orthophosphate and total phosphorus at APTS I-V.

SITE AND LOCATION		OVERALL ORTHOPHOSPHATE (mg/L)		OVERALL TOTAL PHOSPHORUS (mg/L)	
		AVERAGE	RANGE	AVERAGE	RANGE
I	PRIMARY	3.1	1.7-7.0	24.7	3.6-164
	EFFLUENT	2.9	0.0-5.0	6.4	3.6-8.1
II	PRIMARY	6.6	5.7-8.8	200	13.0-542
	EFFLUENT	5.7	5.2-6.1	8.7	5.6-11.5
III	PRIMARY	3.4	2.2-7.3	42.8	7.3-219
	EFFLUENT	2.7	1.9-3.4	8.9	5.6-23.5
IV	PRIMARY	4.7	3.4-6.1	7.4	4.4-10.2
	EFFLUENT	4.6	3.8-5.7	6.4	3.2-9.4
V	PRIMARY	5.2	3.8-6.5	5.3	3.0-7.5
	EFFLUENT	5.1	3.6-6.0	5.2	2.7-7.2

Table 22.
Fecal coliform (FC) and fecal *Streptococcus* (FS) ranges for three trips to APTS I-V.

SITE	LOCATION & PARAMETERS		TRIP 1 (colonies/100mL)	TRIP 2 (colonies/100mL)	TRIP 3 (colonies/100mL)
I	PRI.[1]	FC	$3.2x10^{6}-3.5x10^{7}$	$2.3x10^{6}-4.6x10^{7}$	$1.5x10^{6*}-9.8x10^{6}$
		FS	$>2.0x10^{6}$	$0-2.3x10^{3}$	$1.0x10^{3*}-8.0x10^{3}$
	FILT.[2]	FC	$0-1.0x10^{5*}$	$1.1x10^{6*}-9.5x10^{6*}$	$5.0x10^{4*}-1.0x10^{6*}$
		FS	$2.9x10^{3}-\ >1.0x10^{6}$	$0-2.2x10^{2*}$	$1.1x10^{2*}-5.6x10^{2*}$
	EFFL.[3]	FC	0	$9.0x10^{4*}-2.4x10^{5}$	0
		FS	$2.0x10^{3*}-1.0x10^{4}$	$0-5.6x10^{2*}$	$0-1.1x10^{2*}$
II	PRI.	FC	$1.3x10^{6*}-3.1x10^{6}$	^	$0-3.0x10^{5*}$
		FS	$1.0x10^{4}-4.2x10^{5}$	$1.0x10^{4}-7.8x10^{4}$	$7.0x10^{3}-1.3x10^{4}$
	FILT.	FC	$9.0x10^{4*}-1.6x10^{5*}$	$0-5.0x10^{3}$	0
		FS	$1.7x10^{2*}-1.3x10^{3}$	$0-7.8x10^{2}$	$2.2x10^{2*}-3.9x10^{3}$
	EFFL.	FC	$1.5x10^{4*}-3.4x10^{5}$	$0-5.0x10^{4*}$	0
		FS	$7.8x10^{1*}-1.1x10^{3}$	$2.2x10^{2*}-8.9x10^{2*}$	$6.7x10^{2*}-1.3x10^{3*}$
III	PRI.	FC	$5.4x10^{5}-3.0x10^{6}$	$2.4x10^{6}-9.1x10^{6}$	0
		FS	$2.1x10^{4*}-1.1x10^{5}$	$1.8x10^{4*}-8.3x10^{4}$	$3.3x10^{3}-2.8x10^{4}$
	FILT.	FC	$2.8x10^{5}-4.6x10^{5}$	$1.8x10^{6*}-3.7x10^{6}$	$0-1.0x10^{6*}$
		FS	$5.2x10^{4}-7.9x10^{4}$	$9.4x10^{3}-3.6x10^{4}$	$1.1x10^{3*}-4.4x10^{3*}$
	EFFL.	FC	$2.0x10^{5}-4.4x10^{5}$	$0-1.0x10^{4*}$	$0-5.0x10^{5*}$
		FS	$2.1x10^{4}-6.9x10^{4}$	$0-4.4x10^{2*}$	$1.1x10^{3*}-3.3x10^{3}$

Table 22, cont.

SITE LOCATION & PARAMETERS			TRIP 1 (colonies/100mL)	TRIP 2 (colonies/100mL)	TRIP 3 (colonies/100mL)
IV	PRI.	FC	$3.0x10^{4*}-1.6x10^{6}$	$5.0x10^{4}-5.6x10^{4}$	0
		FS	$1.1x10^{2*}-7.8x10^{2*}$	$0-5.0x10^{3}$	$1.1x10^{2*}$
	FILT.	FC	$0-1.8x10^{5*}$	$0-1.3x10^{5*}$	$0-1.0x10^{5*}$
		FS	0	$3.3x10^{2*}-3.3x10^{2*}$	$2.0x10^{3*}-4.2x10^{3}$
	EFFL.	FC	0	0	0
		FS	0	0	0
V	PRI.	FC	$2.0x10^{6}-4.0x10^{6*}$	0	$5.0x10^{5*}-1.5x10^{6*}$
		FS	$1.9x10^{3*}-3.3x10^{4}$	$5.1x10^{3}-9.8x10^{3}$	$0-4.2x10^{3}$
	FILT.	FC	$0-3.5x10^{5*}$	0	$2.5x10^{4*}-5.0x10^{5*}$
		FS	$1.3x10^{3*}-4.6x10^{3}$	$0-2.7x10^{3}$	$0-1.1x10^{2*}$
	EFFL.	FC	$0-2.0x10^{5*}$	0	$0-9.0x10^{4*}$
		FS	$5.6x10^{2*}-2.4x10^{3}$	0	$0-1.1x10^{2*}$

[1]primary settling chamber
[2]filter: filtered water from submersible pump chamber prior to chlorination/dechlorination
[3]effluent
*value determined from colony density less than 20
^unable to detect if fecal coliform were present in morning and afternoon sample due to contamination with other microorganisms

Table 23.
Chlorine residual averages for three trips to APTS I-V.

SITE AND LOCATION		TRIP 1 (mg/L) TRC[1]	FRC[2]	TRIP 2 (mg/L) TRC	FRC	TRIP 3 (mg/L) TRC	FRC
I	CHLORINATION	0.9	0.2	0.0	0.0	0.0	0.0
	EFFLUENT	0.1	0.0	0.0	0.0	0.0	0.0
II	CHLORINATION	0.0	0.0	0.0	0.0	0.0	0.0
	EFFLUENT	0.0	0.0	0.0	0.0	0.0	0.0
III	CHLORINATION	0.0	0.0	0.0	0.0	0.0	0.0
	EFFLUENT	0.0	0.0	0.0	0.0	0.0	0.0
IV	CHLORINATION	-	>9.0	>16.3	0.2	13.2	0.0
	EFFLUENT	13.0	8.0	0.2	0.0	10.8	0.0
V	CHLORINATION	0.0	0.0	1.9	0.5	0.0	0.0
	EFFLUENT	0.0	0.0	0.3	0.0	0.0	0.0

[1]Total Residual Chlorine
[2]Free Residual Chlorine
[3]The titrator broke during the reading.
[4]Did not have enough titrant to finish the titration.

Table 24.
Flowrate data for spring 1991.

SITE	NUMBER OF DAYS	NUMBER OF PUMP ACTIVATIONS	FLOWRATE (gal/d)
I	18	297	182
II	26	425	180
III	23	290	139
IV	21	316	166
V	21	258	135

Table 25.
Comparison of residential and municipal influent to APTS wastewater in the primary settling chamber.

PARAMETER	APTS I - V AVE (mg/L)	RANGE (mg/L)	SD[a]	RESIDENTIAL RANGE[b] (mg/L)	MUNICIPAL RANGE[c] (mg/L)
BOD_5	218 (43)[d]	33-906	232	200-290	110-400
COD	1220 (43)	81-7180	1970	680-730	250-1000
SS	1030 (43)	14-7580	1880	200-290	100-350
NO_3^--N	12.3 (43)	0.0-180	31.9	<1	0
NH_4^+-N	19.6 (43)	0.5-60	18.2	6-18	12-50
TKN	95.4 (43)	4.5-970	167	35-100[e]	20-85
OP	4.6 (43)	1.7-8.8	1.8	6-24[f]	3-10[g]
TP	59.6 (42)	3.0-542	116	18-29	4-15

[a]standard deviation
[b]EPA 1980 (taken from Table 4-3)
[c]Peavy *et al.* 1985 (taken from Table 5-2)
[d]number of samples in parenthesis
[e]total nitrogen
[f]phosphate
[g]inorganic phosphorus

Table 26.
Effluent results of organic constituents, SS and nutrients for APTS I-V.

PARAMETER	AVE (mg/L)	RANGE (mg/L)	STANDARD DEVIATION
BOD_5	70 (43)[a]	9.0-222	43.0
COD	156 (45)	40-386	80.6
SS	99 (45)	6.0-465	121
NO_3^--N	8.4 (45)	0.2-30	9.0
NH_4^+-N	17 (45)	0.1-56	18.3
TKN	22 (45)	3.1-94	21.8
OP	4.2 (45)	0.0-6.1	1.7
TP	7.1 (45)	2.7-24	3.4

[a]number of samples

Figures

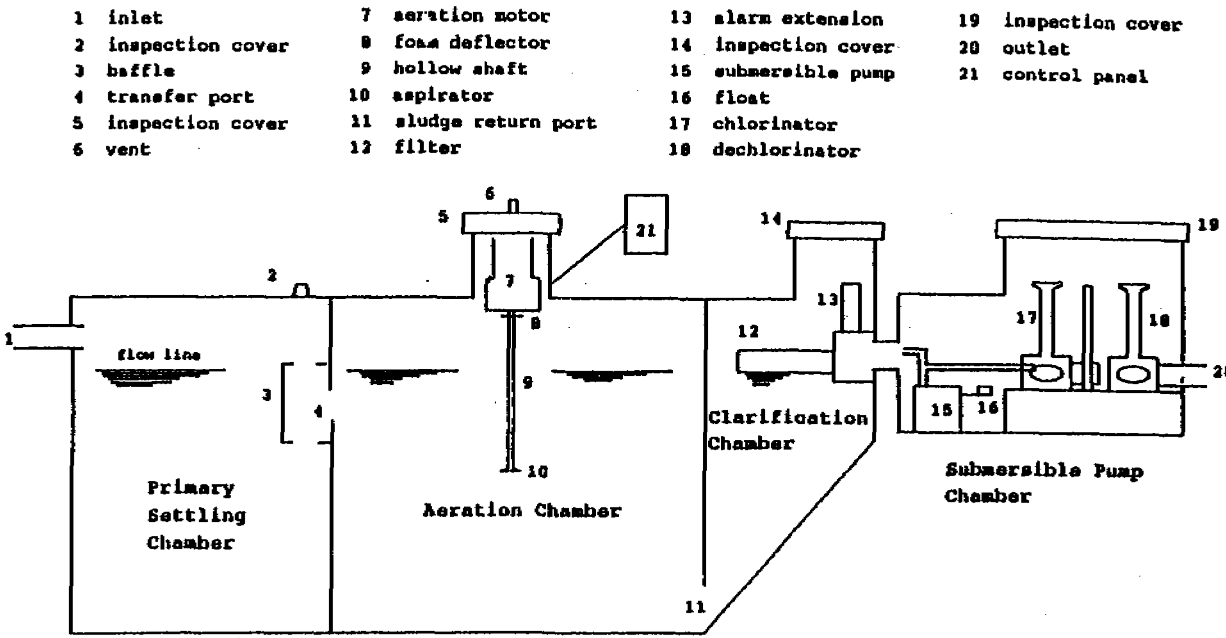
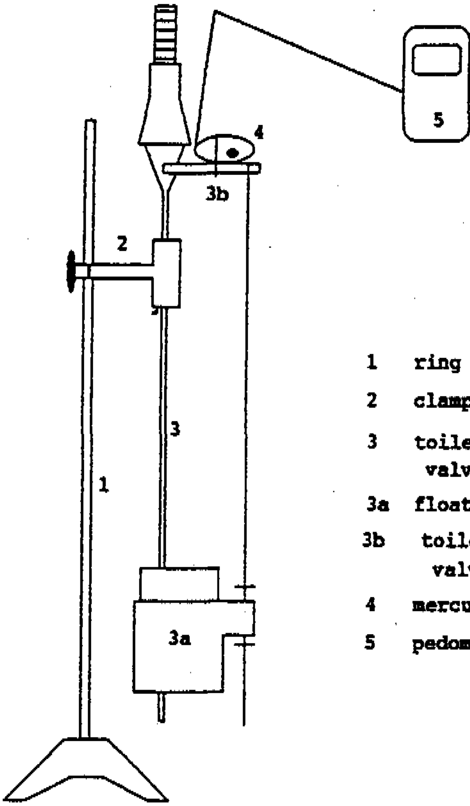


Figure 1. APTS schematic.

