United States
Environmental Protection
Agency

Office Of Water
(4204)

EPA 832-B-96-002
September 1996

EPA

Interim Report–Evaluation Of The Advanced Ecologically Engineered System (AEES) "Living Machine" Wastewater Treatment Technology– Frederick, MD.

EVALUATION OF ALTERNATIVE WASTEWATER TREATMENT TECHNOLOGIES

AN INTERIM PROCESS EVALUATION OF THE AEES "LIVING MACHINE"

FREDERICK COUNTY, MD

PREPARED FOR:

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF WASTEWATER MANAGEMENT
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Report No. 832-B-96-002

Contract No. 68-C2-0102
Work Assignment No. 3-18

September 1996

EPA's Environmental Technology Verification Program

Throughout its history, the U.S. Environmental Protection Agency (EPA) has evaluated technologies to determine their effectiveness in preventing, controlling, and cleaning up pollution. As a part of the Environmental Technology Initiative, EPA is now expanding these efforts by instituting a new program, the Environmental Technology Verification Program -- or ETV -- to verify the performance of a larger universe of innovative technical solutions to problems that threaten human health or the environment. ETV was created to substantially accelerate the entrance of new environmental technologies into the domestic and international marketplace. It supplies technology buyers and developers, consulting engineers, states, and the U.S. EPA Regions with high quality data on the performance of new technologies to encourage more rapid protection of the environment with better and less expensive approaches. EPA will utilize the expertise of both public and private partner "verification organizations," including federal laboratories, states, universities, and private sector facilities, to design efficient processes for conducting performance tests of innovative technologies. Verification organizations will oversee and report verification activities based on testing and quality assurance protocols developed with input from all major stakeholder/customer groups associated with the technology area.

This interim process evaluation report on the Applied Ecological Engineered Systems (AEES) "Living Machine," prepared in cooperation with EPA's contractor -- Parsons Engineering Science, Inc. -- serves as an example of the type of independent testing envisioned under the EPA's new ETV Program. Currently ETV pilot projects are underway involving the testing of small package drinking water systems (EPA has partnered with NSF Int'l.), pollution prevention and waste treatment systems (EPA has partnered with the State of California), site characterization technologies (EPA has partnered with Sandia and Oak Ridge National Labs.), and indoor air products (EPA has partnered with the Research Triangle Institute). For further information regarding the ETV Program, contact the Penelope Hansen, Program Coordinator, at 202/260-2600.

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The information in this document has been funded wholly, or in part, by the United States Environmental Protection Agency under Contract 68-C2-0102, Work Assignment No. 3-18. Mention of trade names or commercial products does not constitute an endorsement or a recommendation for use.

Acknowledgments

Mr. Sherwood Reed, P.E. of Environmental Engineering Consultants, Norwich, VT and Mr. James Salisbury of Parsons Engineering Science, Inc., Fairfax, VA were the principal authors of this report. This work was performed under the direction of Mr. Robert E. Lee, Chief of the Municipal Technology Branch, and Mr. Robert Bastian, Work Assignment Manager, USEPA Office of Wastewater Enforcement and Compliance. Ms. Lauren Fillmore and Ms. Lisa Allard of Parsons Engineering Science, Inc., Fairfax, VA provided project management and direction during the study and the preparation of this report. Additional project support was provided by Mr. Brian Stone, P.E., Mr. Keith Kornegay, Mr. Robert Cain, and Mr. Glenn Pearson of Parsons Engineering Science, Inc., Fairfax, VA.

The authors wish to thank Dr. John Todd and Ms. Beth Josephson of Ocean Arks International, Falmouth, MA, and Mr. Michael Shaw and Ms. Lynne Stuart of Living Technologies, Inc., Burlington, VT for their cooperation and assistance during this study. The authors especially wish to thank Mr. Stanley Serfling, Ms. April Smith, Ms. Janette Emming and Ms. Kerrie Kyde, the Ocean Arks staff at the Frederick, MD facility, for their assistance and patience during the data collection phase of this project.

Foreword

Providing effective and reliable wastewater treatment in a cost-effective manner is a problem facing urbanizing areas across the country. The Clean Water Act (PL92-500 and its more recent amendments) led to the construction of many new wastewater treatment facilities to help control water pollution from both industrial and municipal sources. In the future, add-on processes will be needed to upgrade many of these treatment facilities. In addition, more facilities will be needed to help deal with small volume municipal point sources as well as non-point sources of water pollution if the water quality objectives of the Clean Water Act are ever to be fully realized.