Figure 2.
Schematic of flowrate device.



1 ring stand
2 clamp
3 toilet tank repair valve
3a float
3b toilet tank repair valve arm
4 mercury switch
5 pedometer

Figure 3.
Fluorescence versus time for variable flowrate in the primary settling chamber at APTS I.

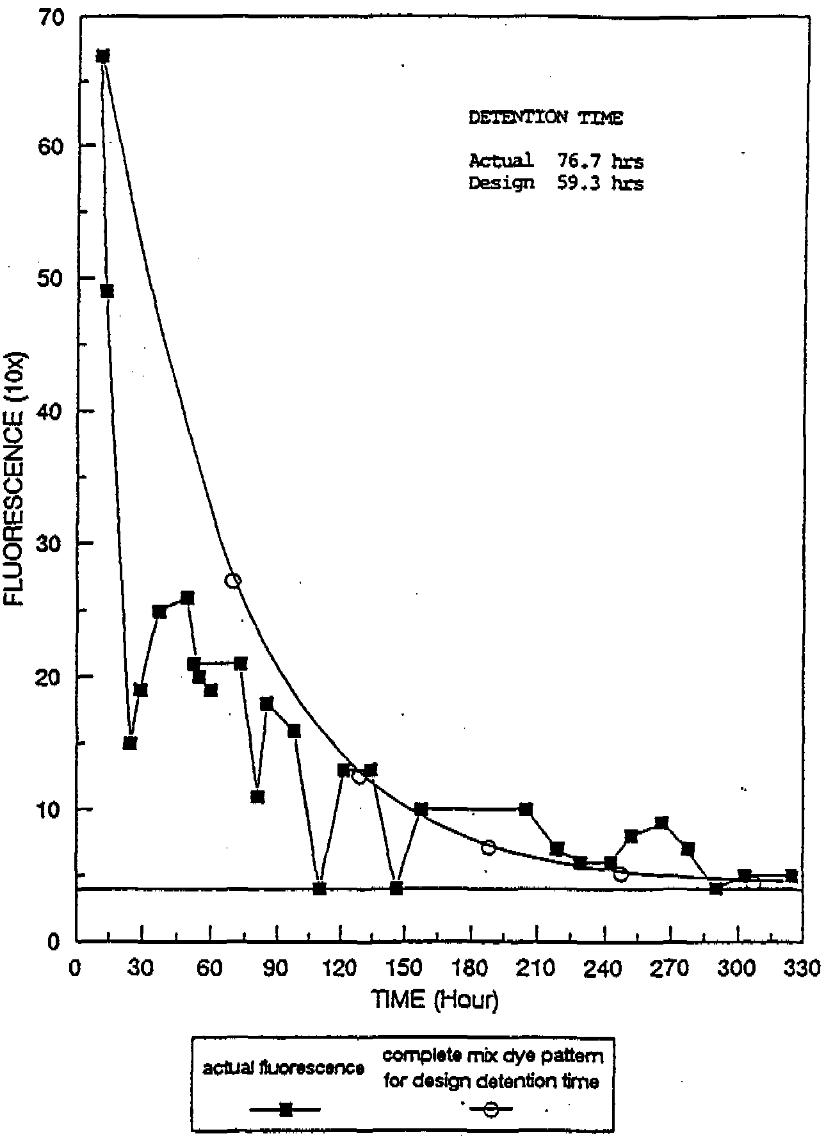


Figure 4.
Fluorescence versus time for variable flowrate in the aeration chamber at APTS I.

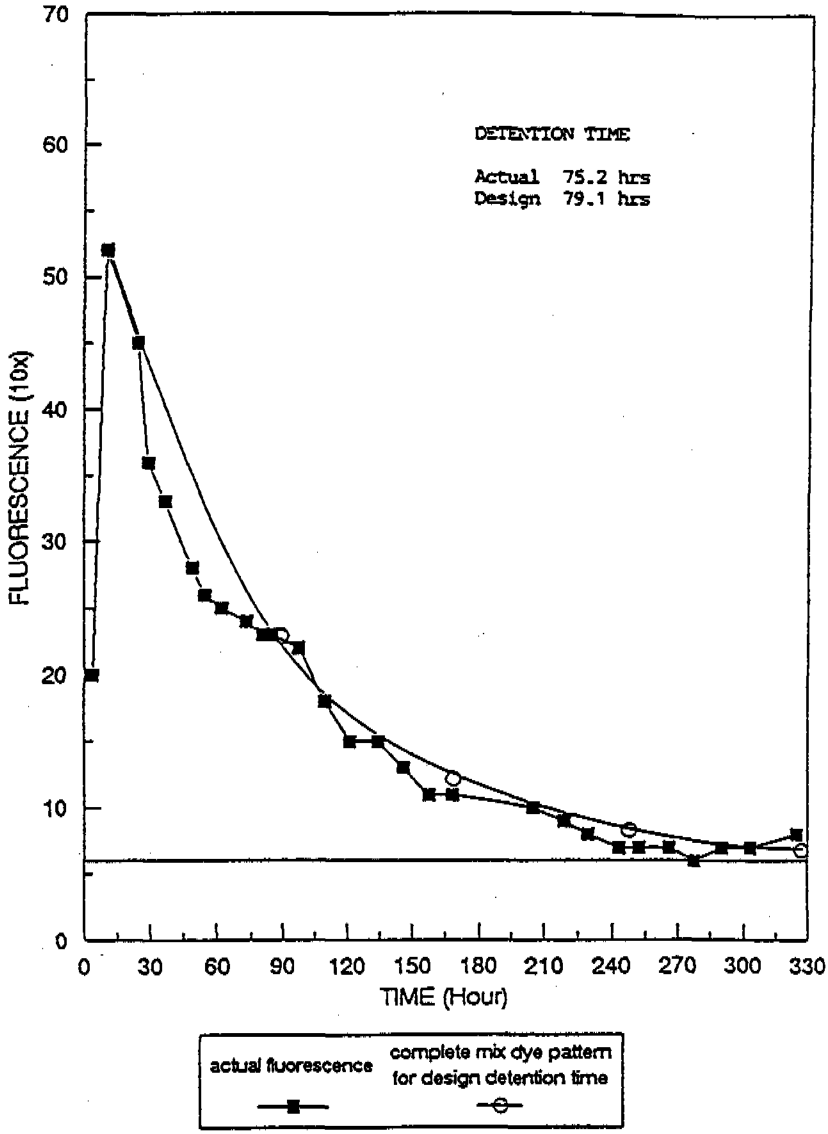


Figure 5.
Fluorescence versus time for variable flowrate in the clarification chamber at APTS I.

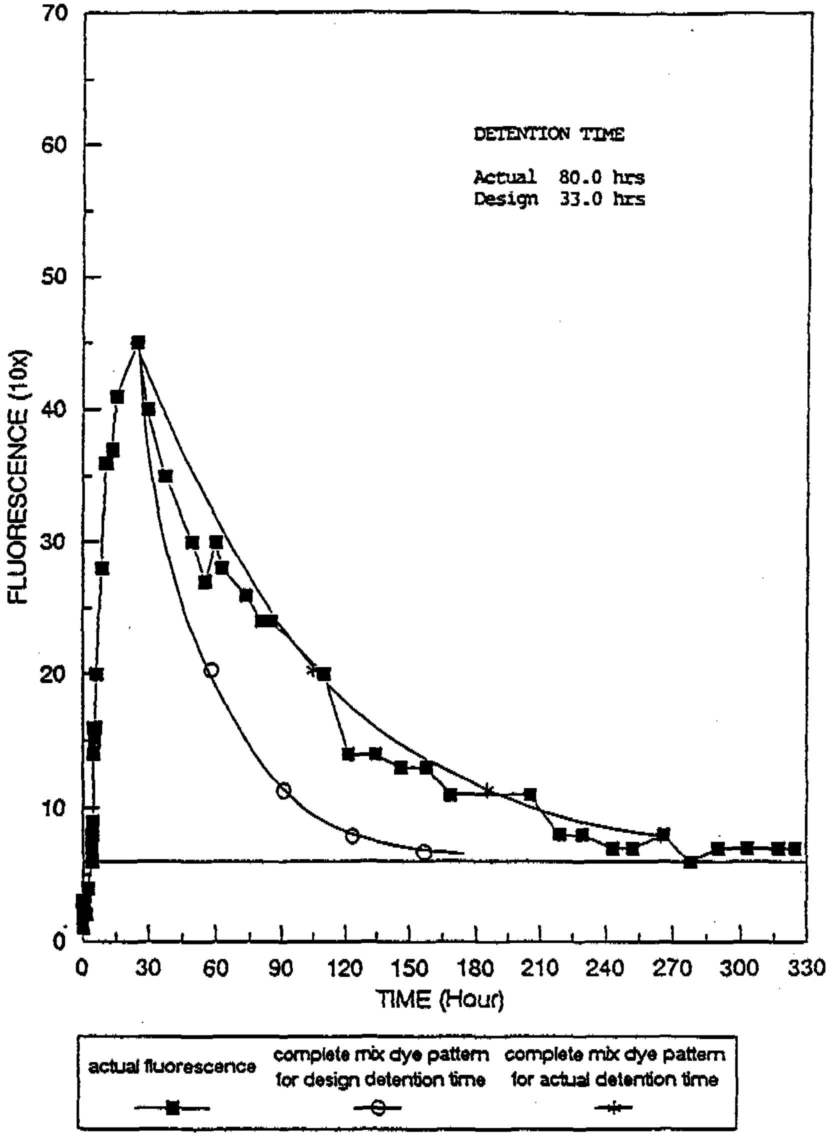


Figure 6.
Fluorescence versus time for constant flowrate in the aeration chamber at APTS I.

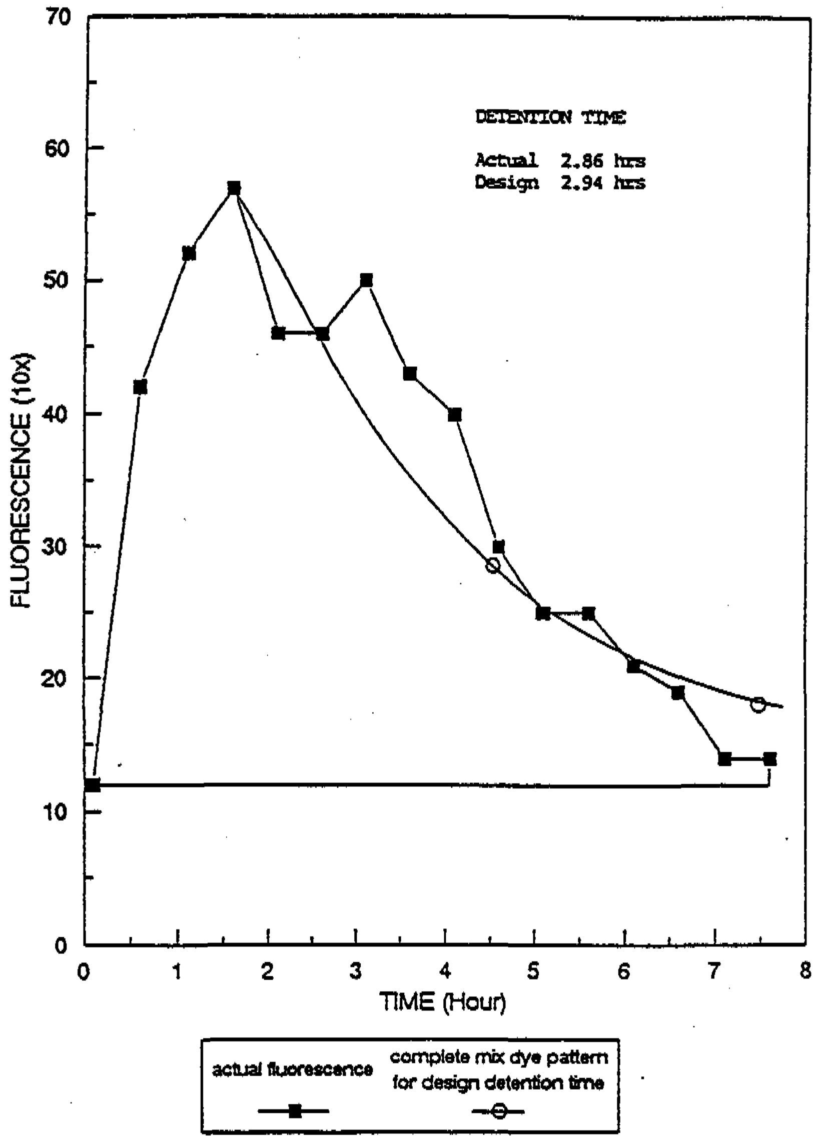


Figure 7.
Fluorescence versus time for constant flowrate in the clarification chamber at APTS I.

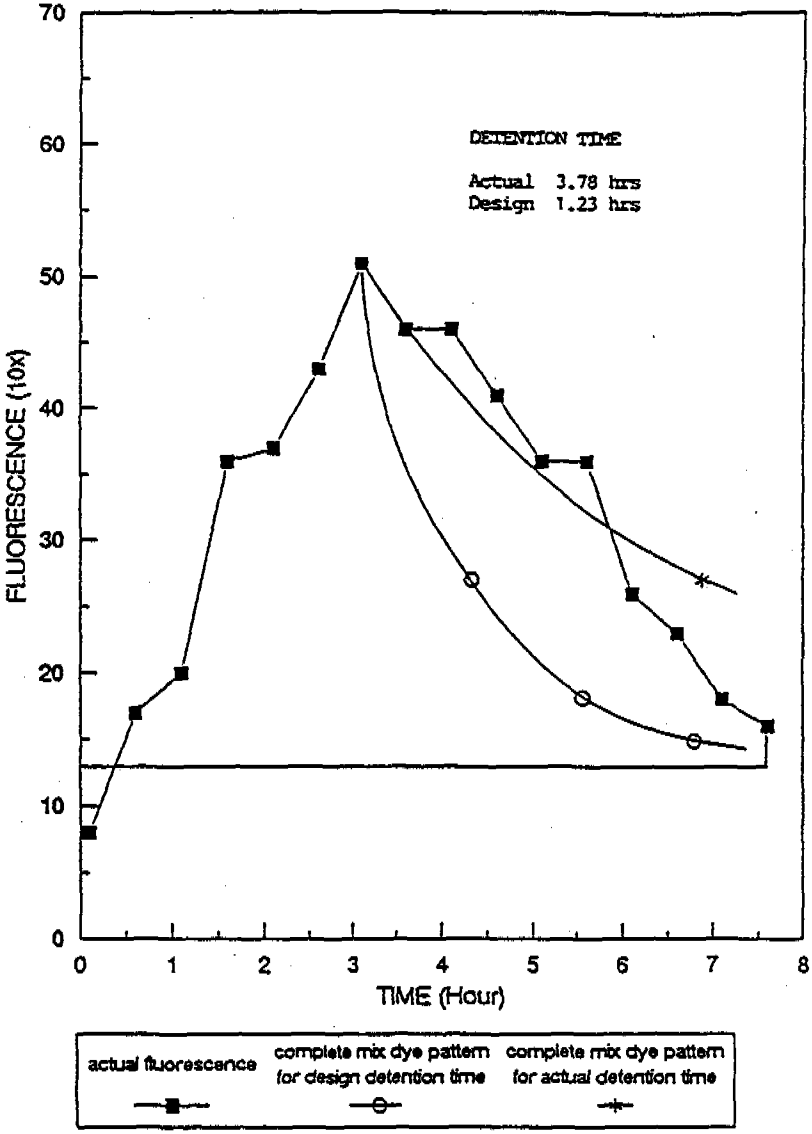


Figure 8.
BOD_5 data for APTS I-V.

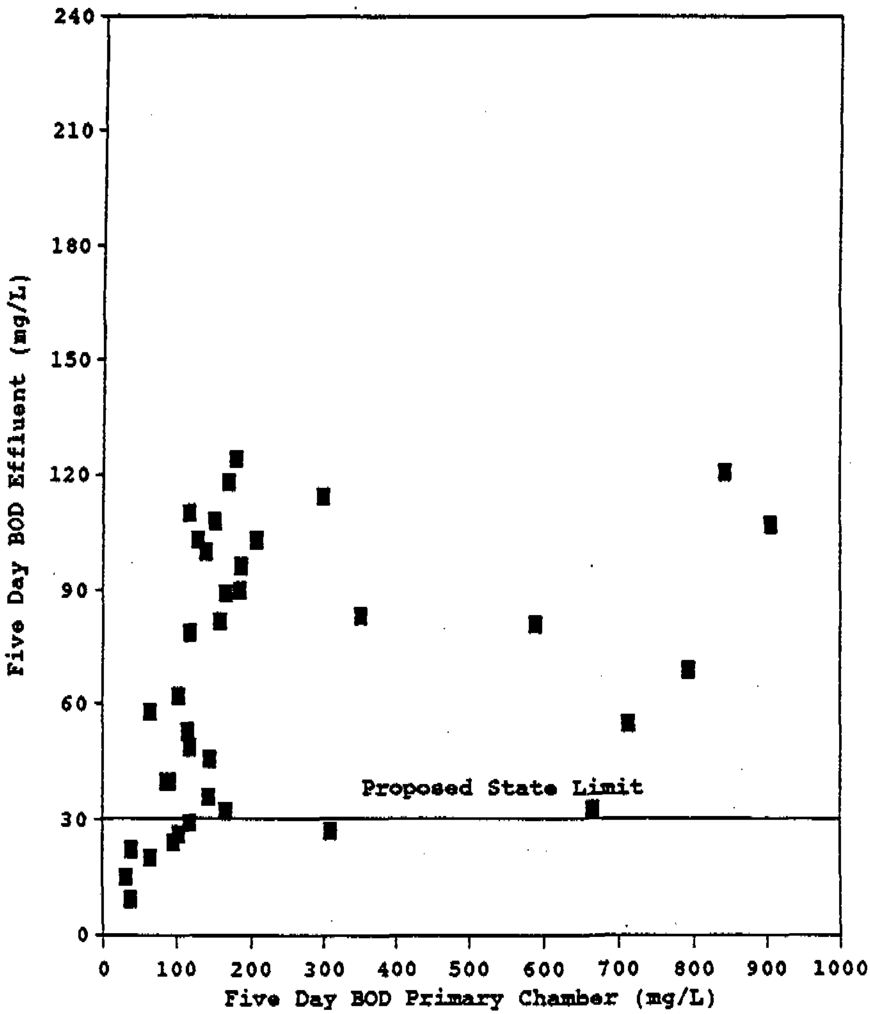


Figure 9.
Total SS data for APTS I-V.

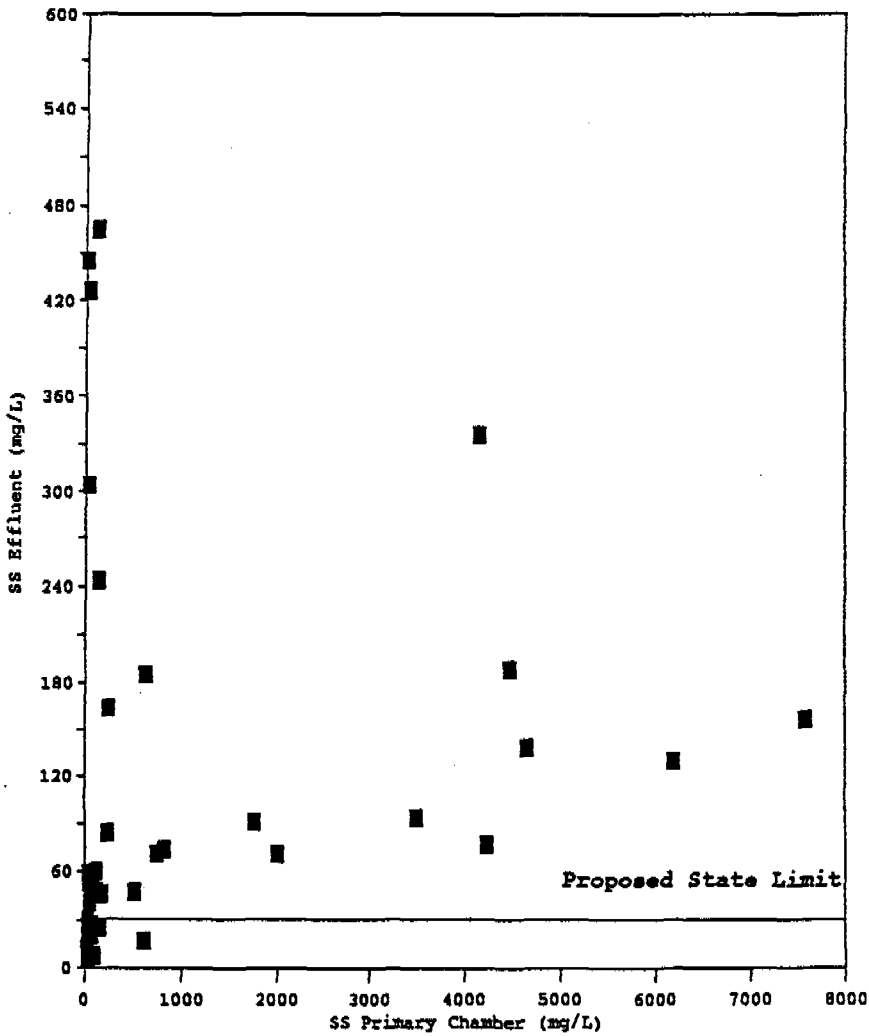


Figure 10.
Relationship between MLSS and BOD_5 reduction.

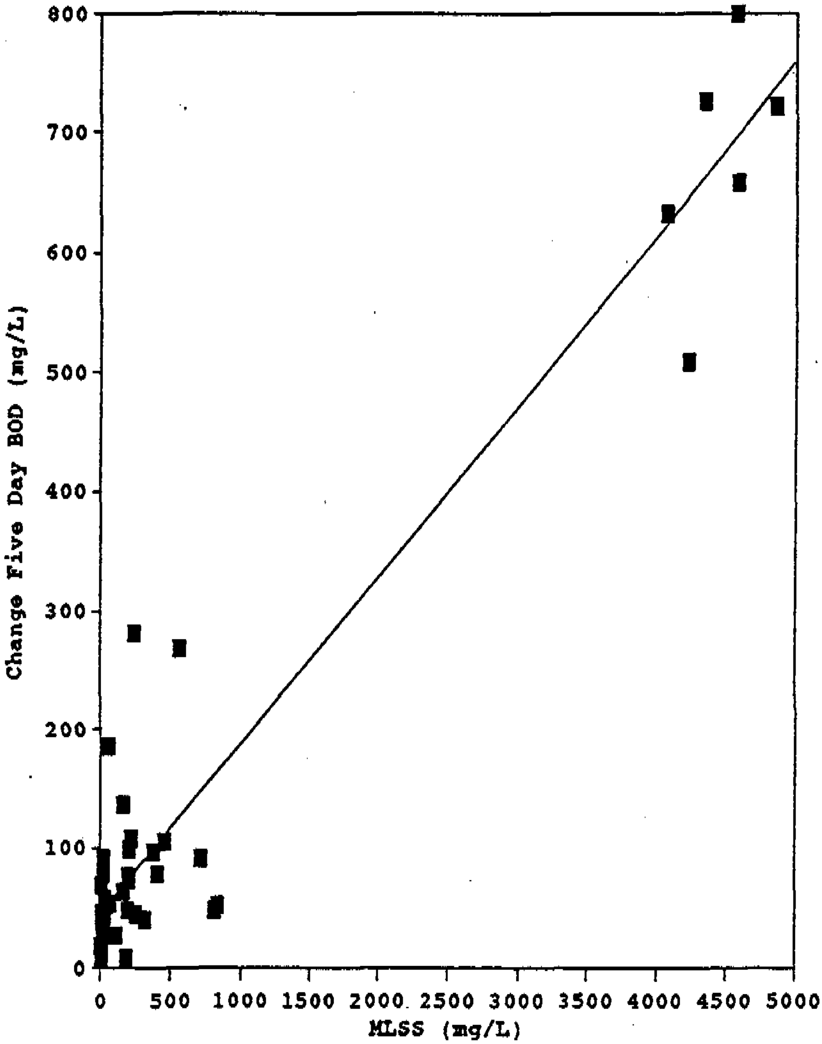


Figure 11.
Relationship between MLSS and SS_{psc}.