Many treatment technologies are currently available for use in meeting essentially any level of wastewater treatment found to be necessary to meet regulatory requirements -- including technologies that can effectively and reliably treat wastewater to meet drinking water quality. However, many of these currently available technologies are expensive to build and operate, require extensive energy resources, and produce large volumes of sludges that are also expensive to properly manage.

In an effort to offer a new approach to meeting a variety of advanced treatment requirements, "ecological engineering" concepts are being used to design wastewater treatment systems that incorporate naturally-occurring, complex ecological systems within a highly controlled environment. After working with a number of small pilot-scale facilities employing his early proprietary designs, generally referred to as "Solar Aquatics" (which evolved from work with self-contained aquaculture production systems), Dr. John Todd, President of the non-profit Ocean Arks Ltd., has developed a series of second generation design (non-proprietary) demonstration-scale projects he refers to as "Advanced Ecologically Engineered Systems" (AEES) or "Living Machines." To date a total of $5.75 million in federal funding to support these demonstration-scale "Living Machine" projects has been provided by Congress in the form of special add-on appropriations to EPA's budget (in FYs '92-'95). Most of these funds were awarded through a cooperative agreement to the Massachusetts Foundation for Excellence in Marine and Polymer Sciences, a financial supporter of Dr. Todd's earlier efforts to develop the original "Solar Aquatics" technology, to assist in the design, construction, operation and documentation of results associated with the demonstration-scale "Living Machine" projects.

Dr. Todd promotes his "Advanced Ecologically Engineered Systems" (AEES) or "Living Machines" as a new, low cost, solar powered, no chemical use alternative wastewater treatment technology capable of being constructed in modules as additional capacity is needed. These systems incorporate many of the same basic processes (e.g., sedimentation, filtration, clarification, adsorption, nitrification, denitrification, volatilization, anaerobic and aerobic decomposition) utilized in more conventional advanced biological treatment systems. Dr. Todd is trying to simulate these processes as they occur in natural biological ecosystems (such as lakes, rivers and wetlands). He is attempting to encourage them to operate at optimal rates under controlled conditions. Still, his ecologically engineered systems incorporate variations of well established treatment technologies such as anaerobic bioreactors, complete mix aerated tanks, aerobic fluidized bed reactors, clarifiers, high rate constructed wetlands, and plant-covered ponds. However, Dr. Todd approaches the design and operation of his facilities from an ecological systems point-of-view and attempts to incorporate objectives well beyond just achieving the desired

wastewater treatment goals into his projects. For example, Todd emphasizes the importance of snails, freshwater clams and other invertebrates in his "ecological fluid beds," as well as utilizing a variety of aquatic and wetland plants throughout his systems. He also stresses the value of his systems as a potential opportunity to produce fish as well as aquatic and wetland horticultural plants to be marketed locally, and for educating the public about the importance of natural biological systems in purifying and recycling wastewater.

Robert Bastian, 24 December 1995

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LIST OF ABBREVIATIONS

AEES	Advanced Ecologically Engineered System
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
EEC	Environmental Engineering Consultants
EQ	Exceptional Quality
gpd	gallons per day
HDTs	Hydraulic Detention Times
kg	kilograms
LD	Laboratory Director
mgd	million gallons per day
MFEMPS	Massachusetts Foundation for Excellence in Marine and Polymer Sciences
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MLSS	Mixed Liquor Suspended Solids
NH_4	Ammonia
NIST	National Institute of Standards in Technology
NO_3	Nitrate
NPDES	National Pollutant Discharge Elimination System
OAI	Ocean Arks International
O&M	Operation and Maintenance
Parsons ES	Parsons Engineering Science, Inc.
PRR	Percent Recovery Range
QAC	Quality Assurance Coordinator
QAM	Quality Assurance Manager
QAPjP	Quality Assurance Project Plan
QA/QC	Quality Assurance/Quality Control
RPD	Relative Percent Difference
SF	Subsurface Flow
SM	Standard Methods
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
USEPA	United States Environmental Protection Agency
VSS	Volatile Suspended Solids
WWTP	Wastewater Treatment Plant

Section 1

Introduction

1.1 Background

The Advanced Ecologically Engineered System (AEES) in Frederick County, MD is one of several related projects in the United States intended to provide water quality improvements for a variety of water sources. The AEES technology is also called a "Living Machine" because of the ecologically-based components in the treatment process. The system was conceived by Dr John Todd, the President of Ocean Arks International (OAI), a non-profit institution based in Falmouth, MA.

The other AEES demonstration facilities are located in South Burlington, VT, San Francisco, CA, and near Harwich, MA. The Frederick facility is intended to provide advanced levels of treatment for untreated raw sewage. The Burlington project uses essentially the same technology, and has the same purpose as Frederick, but is designed to operate at a higher flow rate and in a colder climate. The project in Harwich, MA uses a floating raft incorporating a portion of the AEES technology to provide in-situ water quality improvements in lakes and ponds. The project in San Francisco also uses part of the AEES technology to provide final high flow rate polishing for treated secondary effluent; the intent is to produce a water quality which would allow unrestricted irrigation reuse of the treated water in California. This report describes the evaluation of performance of the AEES facility in Frederick County, MD during the period between the end of February 1995 and late June 1995. The original proposal to the US Environmental Protection Agency (USEPA) stated that the purpose of the demonstration facilities was to: "(1) test the efficacy of using Advanced Ecologically Engineered Systems under the particular climate conditions prevailing in the specific areas; (2) test the ability of the systems, and individual components within the system, to improve water quality in accordance with established parameters; and (3) determine the costs of operating the system under given conditions and during specified time periods". The proposal further stated that the purpose of the demonstration facilities was to enable operators, water resources officials and community users to understand the dynamics of natural systems, and to become involved in revitalizing the water supply in a sustainable way.

These AEES demonstration projects were funded in part with special appropriations from the US Congress, by a grant to the Massachusetts Foundation for Excellence in Marine and Polymer Sciences (MFEMPS) which has subcontracted out much of the effort to OAI. The demonstration facilities are staffed by OAI personnel and performance data are routinely collected. However, it was agreed that an independent evaluation by USEPA would be desirable, and funds from the special appropriations were set-aside for that purpose. All of the AEES facilities were included in the study but the focus for independent data collection was the system in Frederick County, MD, since it was expected to be operating at "steady state" conditions when the study period commenced.

The facility in Frederick County, MD was constructed in 1993 and has been in operation since that time. Following a "ramp-up" period from January to July 1994, the facility continued to move toward "steady state" operations during the latter part of that year. It incorporates the experience gained at previous OAI pilot systems in Massachusetts,

Vermont and Rhode Island, and represents a "second generation" design. This "Living Machine" technology is intended to clean wastewater to advanced treatment standards using "natural, solar-powered, greenhouse-based technology without the use of chemicals". A related but technically distinct concept called "Solar Aquatics" was developed by OAI and also utilizes a greenhouse and contained treatment elements also claimed to be based on solar energy. Although the "Solar Aquatics" technology is sometimes confused with the "Living Machine", the former is now marketed by another firm which holds the exclusive rights to this technology. The "Living Machine" system in Frederick County, MD, is located adjacent to the Ballenger Creek wastewater treatment plant (WWTP) and draws wastewater from Ballenger Creek after screening and degritting for treatment by the AEES process.

Parsons Engineering Science, Inc. (Parsons ES) was selected by USEPA, under Contract Number 68-C2-0102, to perform this independent evaluation. Under the same contract, Mr. Sherwood Reed of Environmental Engineering Consultants (EEC), Norwich, VT, was retained as the technical director of this effort.

1.2 Objectives of the Study

The basic objective of this effort is to provide an independent evaluation of the AEES "Living Machine" technologies which have been built and are operated with federal funding in Maryland, California, Vermont, and Massachusetts. "Natural" treatment processes based on solar energy inputs and with a minimal of mechanical equipment and conventional energy sources may offer considerable advantages for highly effective treatment at relatively low costs. Positive results from this independent evaluation sponsored and published by the USEPA may then serve to help provide a better understanding of these technologies and their potential use in the United States.