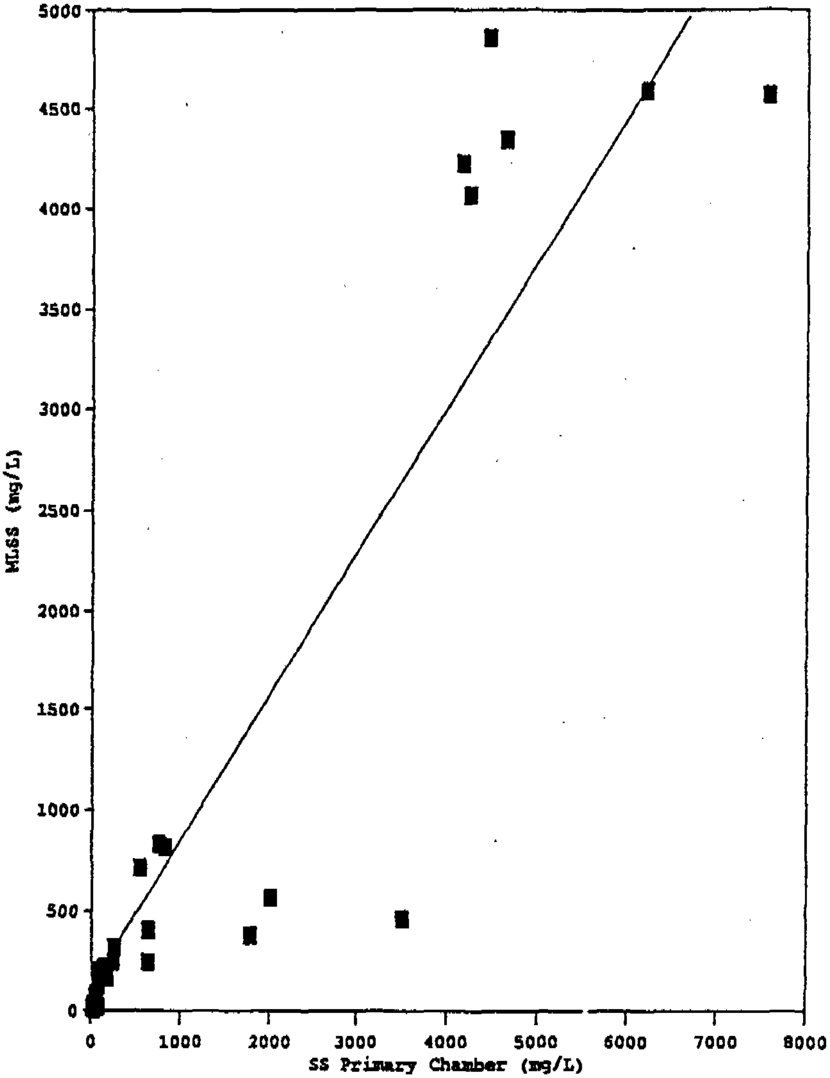


Figure 12.
Total phosphorus data for APTS I-V.

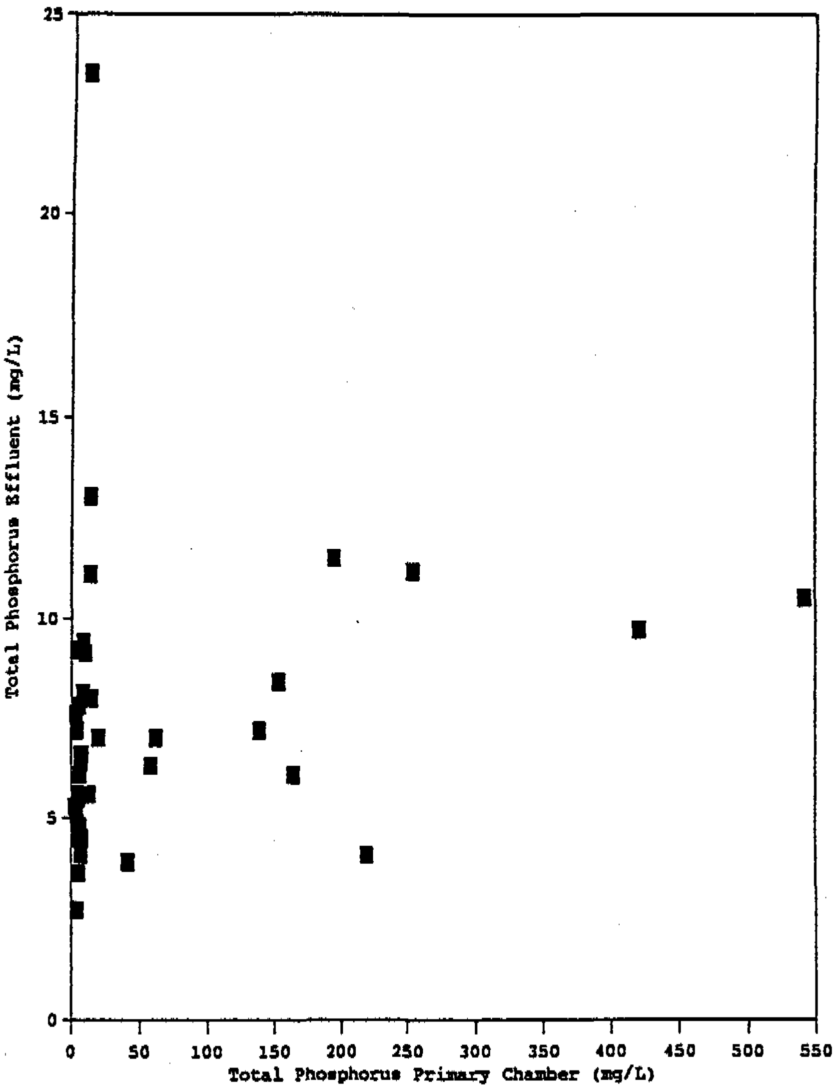


Figure 13.
Orthophosphate data for APTS I-V.

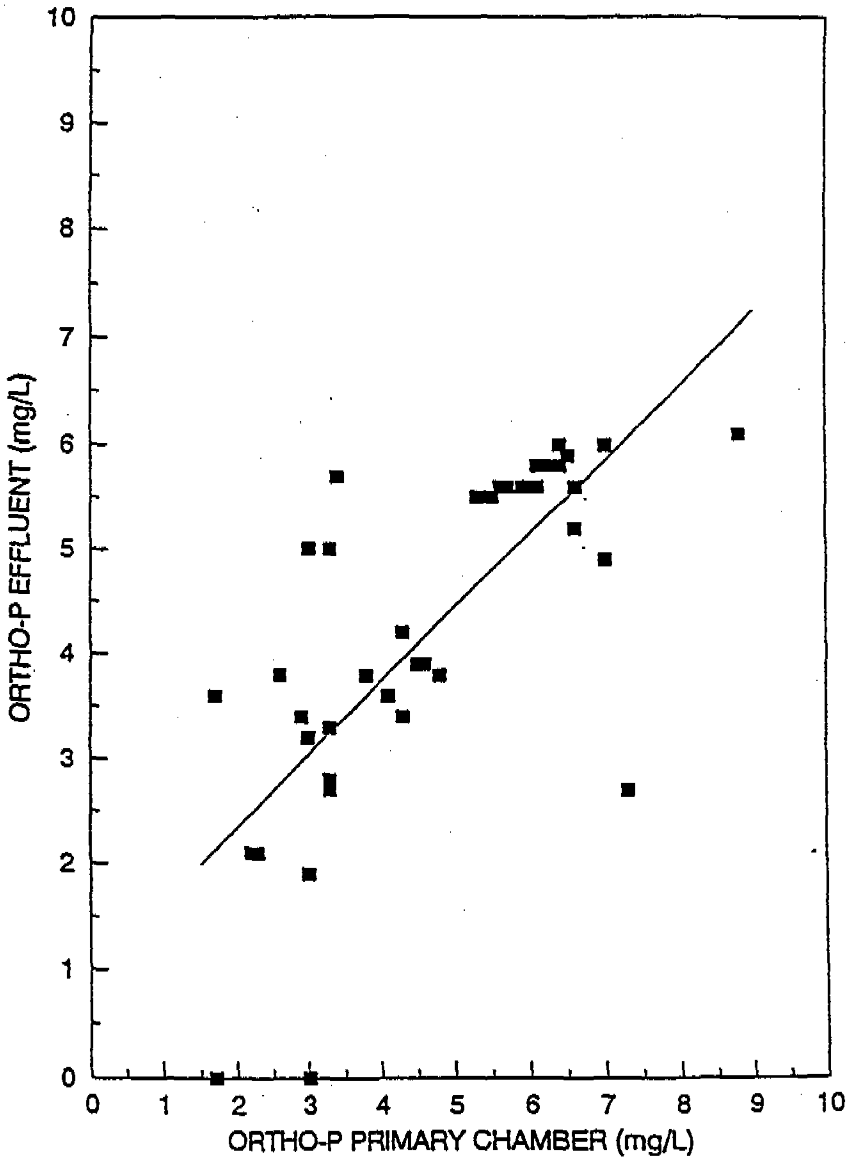


Figure 14.
Nitrate data for APTS I-V.

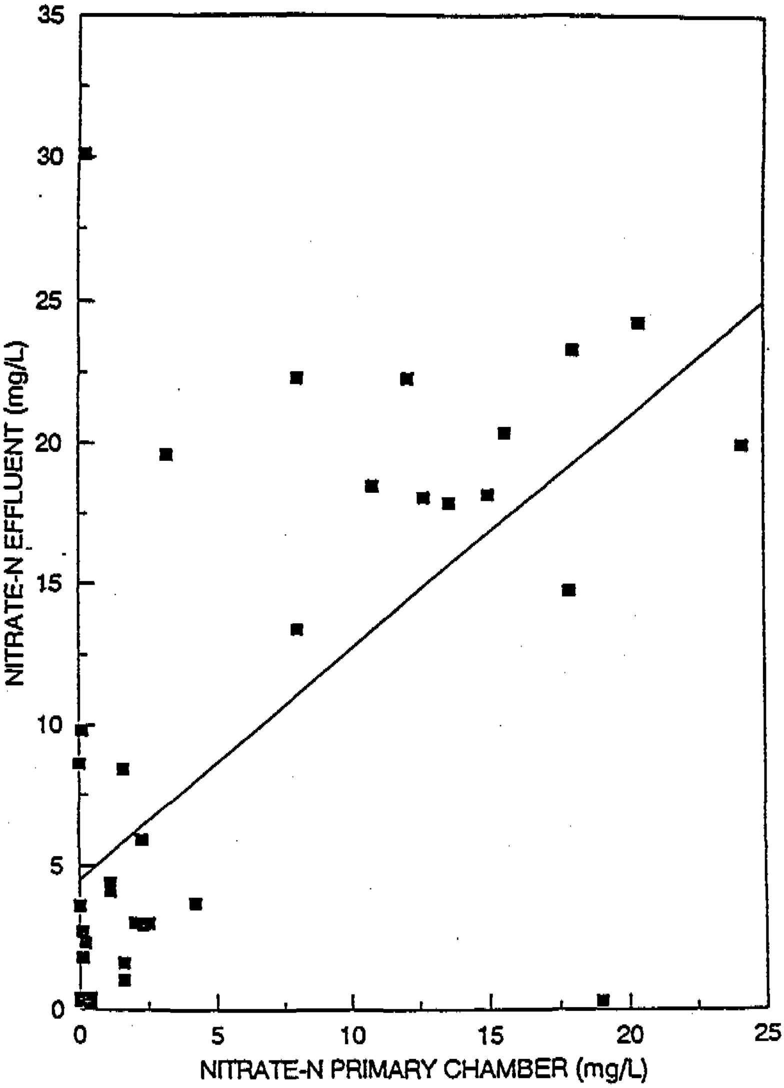
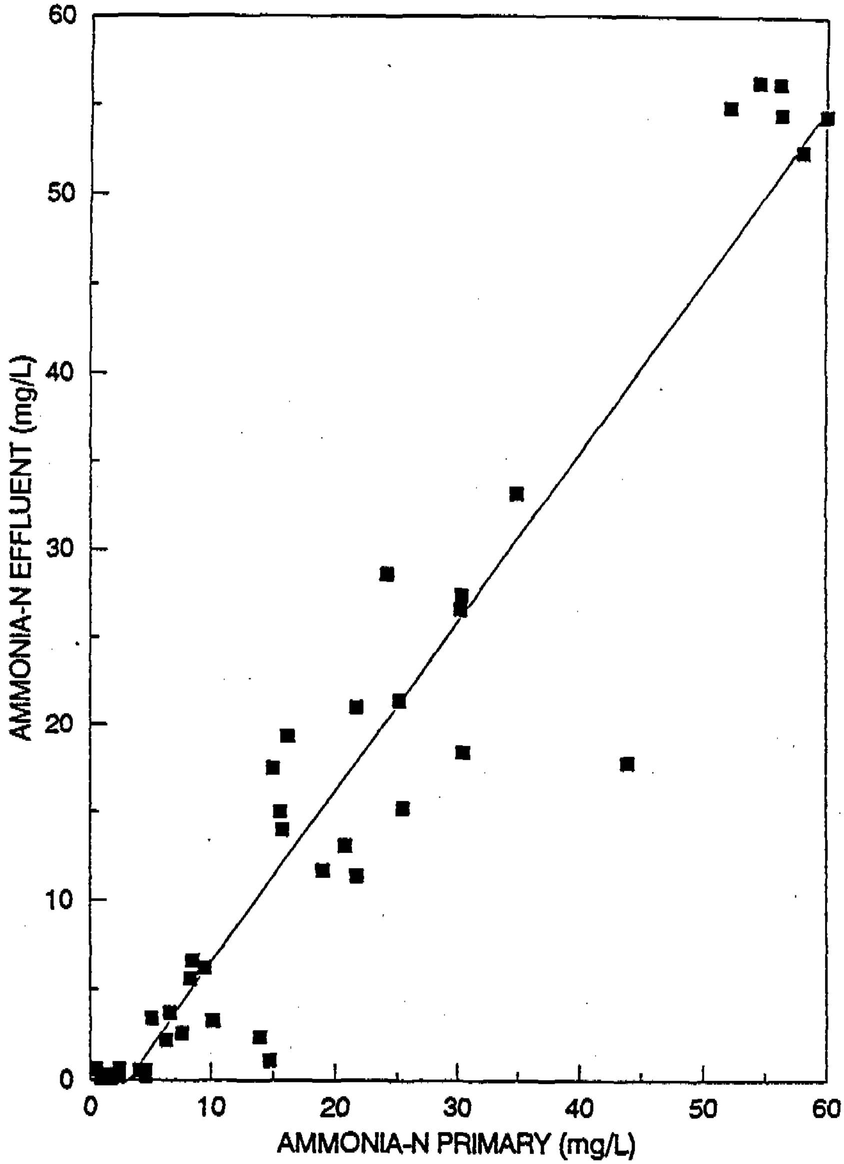


Figure 15.
Ammonia data for APTS I-V.