The major objectives of this study were to:

- Evaluate the performance of the individual treatment components and the overall AEES process through monitoring of flow, characterization of wastewater and residuals, and determination of hydraulic detention times via tracer studies. All of this work was to be performed at the AEES facility in Frederick County, MD. by Parsons ES.
- Compare the capital costs and operation and maintenance (O&M) costs of the AEES process with equivalent conventional wastewater treatment technologies. This comparison would be performed for flow rates of 40,000,80,000 and 1,000,000 gallons per day (gpd). AEES costs would be provided by the designers of the "Living Machine" whereas conventional WWTP costs would be prepared by Parsons ES.
- Carry out a statistical comparison of the water quality data generated by this study to that produced by OAI, both from their on-site laboratory and their certified testing laboratory (at Ballenger Creek WWTP). The purpose of this exercise was to validate the OAI procedures and results, thereby reducing the requirement for independent testing in future evaluations of this type.
- Evaluate the performance of the "Living Machine" with and without plants in the treatment units in order to quantify and document the contribution of the floating macrophyte plant species to the AEES wastewater treatment process.

The original intent was to collect independent water quality data over an 8 week period while the Frederick AEES was operated at steady state conditions. This part of the study was then extended, resulting in an assessment of 11 weeks' duration. The study to

evaluate the role of the plants in treatment was then added, which meant that the total duration of the sampling effort was 14 weeks. The sampling started the week of February 28, 1995 but was not continuous thereafter and the study period actually ended on June 23, 1995.

The Frederick facility contains three sets of parallel units (trains) inside the protective greenhouse. Flow to two of these trains (A & B) was maintained as closely as possible to steady state during the study period. The sampling effort inside the greenhouse focused on just one of the trains (Train B), considering it to be representative of the overall system performance.

1.3 Organization of the Report

This report contains 14 sections, a list of references, and appendices. The appendices contain all of the data collected at the Frederick AEES facility during the study period, the quality assurance project plan and the detailed cost estimates prepared for the AEES process and for the conventional alternatives. Section 2 describes the physical components at the Frederick facility while Sections 3 to 7 describe the data collection and monitoring procedures, and the quality assurance/quality control procedures used.

Section 8 details the flow data collected during the study. Sections 9, 10, 11, and 12 discuss water quality performance, hydraulic detention times in system components, comparison of independent data to OAI data, and the evaluation of the treatment contribution from the plants.

Section 13 provide the cost data for the AEES process and the conventional alternatives, and evaluates the capabilities of the AEES process based on the data collected during the period of the USEPA study. Section 14 presents the conclusions and recommendations drawn from this study.

Section 2

Description of the AEES Facility in Frederick, MD

2.1 Introduction

The AEES facility in Frederick Co., MD is designed to treat 40,000 gpd of screened and degritted sewage. A schematic of the process, prepared by the system designer, is shown on Figure 2-1 (the detention times given on Figure 2-1 are preliminary estimates). All of the components, except the anaerobic bio-reactor are housed in a greenhouse with plastic glazing (Nexus design steel frame, Serac glazing). The anaerobic bio-reactor is outside the greenhouse and is partially buried with an exposed cover. The original water quality goals for this system, when operated at 40,000 gpd, are summarized in Table 2.1.

Table 2.1 Water Quality Goals for the AEES Facility

Water Quality Parameter	Goal for AEES Facility
5-day Biochemical Oxygen Demand (BOD_5)	< 10 mg/l
Total Suspended Solids (TSS)	< 10 mg/l
Ammonia (NH_3/NH_4)	< 1 mg/l
Nitrate (NO_3)	< 5 mg/l
Total Nitrogen (TN)	< 10 mg/l
Total Phosphorus (TP)	< 3 mg/l

The system is located adjacent to the Ballenger Creek Sewage Treatment Facility; the influent for the AEES is taken after the screening and degritting units at the Ballenger plant. Since the AEES system is a demonstration project all effluent and wasted sludges are returned to the Ballenger facility. The greenhouse structure encloses three sets of the components shown on Figure 2-1. Two of these process "trains" are used to demonstrate the capability to treat the design flow rate under steady state conditions. The third train is used for testing and experimentation but typically receives one third of the 40,000 gpd design flow. The nomenclature used to identify the treatment units in this process, as shown on Figure 2-1, was developed by the system designers.

The conceptual design and structural details of the anaerobic bio-reactor were developed by Sunwater Systems, Inc. located in Solano Beach, CA. The "Living Machine" concept, and the conceptual design of the AEES facilities were developed by Ocean Arks International, a non-profit institute located in Falmouth, MA. The engineering and structural details for the greenhouse and enclosed components were provided by Living Technologies, Inc., located in Burlington, VT. The computer controls for the greenhouse units were provided by Q Com Environmental Control in Irvine, CA.

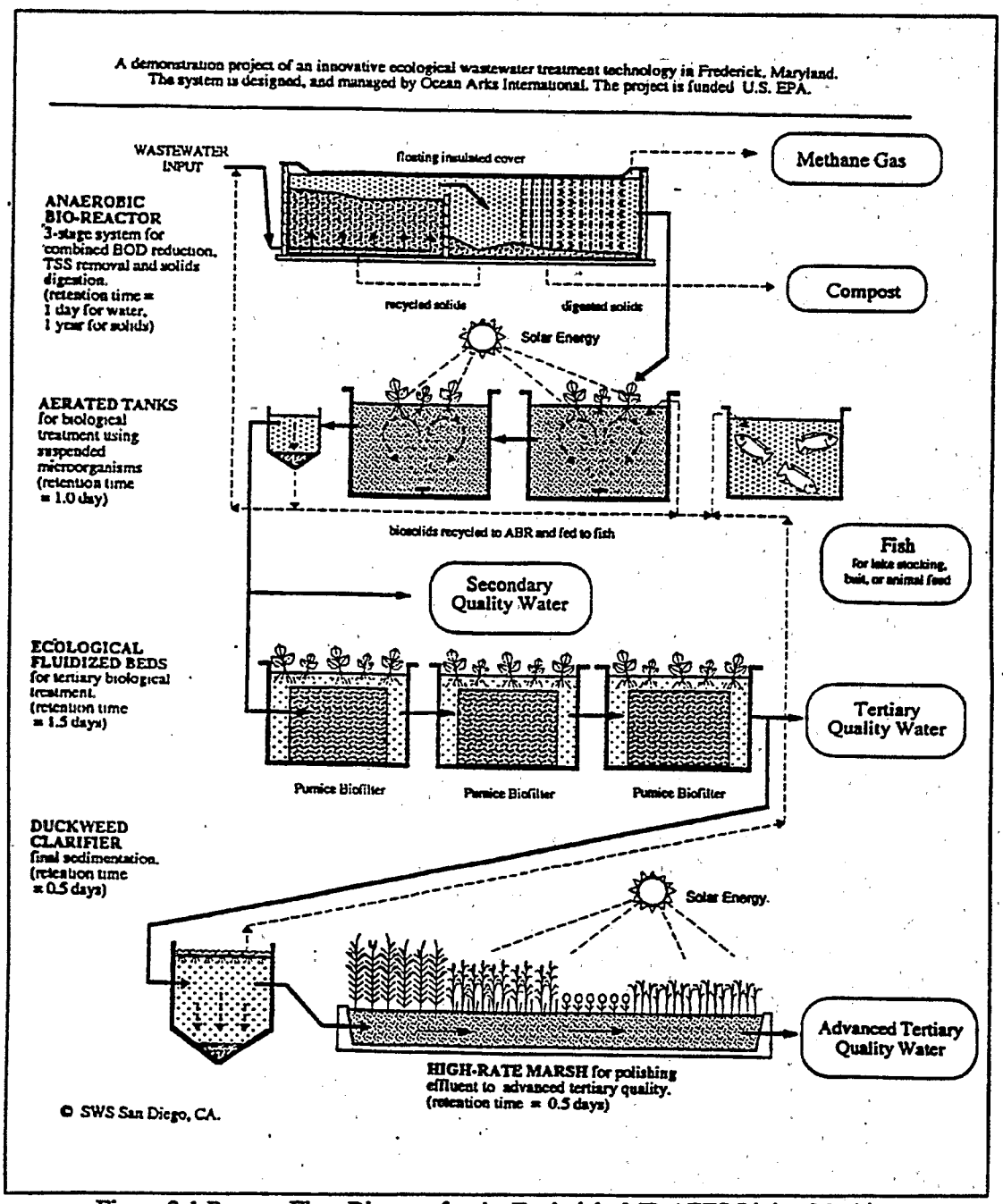


Figure 2.1 Process Flow Diagram for the Frederick, MD AEES Living Machine

2.2 Anaerobic Bio-Reactor

The first treatment unit at the Frederick facility is the partially buried anaerobic reactor. It has a concrete floor and concrete block side walls and is lined with 30 mm high density polyethylene. The floating plastic membrane liner contains a layer of insulation for thermal protection. The reactor is 15 ft wide and 28 ft long and maintains a 9 ft water depth. As shown on Figure 2.1, an internal dam about 6 ft tall contains a permanent sludge blanket. The untreated wastewater enters this zone via diffuser pipes on the bottom of the tank and then flows upward through the sludge blanket and then into the second compartment. A unique aspect of the second compartment are strips of polypropylene mesh netting suspended from the reactor cover and spanning the full width of the tank. This mesh assists in trapping and settling solids and provides significant surface area for colonization by attached growth microorganisms. The settled sludge in this compartment undergoes some anaerobic digestion. Sludge is removed from this compartment on a weekly schedule via perforated pipes on the bottom of the reactor. At a flow rate of 37,000 gpd, the theoretical fluid detention time is 18½ hours in this reactor. Untreated wastewater is pumped, at a constant rate, from the Ballenger WWTP screening and grit removal unit to the bio-reactor. A depth of about two feet of settled sludge from the Ballenger facility was added to the first compartment at start-up to serve as the initial sludge blanket.

In order to control odors in the greenhouse and on the site, the effluent from this reactor is piped to small covered aerated tanks with a detention time of about 20 minutes at design flow. The effluent leaving this unit is aerobic and odor free and ready for treatment in the greenhouse. The exhaust gasses from this aeration unit are routed to an underground earth filter for odor control.

The basic purpose of this anaerobic reactor is to significantly reduce the concentrations of BOD_5 and solids (TSS) in the wastewater prior to treatment in the greenhouse. Supplemental heat is not added to this reactor so a relatively warm climate is required for successful sludge digestion. The designers have replaced this anaerobic reactor with an aerated aerobic unit in the "Living Machine" now under construction in South Burlington, VT.

2.3 Aerated Tanks