Appendix A: BOD$_5$ and COD Data

Table A1.
BOD_5 and COD raw data for three trips to APTS I-V.

SITE & DATE	TIME OF DAY	PRIMARY SETTLING CHAM BOD_5 (mg/L)	PRIMARY SETTLING CHAM COD (mg/L)	FILTRATION BOD_5 (mg/L)	EFFLUENT BOD_5 (mg/L)	EFFLUENT COD (mg/L)
APTS I (7/12/90)	8-10 AM	96	111	19	24	58
	2-4 PM	168	282	36	32	56
	9-11 PM	309	885	29	27	67
APTS II (9/02/90)	8-10 AM	666	3771	16	33	84
	2-4 PM	590	3755	55	81	311
	9-11 PM	714	7614	115	55	139
APTS III (9/23/90)	8-10 AM	145	238	44	46	86
	2-4 PM[a]	119	173	42	110	307
	9-11 PM[a]	144	268	47	36	386
APTS IV (10/21/90)	8-10 AM	38	112	16	9[b]	83
	2-4 PM	44	155	15	-[b]	96
	9-11 PM	34	126	21	-[b]	68
APTS V (10/06/90)	8-10 AM	33	91	9	15	40
	2-4 PM[c]	39	116	10	22	116
	9-11 PM	65	81	17	20	46
APTS I (12/01/90)	8-10 AM	181	313	103[d]	124[d]	264
	2-4 PM	171	274	115[d]	118[d]	262
	9-11 PM	300	422	114[d]	114[d]	260
APTS II (2/04/91)	8-10 AM	843	4407	36	121	208
	2-4 PM	795	4603	43	69	161
	9-11 PM	906	7814	64	107	178
APTS III (1/05/91)	8-10 AM	152	344	103	108	190
	2-4 PM	167	624	119	89	290
	9-11 PM	140	316	130	100	255
APTS IV (1/18/91)	8-10 AM	65	174	89	58	110
	2-4 PM	104	250	68	62	123
	9-11 PM	187	414	88	96	150
APTS V (2/27/91)	8-10 AM	118	118	76	49	128
	2-4 PM	118	110	42	79	77
	9-11 PM	159	202	54	82	80

continued

Table A1, cont.

SITE & DATE	TIME OF DAY	PRIMARY SETTLING CHAM BOD_5 (mg/L)	PRIMARY SETTLING CHAM COD (mg/L)	FILTRATION BOD_5 (mg/L)	EFFLUENT BOD_5 (mg/L)	EFFLUENT COD (mg/L)
APTS I	8-10 AM	33	207	6	37	145
(5/12/91)	2-4 PM	87	267	19	40	94
	9-11 PM	102	321	20	26	129
APTS II	8-10 AM	119	694	37	29[e]	119
(5/30/91)	2-4 PM	88	1135	11	40[e]	173
	9-11 PM	91	988	22	40[e]	163
APTS III	8-10 AM	352	2575	94	83	162
(5/11/91)	2-4 PM	208	4148	96	103	242
	9-11 PM	186	3211	86	90	232
APTS IV	8-10 AM	116	345	58	53	174
(5/26/91)	2-4 PM	-	-	52	58	151
	9-11 PM	-	-	47	56	159
APTS V	8-10 AM	130	144	72	103	148
(6/05/91)	2-4 PM	95	132	79	150	115
	9-11 PM	122	144	61	222	131

[a] low volume in submersible pump when activated
[b] BOD_5 could be influenced by residual chlorine; not enough $Na_2S_2O_3$ to neutralize residual chlorine.
[c] possible contamination with ditch water and/or sediments in the effluent pipe
[d] Residual D.O. < 0.5 mg/L; thus, calculated BOD_5 for the dilutions with the least sample volume.
[e] Used 7.00 mg/L as $D.O._i$ reading in calculations since experienced problems with the probe.

Appendix B: Suspended Solids Data

Table B1.
TSS and VSS raw data for three trips to APTS I-V.

SITE & DATE	TIME OF DAY	PRIMARY SETTLING CHAM		EFFLUENT	
		TSS (mg/L)	VSS (mg/L)	TSS (mg/L)	VSS (mg/L)
APTS I	8-10 AM	104	-	8	-
(7/12/90)	2-4 PM	101	-	8	-
	9-11 PM	620	-	17	-
APTS II	8-10 AM	4240	-	77	-
(9/02/90)	2-4 PM	4160	-	336	-
	9-11 PM	6200	-	130	-
APTS III	8-10 AM	182	-	46	-
(9/23/90)	2-4 PM[a]	146	-	244	-
	9-11 PM[a]	134	-	465	-
APTS IV	8-10 AM	37	-	16	-
(10/21/90)	2-4 PM	83	-	20	-
	9-11 PM	21	-	11	-
APTS V	8-10 AM	20	-	6	-
(10/06/90)	2-4 PM[b]	34	-	426	-
	9-11 PM	24	-	12	-
APTS I	8-10 AM	34	20	26	21
(12/01/90)	2-4 PM	34	20	30	21
	9-11 PM	51	37	26	20
APTS II	8-10 AM	4470	3090	188	127
(2/04/91)	2-4 PM	4650	3140	138	88
	9-11 PM	7580	5170	157	100
APTS III	8-10 AM	243	163	84	58
(1/05/91)	2-4 PM	625	385	185	115
	9-11 PM	247	160	164	106
APTS IV	8-10 AM	20	17	7	5
(1/18/91)	2-4 PM	29	15	6	4
	9-11 PM	32	22	12	9
APTS V	8-10 AM[b]	14	11	445	63
(2/27/91)	2-4 PM[b]	39	28	304	38
	9-11 PM	81	60	27	16

Table B1, cont.

SITE & DATE	TIME OF DAY	PRIMARY SETTLING CHAM		EFFLUENT	
		TSS (mg/L)	VSS (mg/L)	TSS (mg/L)	VSS (mg/L)
APTS I	8-10 AM	92	71	50	37
(5/12/91)	2-4 PM	127	93	48	35
	9-11 PM	116	73	60	41
APTS II	8-10 AM	530	360	47	30
(5/30/91)	2-4 PM	820	533	74	54
	9-11 PM	746	546	71	52
APTS III	8-10 AM	2000	1270	71	62
(5/11/91)	2-4 PM	3500	2114	94	78
	9-11 PM	1770	1100	91	77
APTS IV	8-10 AM	164	105	25	21
(5/26/91)	2-4 PM	-	-	36	31
	9-11 PM	-	-	22	19
APTS V	8-10 AM	61	46	41	22
(6/05/91)	2-4 PM	46	36	59	35
	9-11 PM	51	41	53	28

[a] low volume in submersible pump when activated
[b] possible contamination with ditch water and/or sediments in the effluent pipe

Appendix C:
Aeration Chamber Data

Table C1.
MLSS and MLVSS raw data for three trips to APTS I-V.

SITE & DATE	TIME OF DAY	4' BELOW WATER LEVEL MLSS (mg/L)	4' BELOW WATER LEVEL MLVSS (mg/L)	2' BELOW WATER LEVEL MLSS (mg/L)	2' BELOW WATER LEVEL MLVSS (mg/L)
APTS I (7/12/90)	8-10 AM	205	152	-	-
	2-4 PM	167	117	-	-
	9-11 PM	243	167	-	-
APTS II (9/02/90)	8-10 AM	4067	2587	-	-
	2-4 PM	4227	2747	-	-
	9-11 PM	4587	2947	-	-
APTS III (9/23/90)	8-10 AM	203	130	-	-
	2-4 PM	182	120	-	-
	9-11 PM	220	143	-	-
APTS IV (10/21/90)	8-10 AM	14	13	-	-
	2-4 PM	16	14	-	-
	9-11 PM	14	13	-	-
APTS V (10/06/90)	8-10 AM	9	8	-	-
	2-4 PM	5	5	-	-
	9-11 PM	9	7	-	-
APTS I (12/01/90)	8-10 AM	36	23	67	40
	2-4 PM	67	40	71	45
	9-11 PM	63	36	60	33
APTS II (2/04/91)	8-10 AM	4860	3270	4600	3100
	2-4 PM	4350	2910	4350	2930
	9-11 PM	4570	3040	4560	3070
APTS III (1/05/91)	8-10 AM	247	87	267	173
	2-4 PM	403	250	420	245
	9-11 PM	317	200	316	200
APTS IV (1/18/91)	8-10 AM	10	2	14	10
	2-4 PM	27	18	19	13
	9-11 PM	24	16	22	15
APTS V (2/27/91)	8-10 AM	12	8	14	9
	2-4 PM	12	9	15	10
	9-11 PM	20	13	36	25

continued

Table C1, cont.

SITE & DATE	TIME OF DAY	4' BELOW WATER LEVEL MLSS (mg/L)	4' BELOW WATER LEVEL MLVSS (mg/L)	2' BELOW WATER LEVEL MLSS (mg/L)	2' BELOW WATER LEVEL MLVSS (mg/L)
APTS I	8-10 AM	200	120	-	-
(5/12/91)	2-4 PM	192	118	-	-
	9-11 PM	198	128	-	-
APTS II	8-10 AM	715	508	-	-
(5/30/91)	2-4 PM	817	550	-	-
	9-11 PM	833	575	-	-
APTS III	8-10 AM	565	355	-	-
(5/11/91)	2-4 PM	460	287	-	-
	9-11 PM	380	235	-	-
APTS IV	8-10 AM	167	118	-	-
(5/26/91)	2-4 PM	166	118	-	-
	9-11 PM	148	108	-	-
APTS V	8-10 AM	113	80	-	-
(6/05/91)	2-4 PM	82	61	-	-
	9-11 PM	91	64	-	-

Table C2.
Morning, afternoon, and night results of MLSS and MLVSS/MLSS ratios for APTS I-V.

SITE AND PARAMETER		8-10 AM AVE	8-10 AM RANGE	2-4 PM AVE	2-4 PM RANGE	9-11 PM AVE	9-11 PM RANGE
I	MLSS (mg/L)	127	36-205	124	67-192	141	60-243
	MLVSS/MLSS	0.66	-	0.64	-	0.64	-
II	MLSS (mg/L)	3560	715-4860	3436	817-4350	3638	833-4587
	MLVSS/MLSS	0.67	-	0.66	-	0.67	-
III	MLSS (mg/L)	320	203-565	366	182-460	253	220-380
	MLVSS/MLSS	0.54	-	0.63	-	0.63	-
IV	MLSS (mg/L)	51	10-167	57	16-166	52	14-148
	MLVSS/MLSS	0.61	-	0.75	-	0.78	-
V	MLSS (mg/L)	37	9-113	28	5-82	39	9-91
	MLVSS/MLSS	0.75	-	0.83	-	0.71	-

Table C3.
pH, temperature, and DO raw data for three trips to APTS I-V.