As shown on Figure 2.1, the aerated effluent from the anaerobic bio-reactor flows to the first of two aerated tanks in series. Each tank is 10 ft in diameter and 9 ft deep, the top 4 ft of the tank is above the concrete greenhouse floor the remainder is below ground. The cylindrical tank walls are corrugated steel, of the type commonly used for culvert pipe. The interior of the tank is lined with a 20 mm plastic membrane container to insure complete fluid retention. Both aeration tanks are operated in the complete-mix aeration mode to keep all solids in suspension and to insure rapid circulation and contact with the submerged roots of the plants floating on the water surface of these tanks. Wifley Weber circular diffusers are used as the aeration source in these tanks, and other process units. Air is supplied for the entire system with three Roots blowers (1-1hp, 1-1.5 hp, 1-2 hp) which operate continuously.

The plants used on these tanks are floating macrophytes; the first tank usually is covered with water hyacinth (*Eichhornia crassipes*), the second with pennywort (*Hydrocotyle umbellata*). About 1 hour per week of operator time is required for the care of these plants. Any plant material removed from these tanks is composted. The theoretical detention time in each tank is 8.5 hr at design flow (13,300 gpd/train). Table 10.1 in Section 10 compares theoretical to actual detention times in all of the process units.

A variety of biological, bacterial, and mineral additives are applied to the wastewater prior to the aeration tanks to enhance treatment responses and maintain health of the plants. Bacterial additions include *Bactapure N* for nitrification, and *XL* to assist in breakdown of grease and sludges; mineral additions consist of *Mariah powder* intended to improve mineral content and health of plants; the biological additive is *Kelp meal* to supplement the potassium content in the wastewater. Typical dosages of these materials can be found in Table 9.6 in Section 9 of this report.

It is the basic purpose of these aeration tanks to reduce the dissolved wastewater BOD_5 to low levels and to commence the nitrification of ammonia. The roots of the floating plants are intended to serve as a substrate for the support of attached growth nitrifying organisms.

In the original design and layout of units in the Frederick greenhouse the flow from the second aeration tank passed directly to the next treatment component which is the "ecological fluidized beds". Sludge accumulation in these beds required very frequent cleaning so a small clarifier was added to the process train after the second aeration tank, this is shown on Figure 2.1. Most of the sludge removed from this clarifier is wasted to the anaerobic bio-reactor; a small percentage is recycled to the first aeration tank. The mixed liquor suspended solids in these tanks was typically less than 150 mg/L, in a complete mix activated sludge process the mixed liquor solids might range from 1500 to 4000 mg/L depending on the purpose of the reactor.

2.4 Ecological Fluidized Beds

As shown on Figure 2.1, there are three of these units in the process train. The outer container of these tanks is the same size and constructed of the same materials used for the aeration tanks. These units also include an inner tank which contains the pumice gravel which is the media used in these beds. Flow enters in the annular space between the inner and outer tanks and is lifted by air lift pipes to the top of the inner ring containing the pumice media. The bottom of the inner tank is not sealed so the down flowing liquid returns to the outer annular space and is again circulated onto the top of the pumice gravel. The air lifts not only move the liquid but the air bubbles provide the oxygen source to maintain aerobic conditions in the circulating liquid.

The depth of pumice in the inner tank is about 8 ft. The pumice gravel has a median size of about 0.5 inch. This size media was selected to provide a high surface to volume ratio for the attachment of the microbial organisms for effective nitrification in the bed. Pumice was selected as the material because of it's low density which renders it nearly buoyant. This feature is critically important to successful operation of the unit. As sludge is separated from the fluid stream in the bed the hydraulic capacity in the forward flow direction is impeded, if accumulation were allowed to continue the bed would eventually become completely clogged. To correct this potential problem the unit is designed with additional aeration diffusers beneath the pumice bed. When these aerators are on the whole inner tank acts as an upflow airlift so the flow direction is reversed; the aeration also "fluidizes" the pumice bed and suspends the buoyant pumice gravel in the liquid. This also releases the trapped sludge which is washed over into, and settles at the bottom of, the outer annular space. Most of this sludge is removed manually from this space and is also returned to the anaerobic reactor.

The choice of "ecological fluidized bed" as the name for this unit is somewhat misleading. It is normal practice to define the function of a treatment unit while operating in the forward flow direction. In this case, when the bed is in the treatment mode the

pumice is not fluidized and the bed acts as a downflow, coarse media, filter unit. It is only during the backwash cleaning operations that the pumice is fluidized.

The three Ecological Fluidized Beds were originally designed and operated as three aerobic units in series. Operational experience soon indicated that nitrification was essentially complete after the second unit. The third tank was therefore converted to an anoxic unit to provide additional capacity for denitrification. This was accomplished without major physical changes in the unit. The airlift delivery pipes were turned off and a 1.5 hp recirculating pump located at the top of the central tank. This induces an upflow direction in the pumice bed and the pump delivered the fluid to the bottom of the annular space. The lack of aeration and the resulting low oxygen levels created anoxic conditions in the pumice creating an environment suitable for denitrification. This modified unit is still backwashed in the same manner described previously.

Denitrification requires a carbon source for the reaction to function and the available carbon (BOD_5) in the wastewater is very low at this point and insufficient. As a result it is necessary to add a carbon source to the water prior to the denitrification process. A variety of carbon sources were tried including sugar and acetate but methanol has become the standard. Table 9.6 in Section 9 summarizes the carbon source additions during the EPA study period.

The theoretical detention time in each of these units is about 7 hours at design flow. Table 10.1 in Section 1 compares theoretical detention times to actual times as measured during the EPA study period. It is the basic purpose of the first two units to essentially complete removal of BOD_5 and nitrification of the ammonia contained in the wastewater. The third unit is now used for denitrification of that ammonia.

The water surface of the annular space in these tanks is used to support the hydroponic growth of tree seedlings and other plants suspended in pots around the perimeter of the tank. The plants do remove some nutrients and micronutrients from the water but their contribution to the treatment function of the system is believed to be minimal. However, these plants can provide a beneficial return since they can be sold. It is estimated that an annual revenue of about $1,200 could be achieved from sale of these plants during the spring/summer gardening season in Maryland.

2.5 Duckweed Clarifier

The three Ecological Fluidized Beds are followed by a hopper bottomed clarifier for final separation of most of the remaining sludge prior to the final marsh component in the system. The tank for this clarifier and the materials used are the same as previously described for the aeration tanks. The settled sludge is periodically removed from this tank and discharged to the Ballenger Creek WWTP. The water surface on this tank is covered with duckweed (*Lemna sp.*) and other small floating plants. It is not believed that these plants contribute significantly to treatment due to the very small root structure. The theoretical detention time in this final clarifier is calculated as 8.5 hours at design flow.