SITE & DATE	TIME OF DAY	4' BELOW WATER LEVEL pH	TEMP (C)	D.O. (mg/L)	2' BELOW WATER LEVEL pH	TEMP (C)	D.O. (mg/L)
APTS I	8-10 AM	7.2	28.7	4.6	-	-	-
(7/12/90)	2-4 PM	7.5	29.4	6.1	-	-	-
	9-11 PM	7.1	27.4	4.8	-	-	-
APTS II	8-10 AM	6.7	27.2	2.6	-	-	-
(9/02/90)	2-4 PM	6.8	28.3	2.5	-	-	-
	9-11 PM	6.8	27.2	4.1	-	-	-
APTS III	8-10 AM	7.3	23.8	5.9	-	-	-
(9/23/90)	2-4 PM	7.1	23.4	4.9	-	-	-
	9-11 PM	7.1	22.4	5.3	-	-	-
APTS IV	8-10 AM	7.5	21.9	6.0	-	-	-
(10/21/90)	2-4 PM	7.3	23.0	6.5	-	-	-
	9-11 PM	7.1	21.1	6.1	-	-	-
APTS V	8-10 AM	7.8	21.5	5.8	-	-	-
(10/06/90)	2-4 PM	7.9	23.6	5.6	-	-	-
	9-11 PM	7.8	21.2	6.0	-	-	-
APTS I	8-10 AM[a]	6.8	18.0	0.9	6.8	18.4	1.0
(12/01/90)	2-4 PM	7.2	19.9	6.2	7.3	20.2	6.5
	9-11 PM	7.2	16.4	8.4	7.3	18.2	8.0
APTS II	8-10 AM	6.8	16.4	1.4	6.7	16.0	1.1
(2/04/91)	2-4 PM	6.8	19.5	2.4	6.7	19.8	2.2
	9-11 PM	6.9	15.1	4.8	6.8	15.6	4.8
APTS III	8-10 AM	7.1	11.1	8.0	7.2	10.9	8.0
(1/05/91)	2-4 PM	7.2	12.1	7.1	7.2	12.3	7.5
	9-11 PM	7.2	11.5	7.5	7.2	11.8	7.4
APTS IV	8-10 AM	7.0	13.2	6.2	7.0	13.7	5.8
(1/18/91)	2-4 PM	6.9	13.6	4.0	7.0	14.3	3.9
	9-11 PM	7.0	13.4	4.4	7.1	11.9	4.2
APTS V	8-10 AM	6.5	12.0	8.4	6.5	12.0	8.4
(2/27/91)	2-4 PM	6.5	13.5	8.1	6.5	13.5	8.0
	9-11 PM	6.5	11.8	8.4	6.5	11.9	8.4

continued

Table C3, cont.

SITE & DATE	TIME OF DAY	4' BELOW WATER LEVEL pH	TEMP (C)	D.O. (mg/L)	2' BELOW WATER LEVEL pH	TEMP (C)	D.O. (mg/L)
APTS I	8-10 AM	7.5	24.6	4.4	-	-	-
(5/12/91)	2-4 PM	7.4	23.5	4.7	-	-	-
	9-11 PM	7.3	23.5	4.1	-	-	-
APTS II	8-10 AM	7.1	26.1	1.8	-	-	-
(5/30/91)	2-4 PM	7.3	26.6	2.5	-	-	-
	9-11 PM	7.3	26.1	2.1	-	-	-
APTS III	8-10 AM	7.4	20.8	-	-	-	-
(5/11/91)	2-4 PM	7.4	20.8	4.5	-	-	-
	9-11 PM	7.4	20.5	4.5	-	-	-
APTS IV	8-10 AM	8.1	22.7	4.5	-	-	-
(5/26/91)	2-4 PM	8.1	22.6	4.6	-	-	-
	9-11 PM	8.2	21.9	5.1	-	-	-
APTS V	8-10 AM	7.2	22.7	4.6	-	-	-
(6/05/91)	2-4 PM	7.4	23.1	4.7	-	-	-
	9-11 PM	7.3	22.6	5.2	-	-	-

[a]aeration motor found unplugged

Appendix D:
Nutrient Data

Table D1.
Nitrate, ammonia, and TKN raw data for three trips to APTS I-V.

SITE & DATE	TIME OF DAY	PRIMARY SETTLING CHAMBER NITRATE (mg/L)	PRIMARY SETTLING CHAMBER AMMONIA (mg/L)	PRIMARY SETTLING CHAMBER TKN (mg/L)	EFFLUENT NITRATE (mg/L)	EFFLUENT AMMONIA (mg/L)	EFFLUENT TKN (mg/L)
APTS I	8-10 AM	1.6	13.9	12.4[a]	8.4	2.4	3.9
(7/12/90)	2-4 PM	0.0	6.3	7.1	8.6	2.2	10.3
	9-11 PM	0.1	7.6	9.2	9.8	2.6	24.2
APTS II	8-10 AM	18.0	4.6	154.5	23.3	0.5	4.5
(9/02/90)	2-4 PM	20.4	4.1	145.5	24.3	0.5	6.7
	9-11 PM	0.2	14.7	970.0	30.1	1.1	16.0
APTS III	8-10 AM	10.8	10.1	124.5	18.5	3.3	9.8
(9/23/90)	2-4 PM	15.6	5.1	9.9	20.4	3.4	4.5
	9-11 PM	10.8	6.6	10.3	18.5	3.7	4.5
APTS IV	8-10 AM	0.0	4.6	5.8	3.6	0.2	3.1
(10/21/90)	2-4 PM	0.0	2.4	4.5	3.6	0.2	4.3
	9-11 PM	4.2	1.7	4.9	3.7	0.1	4.3
APTS V	8-10 AM	13.6	2.0	111.2	17.9	0.3	7.6
(10/06/90)	2-4 PM	15.0	0.9	102.3	18.2	0.1	4.5
	9-11 PM	12.7	1.2	59.1	18.1	0.3	8.2
APTS I	8-10 AM	0.3	20.8	22.6	0.4	13.1	19.1
(12/01/90)	2-4 PM	0.4	15.8	29.3	0.4	14.0	17.6
	9-11 PM	0.4	19.0	24.2	0.4	11.7	54.3
APTS II	8-10 AM	3.2	21.7	271.0	19.6	11.4	22.3
(2/04/91)	2-4 PM	12.1	30.5	210.0	22.3	18.4	15.3[a]
	9-11 PM	8.0	43.9	381.0	22.3	17.8	13.0[a]
APTS III	8-10 AM	2.3	56.3	120.1	2.9	54.5	72.7
(1/05/91)	2-4 PM	2.0	52.1	96.1	3.0	54.9	77.7
	9-11 PM	2.5	54.5	55.9	3.0	56.3	93.4
APTS IV	8-10 AM	1.6	30.4	33.9	1.6	27.4	31.6
(1/18/91)	2-4 PM	1.6	30.3	36.2	1.6	26.6	31.8
	9-11 PM	1.6	24.2	30.4	1.0	28.6	33.4
APTS V	8-10 AM	8.0	1.8	11.2	13.4	0.3	6.4
(2/27/91)	2-4 PM	17.9	0.5	10.6	14.8	0.6	5.3
	9-11 PM	24.2	2.4	12.5	20.0	0.6	4.3

continued

Table D1, cont.

SITE & DATE	TIME OF DAY	PRIMARY SETTLING CHAMBER NITRATE (mg/L)	AMMONIA (mg/L)	TKN (mg/L)	EFFLUENT NITRATE (mg/L)	AMMONIA (mg/L)	TKN (mg/L)
APTS I	8-10 AM	180.3	25.5	25.0[a]	0.3	15.2	15.0[a]
(7/12/90)	2-4 PM	115.3	15.6	21.5	0.3	15.0	13.5[a]
	9-11 PM	19.0	15.0	19.5	0.3	17.5	14.0[a]
APTS II	8-10 AM	0.0	25.2	47.0	0.3	21.4	18.5[a]
(9/02/90)	2-4 PM	0.0	21.7	87.5	0.3	21.0	21.5
	9-11 PM	0.0	16.2	34.0	0.4	19.3	18.5[a]
APTS III	8-10 AM	0.1	58.1	430.0	2.7	52.4	45.5[a]
(9/23/90)	2-4 PM	0.1	60.0	145.0	1.8	54.4	51.5[a]
	9-11 PM	0.2	56.2	135.1	2.3	56.2	55.0[a]
APTS IV	8-10 AM	0.4	34.9	45.5	0.2	33.2	32.0[a]
(10/21/90)	2-4 PM	-	-	-	0.3	34.9	41.0
	9-11 PM	-	-	-	0.4	34.5	43.0
APTS V	8-10 AM	2.3	8.3	15.0	5.9	5.6	9.0
(10/06/90)	2-4 PM	1.1	8.5	10.0	4.4	6.6	5.5[a]
	9-11 PM	1.1	9.5	11.5	4.1	6.2	6.5

[a]Denotes impossible reading, TKN < Ammonia; more confidence with ammonia reading since that test is calibrated and more direct.

Table D2.
Orthophosphate and total phosphorus raw data for three trips to APTS I-V.

SITE & DATE	TIME OF DAY	PRIMARY SETTLING CHAM ORTHO-P (mg/L)	TP (mg/L)	EFFLUENT ORTHO-P (mg/L)	TP (mg/L)
APTS I	8-10 AM	4.3	164.0	3.4	6.1
(7/12/90)	2-4 PM	1.7	3.6	3.6	7.6
	9-11 PM	2.6	8.4	3.8	6.6
APTS II	8-10 AM	6.1	152.8	5.8	8.4
(9/02/90)	2-4 PM	7.0	139.0	6.0	7.2
	9-11 PM	8.8	542.5	6.1	10.5
APTS III	8-10 AM	3.0	11.2	1.9	5.6
(9/23/90)	2-4 PM	2.3	7.3	2.1	6.6
	9-11 PM	2.2	11.4	2.1	23.5
APTS IV	8-10 AM	4.8	5.6	3.8	4.5
(10/21/90)	2-4 PM	4.6	8.4	3.9	4.5
	9-11 PM	4.5	-	3.9	4.4
APTS V	8-10 AM	5.4	5.9	5.5	5.5
(10/06/90)	2-4 PM	5.3	5.6	5.5	5.5
	9-11 PM	5.6	5.8	5.6	5.6
APTS I	8-10 AM	3.3	5.6	5.0	7.8
(12/01/90)	2-4 PM	3.0	8.9	5.0	8.1
	9-11 PM	7.0	15.0	4.9	8.0
APTS II	8-10 AM	6.4	255.2	5.8	11.2
(2/04/91)	2-4 PM	5.7	195.2	5.6	11.5
	9-11 PM	6.6	421.7	5.6	9.7
APTS III	8-10 AM	3.3	9.2	3.3	5.6
(1/05/91)	2-4 PM	2.9	13.4	3.4	13.0
	9-11 PM	3.0	13.6	3.2	11.1
APTS IV	8-10 AM	6.1	10.2	5.6	9.1
(1/18/91)	2-4 PM	5.5	9.0	5.5	9.4
	9-11 PM	3.4	4.4	5.7	9.2
APTS V	8-10 AM	4.1	6.6	3.6	6.1
(2/27/91)	2-4 PM	3.8	4.6	3.8	2.7[a]
	9-11 PM	3.8	7.5	3.8	4.1

continued

Table D2, cont.

SITE & DATE	TIME OF DAY	PRIMARY SETTLING CHAM ORTHO-P (mg/L)	TP (mg/L)	EFFLUENT ORTHO-P (mg/L)	TP (mg/L)
APTS I	8-10 AM	3.0	5.2	0.0	4.9
(5/12/91)	2-4 PM	1.7	5.9	0.0	3.6
	9-11 PM	1.7	6.1	0.0	4.8
APTS II	8-10 AM	6.2	19.9	5.8	7.0
(5/30/91)	2-4 PM	5.9	62.4	5.6	7.0
	9-11 PM	6.6	13.0	5.2	5.6
APTS III	8-10 AM	7.3	219.4	2.7	4.1
(5/11/91)	2-4 PM	3.3	58.1	2.7	6.3
	9-11 PM	3.3	41.7	2.8	3.9
APTS IV	8-10 AM	4.3	6.9	4.2	6.4
(5/26/91)	2-4 PM	-	-	4.4	7.0
	9-11 PM	-	-	4.5	3.2[a]
APTS V	8-10 AM	6.2	4.2[a]	5.8	7.2
(6/05/91)	2-4 PM	6.4	3.0[a]	6.0	5.3[a]
	9-11 PM	6.5	4.9[a]	5.9	5.1[a]

[a]Denotes impossible reading, TP < Ortho-P; more confidence is placed in ortho-P reading since that test is calibrated and more direct.

Table D3.
Nitrate results for three trips to APTS I-V.

SITE AND LOCATION		TRIP 1 (mg/L) AVE	RANGE	TRIP 2 (mg/L) AVE	RANGE	TRIP 3 (mg/L) AVE	RANGE
I	PRIMARY	0.6	0.0-1.6	0.4	0.3-0.4	105	19.0-180
	EFFLUENT	8.9	8.4-9.8	0.4	0.4	0.3	0.3
II	PRIMARY	12.9	0.2-20.4	7.8	3.2-12.1	0.0	0.0
	EFFLUENT	25.9	23.3-30.1	21.4	19.6-22.3	0.4	0.3-0.4
III	PRIMARY	12.4	10.8-15.6	2.3	2.0-2.5	0.2	0.1-0.2
	EFFLUENT	19.1	18.5-20.4	3.0	2.9-3.0	2.3	1.8-2.7
IV	PRIMARY	1.4	0.0-4.2	1.6	1.6	0.4	-
	EFFLUENT	3.6	3.6-3.7	1.4	1.0-1.6	0.3	0.2-0.4
V	PRIMARY	13.8	12.7-15.0	16.7	8.0-24.2	1.5	1.1-2.3
	EFFLUENT	18.1	17.9-18.2	16.1	13.4-20.0	4.8	4.1-5.9

Table D4.
Nitrate results for APTS I-V for morning, afternoon, and night.

SITE AND LOCATION		8-10 AM (mg/L) AVE	RANGE	2-4 PM (mg/L) AVE	RANGE	9-11 PM (mg/L) AVE	RANGE
I	PRIMARY	60.7	0.3-180	38.6	0.0-115	6.5	0.1-19.0
	EFFLUENT	3.0	0.3-8.4	3.1	0.3-8.6	3.5	0.3-9.8
II	PRIMARY	7.1	0.0-18.0	10.8	0.0-20.4	2.7	0.0-8.0
	EFFLUENT	14.4	0.3-23.3	15.6	0.3-24.3	17.6	0.4-30.1
III	PRIMARY	4.4	0.1-10.8	5.9	0.1-15.6	4.5	0.2-10.8
	EFFLUENT	8.0	2.7-18.5	8.4	1.8-20.4	7.9	2.3-18.5
IV	PRIMARY	0.7	0.0-1.6	0.8	0.0-1.6	2.9	1.6-4.2
	EFFLUENT	1.8	0.2-3.6	1.8	0.3-3.6	1.7	0.4-3.7
V	PRIMARY	8.0	2.3-13.6	11.3	1.1-17.9	12.7	1.1-24.2
	EFFLUENT	12.4	5.9-17.9	12.5	4.4-18.2	14.1	4.1-20.0

Table D5.
Ammonia results for three trips to APTS I-V.

SITE AND LOCATION		TRIP 1 (mg/L) AVE	RANGE	TRIP 2 (mg/L) AVE	RANGE	TRIP 3 (mg/L) AVE	RANGE
I	PRIMARY	9.3	6.3-13.9	18.5	15.8-20.8	18.7	15.0-25.5
	EFFLUENT	2.4	2.2-2.6	12.9	11.7-13.1	15.9	15.0-17.5
II	PRIMARY	7.8	4.1-14.7	32.0	21.7-43.9	21.0	16.2-25.2
	EFFLUENT	0.7	0.5-1.1	15.9	11.4-18.4	20.6	19.3-21.4
III	PRIMARY	7.3	5.1-10.1	54.3	52.1-56.3	58.1	56.2-60.0
	EFFLUENT	3.5	3.3-3.7	55.2	54.5-56.3	54.3	52.4-56.2
IV	PRIMARY	2.9	1.7-4.6	28.3	24.2-30.4	34.9	-
	EFFLUENT	0.2	0.1-0.2	27.5	26.6-28.6	34.2	33.2-34.9
V	PRIMARY	1.4	0.9-2.0	1.6	0.5-2.4	8.8	8.3-9.5
	EFFLUENT	0.2	0.1-0.3	0.5	0.3-0.6	6.1	5.6-6.6

Table D6.
Ammonia results for APTS I-V for morning, afternoon, and night.

SITE AND LOCATION		8-10 AM (mg/L) AVE	RANGE	2-4 PM (mg/L) AVE	RANGE	9-11 PM (mg/L) AVE	RANGE
I	PRIMARY	20.1	13.9-25.5	12.6	6.3-15.8	13.9	7.6-19.0
	EFFLUENT	10.2	2.4-15.2	10.4	2.2-15.0	10.6	2.6-17.5
II	PRIMARY	17.2	4.6-25.2	18.7	4.1-30.5	24.9	14.7-43.9
	EFFLUENT	11.1	0.5-21.4	13.3	0.5-21.0	12.7	1.1-19.3
III	PRIMARY	41.5	10.1-58.1	39.1	5.1-60.0	39.1	6.6-56.2
	EFFLUENT	36.7	3.3-54.5	37.6	3.4-54.9	38.7	3.7-56.3
IV	PRIMARY	23.3	4.6-34.9	16.4	2.4-30.3	13.0	1.7-24.2
	EFFLUENT	20.3	0.2-33.2	20.6	0.2-34.9	21.1	0.1-34.5
V	PRIMARY	4.0	1.8-8.3	3.3	0.5-8.5	4.4	1.2-9.5
	EFFLUENT	2.1	0.3-5.6	2.4	0.1-6.6	2.4	0.3-6.2

Table D7.
TKN results for three trips to APTS I-V.

SITE AND LOCATION		TRIP 1 (mg/L) AVE	RANGE	TRIP 2 (mg/L) AVE	RANGE	TRIP 3 (mg/L) AVE	RANGE
I	PRIMARY	9.6	7.1-12.4	25.4	22.6-29.3	22.0	19.5-25.0
	EFFLUENT	12.8	3.9-24.2	30.3	17.6-54.3	14.2	13.5-15.0
II	PRIMARY	423	146-970	287	210-381	56.2	34.0-87.5
	EFFLUENT	9.1	4.5-16.0	16.9	13.0-22.3	19.5	18.5-21.5
III	PRIMARY	48.2	9.9-124	90.7	55.9-120	236.7	135-430
	EFFLUENT	6.3	4.5-9.8	81.3	72.7-93.4	50.7	45.5-55.0
IV	PRIMARY	5.1	4.5-5.8	33.5	30.4-36.2	45.5	-
	EFFLUENT	3.9	3.1-4.3	32.3	31.4-33.4	38.7	32.0-43.0
V	PRIMARY	90.9	59.1-111	11.4	10.6-12.5	12.2	10.0-15.0
	EFFLUENT	6.8	4.5-8.2	5.3	4.3-6.4	7.0	5.5-9.0

Table D8.
Ammonia results for APTS I-V for morning, afternoon, and night.

SITE AND LOCATION		8-10 AM (mg/L) AVE	RANGE	2-4 PM (mg/L) AVE	RANGE	9-11 PM (mg/L) AVE	RANGE
I	PRIMARY	20.0	12.4-25.0	19.3	7.1-29.3	17.6	9.2-24.2
	EFFLUENT	12.7	3.9-19.1	13.8	10.3-17.6	30.8	14.0-54.3
II	PRIMARY	158	47.0-271	148	87.5-210	462	34.0-970
	EFFLUENT	15.1	4.5-22.3	14.5	6.7-21.5	15.8	13.0-18.5
III	PRIMARY	225	120-430	83.7	9.9-145	67.1	10.3-135
	EFFLUENT	42.7	9.8-72.7	44.6	4.5-77.7	51.0	4.5-93.4
IV	PRIMARY	28.4	5.8-45.5	20.4	4.5-36.2	17.7	4.9-30.4
	EFFLUENT	22.2	3.1-33.9	25.7	4.3-41.0	26.9	4.3-43.0
V	PRIMARY	45.8	11.2-111	41.0	10.0-102	27.7	11.1-59.1
	EFFLUENT	7.7	6.4-9.0	5.1	4.5-5.5	6.3	4.3-8.2

Table D9.
Orthophosphate results for three trips to APTS I-V.

SITE AND LOCATION		TRIP 1 (mg/L) AVE	RANGE	TRIP 2 (mg/L) AVE	RANGE	TRIP 3 (mg/L) AVE	RANGE
I	PRIMARY	2.9	1.7-4.3	4.4	3.0-7.0	2.1	1.7-3.0
	EFFLUENT	3.6	3.4-3.8	5.0	4.9-5.0	0.0	0.0
II	PRIMARY	7.3	6.1-8.8	6.2	5.7-6.6	6.2	5.9-6.6
	EFFLUENT	6.0	5.8-6.1	5.7	5.6-5.8	5.5	5.2-5.8
III	PRIMARY	2.5	2.2-3.0	3.1	2.9-3.3	4.6	3.3-7.3
	EFFLUENT	2.0	1.9-2.1	3.3	3.2-3.4	2.7	2.7-2.8
IV	PRIMARY	4.6	4.5-4.8	5.0	3.4-6.1	4.3	-
	EFFLUENT	3.9	3.8-3.9	5.6	5.5-5.7	4.4	4.2-4.5
V	PRIMARY	5.4	5.3-5.6	3.9	3.8-4.1	6.4	6.2-6.5
	EFFLUENT	5.6	5.5-5.6	3.7	3.6-3.8	5.9	5.8-6.0

Table D10.
Orthophosphate results for APTS I-V for morning, afternoon, and night.

SITE AND LOCATION		8-10 AM (mg/L) AVE	RANGE	2-4 PM (mg/L) AVE	RANGE	9-11 PM (mg/L) AVE	RANGE
I	PRIMARY	3.5	3.0-4.3	2.1	1.7-3.0	3.8	1.7-7.0
	EFFLUENT	2.8	0.0-5.0	2.9	0.0-5.0	2.9	0.0-4.9
II	PRIMARY	6.2	6.1-6.4	6.2	5.7-7.0	7.3	6.6-8.8
	EFFLUENT	5.8	5.8	5.7	5.6-6.0	5.6	5.2-6.1
III	PRIMARY	4.4	3.0-7.3	2.8	2.3-3.3	2.8	2.2-3.3
	EFFLUENT	2.6	1.9-3.3	2.7	2.1-3.4	2.7	2.1-3.2
IV	PRIMARY	5.1	4.3-6.1	5.0	4.6-5.5	4.0	3.4-4.5
	EFFLUENT	4.5	3.8-5.6	4.6	3.9-5.5	4.7	3.9-5.7
V	PRIMARY	5.2	4.1-6.2	5.2	3.8-6.4	5.3	3.8-6.5
	EFFLUENT	5.0	3.6-5.8	5.1	3.8-6.0	5.1	3.8-5.9

Table D11.
Total phosphorus results for three trips to APTS I-V.

SITE AND LOCATION		TRIP 1 (mg/L) AVE	RANGE	TRIP 2 (mg/L) AVE	RANGE	TRIP 3 (mg/L) AVE	RANGE
I	PRIMARY	58.7	3.6-164	9.8	5.6-15.0	5.7	5.2-6.1
	EFFLUENT	6.8	6.1-7.6	8.0	7.8-8.1	4.4	3.6-4.9
II	PRIMARY	278	139-542	291	195-422	31.8	13.0-62.4
	EFFLUENT	8.7	7.2-10.5	10.8	9.7-11.5	6.5	5.6-7.0
III	PRIMARY	10.0	7.3-11.4	12.1	9.2-13.6	106	41.7-219
	EFFLUENT	11.9	5.6-23.5	9.9	5.6-13.0	4.8	3.9-6.3
IV	PRIMARY	7.0	5.6-8.4	7.9	4.4-10.2	6.9	-
	EFFLUENT	4.5	4.5	9.2	9.1-9.4	5.5	3.2-7.0
V	PRIMARY	5.8	5.6-5.9	6.2	4.6-7.5	4.0	3.0-4.9
	EFFLUENT	5.5	5.5-5.6	4.3	2.7-6.1	5.9	5.1-7.2

Table D12.
Total phosphorus results for APTS I-V for morning, afternoon, and night.

SITE AND LOCATION		8-10 AM (mg/L) AVE	RANGE	2-4 PM (mg/L) AVE	RANGE	9-11 PM (mg/L) AVE	RANGE
I	PRIMARY	58.3	5.2-164	6.1	3.6-8.9	9.8	6.1-15.0
	EFFLUENT	6.3	4.9-7.8	6.4	3.6-8.1	6.5	4.8-8.0
II	PRIMARY	143	19.9-255	132	62.4-195	326	13-542
	EFFLUENT	8.9	7.0-11.2	8.6	7.0-11.5	8.6	5.6-10.5
III	PRIMARY	79.9	9.2-219	26.3	7.3-58.1	22.2	11.4-41.7
	EFFLUENT	5.1	4.1-5.6	8.6	6.3-13.0	12.8	3.9-23.5
IV	PRIMARY	7.6	5.6-10.2	8.7	8.4-9.0	4.4	-
	EFFLUENT	6.7	4.5-9.1	7.0	4.5-9.4	5.6	4.5-9.2
V	PRIMARY	5.6	4.2-6.6	4.4	3.0-5.6	6.1	4.9-7.5
	EFFLUENT	6.3	5.5-7.2	4.5	2.7-5.5	4.9	4.1-5.6

Appendix E: Bacterial Data

Table E1.
FS[a] and FC[b] data for three trips to APTS I-V.

SITE & DATE	TIME OF DAY	PRIMARY SETTLING CHAM FS (colonies/100 mL)	PRIMARY SETTLING CHAM FC	PRIOR TO CHLORINATION FS (colonies/100 mL)	PRIOR TO CHLORINATION FC	EFFLUENT FS (colonies/100 mL)	EFFLUENT FC
APTS I (7/12/90)	8-10 AM	$>2\times10^{6}$	3.2×10^{6}	$>1\times10^{6}$	1.0×10^{5}[c]	1.0×10^{3}	0
	2-4 PM	$>2\times10^{6}$	3.5×10^{7}	2.9×10^{3}	0	2.7×10^{3}[c]	0
	9-11 PM	$>2\times10^{6}$	6.2×10^{6}	$>1\times10^{6}$	1.0×10^{5}[c]	2.0×10^{3}[c]	0
APTS II (9/02/90)	8-10 AM	1.0×10^{4}	1.3×10^{6}[c]	167[c]	1.3×10^{5}[c]	244	1.5×10^{4}[c]
	2-4 PM	1.8×10^{6}	2.6×10^{6}	433	9.0×10^{4}[c]	78[c]	1.0×10^{5}[c]
	9-11 PM	4.2×10^{5}	3.1×10^{6}	1.3×10^{3}	1.6×10^{5}[c]	1.1×10^{3}	3.4×10^{5}
APTS III (9/23/90)	8-10 AM	5.8×10^{4}	6.9×10^{4}	7.4×10^{4}	2.8×10^{5}	2.1×10^{4}	4.2×10^{5}
	2-4 PM	2.1×10^{4}[c]	5.4×10^{5}	7.9×10^{4}	4.6×10^{5}	6.9×10^{4}	2.0×10^{5}
	9-11 PM	1.1×10^{5}	3.0×10^{6}	5.2×10^{4}	3.6×10^{5}	6.7×10^{4}	4.4×10^{5}
APTS IV (10/21/90)	8-10 AM	778[c]	8.2×10^{5}	0	0	0	0
	2-4 PM	111[c]	1.6×10^{6}	0	1.8×10^{5}[c]	0	0
	9-11 PM	111[c]	3.0×10^{4}	0	0	0	0
APTS V (10/06/90)	8-10 AM	1.9×10^{3}[c]	2.0×10^{6}[c]	4.6×10^{3}	1.5×10^{5}[c]	2.4×10^{3}	2.0×10^{5}[c]
	2-4 PM	9.2×10^{3}[c]	3.5×10^{6}[c]	1.4×10^{3}[c]	3.5×10^{5}[c]	2.1×10^{3}[c]	1.8×10^{5}
	9-11 PM	3.3×10^{4}	4.0×10^{6}	1.3×10^{3}[c]	0	556[c]	0
APTS I (12/01/90)	8-10 AM	0	3.2×10^{6}	220[c]	9.5×10^{6}[c]	0	9.0×10^{4}
	2-4 PM	3.3×10^{2}[c]	4.6×10^{7}	0	1.1×10^{6}[c]	0	2.0×10^{5}
	9-11 PM	2.3×10^{3}	2.3×10^{6}	0	1.1×10^{6}[c]	5.6×10^{2}[c]	2.4×10^{5}
APTS II (2/04/91)	8-10 AM	7.8×10^{4}	d	0	0	333[c]	0
	2-4 PM	1.0×10^{4}	d	0	0	222[c]	5.0×10^{4}[c]
	9-11 PM	2.1×10^{4}[c]	0	778	5.0×10^{3}	889[c]	0
APTS III (1/05/91)	8-10 AM	4.0×10^{4}	3.6×10^{6}	1.3×10^{4}	1.8×10^{6}[c]	444[c]	1.0×10^{4}[c]
	2-4 PM	8.3×10^{4}	2.4×10^{6}	3.6×10^{4}	3.7×10^{6}	0	0
	9-11 PM	1.8×10^{4}[c]	9.1×10^{6}	9.4×10^{3}	2.0×10^{6}	0	0
APTS IV (1/18/91)	8-10 AM	1.2×10^{3}[c]	5.0×10^{5}	333[c]	0	0	0
	2-4 PM	5.0×10^{3}	5.5×10^{5}	2.2×10^{3}	1.1×10^{5}	0	0
	9-11 PM	0	5.6×10^{5}	3.3×10^{3}[c]	1.3×10^{5}[c]	0	0
APTS V (2/27/91)	8-10 AM	5.1×10^{3}	0	0	0	0	0
	2-4 PM	7.4×10^{3}	0	0	0	0	0
	9-11 PM	9.8×10^{3}	0	2.7×10^{3}	0	0	0

continued

Table E1, cont.

SITE & DATE	TIME OF DAY	PRIMARY SETTLING CHAM FS (colonies/100 mL)	PRIMARY SETTLING CHAM FC (colonies/100 mL)	PRIOR TO CHLORINATION FS (colonies/100 mL)	PRIOR TO CHLORINATION FC (colonies/100 mL)	EFFLUENT FS (colonies/100 mL)	EFFLUENT FC (colonies/100 mL)
APTS I	8-10 AM	8.0×10^{3}	9.0×10^{6}[c]	5.6×10^{2}[c]	1.0×10^{6}[c]	111[c]	0
(5/12/91)	2-4 PM	2.4×10^{3}	1.5×10^{6}[c]	111[c]	5.0×10^{4}[c]	0	0
	9-11 PM	1.0×10^{3}[c]	9.8×10^{6}	222[c]	3.0×10^{5}[c]	0	0
APTS II	8-10 AM	1.3×10^{4}	0	222[c]	0	667[c]	0
(5/30/91)	2-4 PM	7.0×10^{3}	3.0×10^{5}[c]	3.9×10^{3}	0	667[c]	0
	9-11 PM	1.2×10^{4}	0	1.3×10^{3}[c]	0	1.3×10^{3}[c]	0
APTS III	8-10 AM	2.8×10^{4}	0	1.1×10^{3}[c]	1.0×10^{5}[c]	3.3×10^{3}	0
(5/11/91)	2-4 PM	8.0×10^{3}	0	4.4×10^{3}[c]	0	1.1×10^{3}[c]	0
	9-11 PM	3.3×10^{3}	0	2.3×10^{3}	1.0×10^{6}[c]	1.9×10^{3}[c]	5.0×10^{5}[c]
APTS IV	8-10 AM	111[c]	0	4.1×10^{3}	0	0	0
(5/26/91)	2-4 PM	-	-	4.2×10^{3}	0	0	0
	9-11 PM	-	-	2.0×10^{3}[c]	1.0×10^{5}[c]	0	0
APTS V	8-10 AM	4.2×10^{3}	1.0×10^{6}[c]	111[c]	5.0×10^{4}[c]	0	9.0×10^{4}[c]
(6/05/91)	2-4 PM	0	1.5×10^{6}[c]	0	5.0×10^{5}[c]	0	9.0×10^{4}[c]
	9-11 PM	111[c]	5.0×10^{7}[c]	0	2.5×10^{4}[c]	111[c]	0

[a]fecal streptococcus
[b]fecal coliform
[c]value determined from colony density less than 20
[d]too contaminated for colony determination

Appendix F:
Chlorine Residual Data

Table F1.
TRC and FRC raw data for three trips to APTS I-V.

SITE & DATE	TIME OF DAY	AFTER CHLORINATION TRC (mg/L)	AFTER CHLORINATION FRC (mg/L)	EFFLUENT TRC (mg/L)	EFFLUENT FRC (mg/L)
APTS I (7/12/90)	8-10 AM	0.6	0.1	0.0	0.0
	2-4 PM	1.2	0.3	0.0	0.0
	9-11 PM	-	-	0.4	0.0
APTS II (9/02/90)	8-10 AM	0.0	0.0	0.0	0.0
	2-4 PM	0.0	0.0	0.0	0.0
	9-11 PM	0.0	0.0	0.0	0.0
APTS III (9/23/90)	8-10 AM	0.0	0.0	0.0	0.0
	2-4 PM	0.0	0.0	0.0	0.0
	9-11 PM	0.0	0.0	0.0	0.0
APTS IV (10/21/90)	8-10 AM	-	>9.0[a]	13.0	8.0
	2-4 PM	-	-	-	-
	9-11 PM	-	-	-	-
APTS V (10/06/90)	8-10 AM	0.0	0.0	0.0	0.0
	2-4 PM	0.0	0.0	0.0	0.0
	9-11 PM	0.0	0.0	0.0	0.0
APTS I (12/01/90)	8-10 AM	0.0	0.0	0.0	0.0
	2-4 PM	0.0	0.0	0.0	0.0
	9-11 PM	0.0	0.0	0.0	0.0
APTS II (2/04/91)	8-10 AM	0.0	0.0	0.0	0.0
	2-4 PM	0.0	0.0	0.0	0.0
	9-11 PM	0.0	0.0	0.0	0.0
APTS III (1/05/91)	8-10 AM	0.0	0.0	0.0	0.0
	2-4 PM	0.0	0.0	0.0	0.0
	9-11 PM	0.0	0.0	0.0	0.0
APTS IV (1/18/91)	8-10 AM	>10.0[b]	0.0	0.0	0.0
	2-4 PM	21.5	0.1	0.0	0.0
	9-11 PM	17.5	0.6	0.6	0.0
APTS V (2/27/91)	8-10 AM	2.0	0.4	1.0	0.1
	2-4 PM	2.0	0.5	0.0	0.0
	9-11 PM	1.7	0.6	0.0	0.0

continued

Table F1, cont.

SITE & DATE	TIME OF DAY	AFTER CHLORINATION TRC (mg/L)	FRC (mg/L)	EFFLUENT TRC (mg/L)	FRC (mg/L)
APTS I	8-10 AM	0.0	0.0	0.0	0.0
(5/12/91)	2-4 PM	0.0	0.0	0.0	0.0
	9-11 PM	0.0	0.0	0.0	0.0
APTS II	8-10 AM	0.0	0.0	0.0	0.0
(5/30/91)	2-4 PM	0.0	0.0	0.0	0.0
	9-11 PM	0.0	0.0	0.0	0.0
APTS III	8-10 AM	0.0	0.0	0.0	0.0
(5/11/91)	2-4 PM	0.0	0.0	0.0	0.0
	9-11 PM	0.0	0.0	0.0	0.0
APTS IV	8-10 AM	12.8	0.0	20.5	0.0
(5/26/91)	2-4 PM	13.7	0.0	4.7	0.0
	9-11 PM	13.2	0.0	7.2	0.0
APTS V	8-10 AM	0.0	0.0	0.0	0.0
(6/05/91)	2-4 PM	0.0	0.0	0.0	0.0
	9-11 PM	0.0	0.0	0.0	0.0

[a]titrator broke during reading
[b]ran out of titrant during reading

Appendix G:
Dye Study Data

Table G1.
Fluorescence data for first dye study at APTS I.

TIME (HRS)	PRIMARY	AERATION	EFFLUENT	TIME (HRS)	PRIMARY	AERATION	EFFLUENT
0.08			3	24.83	15	45	
0.17			3	29.33	19	36	40
0.25			2	37.08	25	33	35
0.33			1	49.33	26	28	30
0.42			1	55.00	20	26	27
0.58			2	59.92	19	25	30
0.75			2	62.33			28
0.92			3	62.42	21	25	
1.08			3	73.20	21	24	26
1.25			2	81.00	11	23	24
1.42			2	85.07	18	23	24
1.85			2	97.63	16		
2.33			4	97.66		22	
4.00		20		110.00	4	18	20
4.33			6	121.58	13	15	14
4.45			7	134.63	13	15	14
4.50			8	146.17	4	13	13
4.75			9	157.50	10	11	13
5.03			14	168.33		11	11
5.25			16	205.00	10	10	11
5.50			15	219.00	7	9	8
5.75			16	229.50	6	8	8
6.17			20	243.00	6	7	7
8.58			28	252.00	8	7	7
10.36			36	266.00	9	7	8
10.50	67	52		277.50	7	6	6
10.80			36	290.00	4	7	7
13.33			37	303.00	5	7	7
13.50	49			317.00			7
15.28			41	324.50	5	8	7
24.75			45				

Table G2.
Fluorescence data for second dye study at APTS I.

TIME (Hours)	PRIMARY SETTLING CHAMBER	AERATION CHAMBER	EFFLUENT
0.1	>100	12	8
0.6	>100	42	17
1.1	>100	52	20
1.6	>100	57	36
2.1	53	46	37
2.6	16	46	43
3.1	11	50	51
3.6	15	43	46
4.1	12	40	46
4.6	6	30	41
5.1	3	25	36
5.6	3	25	36
6.1	2	21	26
6.6	2	19	23
7.1	1	14	18
7.6	1	14	16