2.6 High-rate Marsh

The High-rate Marsh is the final component in the process train. It is similar in concept to the subsurface flow (SF) constructed wetland concept used for treatment of municipal and domestic wastewaters. This High-rate Marsh consists of a lined excavation in the floor of the greenhouse filled with clean selected gravel, and planted at the top with a variety of plant species. The rectangular bed is about 13 ft wide and 30 ft long and contains a 3½ ft depth of gravel. The top foot of gravel is small 3/8" stone, the remaining

depth is composed of 1½" stone. The theoretical detention time, at design flow in this unit is about 9 hours.

This high rate marsh is operated and maintained differently than the conventional subsurface flow wetland. In the latter case, the depth of the SF wetland bed typically does not exceed 2 ft to allow the roots of the vegetation to interact with all of the wastewater flowing through the bed. Deeply rooted emergent vegetation such as bulrush (*Scirpus)* or common reeds (*Phragmites)* are typically used. This is necessary in the SF system since the plant roots supply the oxygen which is necessary for nitrification of the wastewater ammonia. The plant litter is allowed to accumulate on top of the bed and the decomposition of this material provides some of the carbon source needed for denitrification. The SF wetland bed is sized to accomplish the limiting treatment response, typically either nitrification or denitrification. One of these SF wetland units, depending on only the plant litter as a carbon source for denitrification would have to be much larger than the "Living Machine" High-rate Marsh.

The "Living Machine" high rate marsh does not have to provide significant nitrification since the ecological fluidized beds are intended for that purpose. Since methanol is used as a carbon source the plant litter is not allowed to accumulate on top of the bed. Since deeply rooted plants are not really needed a variety of plants can be grown for aesthetic and commercial horticultural purposes. These plant roots are in contact with the flowing wastewater and certainly provide some uptake of nutrients and micro nutrients, but they are not one of the major components responsible for treatment as in the SF concept. In essence this final high rate marsh acts as a polishing filter with the upper surface maintained as a commercial horticultural operation. Seedlings are planted and raised to marketable size and then replaced with new plant material. It is estimated that a revenue of about $3,600 per year could be achieved from sale of these plants during the summer gardening season in Maryland.

Based on the performance data documented in Section 9 this high rate marsh unit, as operated in Frederick County, provides a relatively small improvement in wastewater and therefore, may not be an essential treatment component in the "Living Machine" process. A marsh with a larger area might contribute more significantly to treatment but would result in a very high cost for the enclosing greenhouse structure. In most climates it should be possible to locate a larger marsh outside the greenhouse but then it could not serve for commercial horticultural purposes. The 80,000 gpd "Living Machine" now under construction in South Burlington, VT does not include a marsh component.

Section 3

Flow Monitoring

3.1 Introduction

Influent and effluent flow monitoring was carried out over the duration of the study. This monitoring was necessary to provide data concerning the quantities of wastewater treated during the study period, and to assist with the calculation of system hydraulic detention times (Section 5). The following section describes where and how this flow monitoring was performed.

3.2 Influent Flow Monitoring

Influent flow monitoring was achieved using a flow meter installed by the field study team. This meter was a doppler flow meter, manufactured by Controllotron, and was installed on the influent pipe to the first Train B Aerated Tank. The flow meter measured flow rates and totalized flows, and downloaded its data to a local computer. This meter monitored the average daily influent flows into Train B which was the treatment train investigated in this study.

3.3 Effluent Flow Monitoring

Effluent flow monitoring was performed using the existing OAI flow meter at the discharge pipe of the Train B High-rate Marsh. This flow meter was a tee-mount, impellor flow sensor manufactured by Great Lakes Flow Meters. The flow meter measured mean flow rates and downloaded its data to a local computer. Using this meter, it would be possible to calculate the average daily effluent flows from Train B of the AEES Facility.

Section 4

Wastewater and Residuals Sampling

4.1 Introduction

This section describes the water quality and residuals sampling protocol that was followed during the evaluation of the AEES Facility. Composite and grab wastewater samples were collected for the system performance assessment. Samples of the process residuals (sludge and plants) were also collected during the study. Information on the sampling locations and methods is provided below.

4.2 Sampling Locations

4.2.1 Wastewater Sampling Locations

During the study, wastewater samples were taken from six locations throughout the AEES Facility. The study examined Train B of the treatment system. These sampling points are listed in Table 4.1 and displayed graphically in Figure 4-1.

Table 4.1 Wastewater Sampling Locations

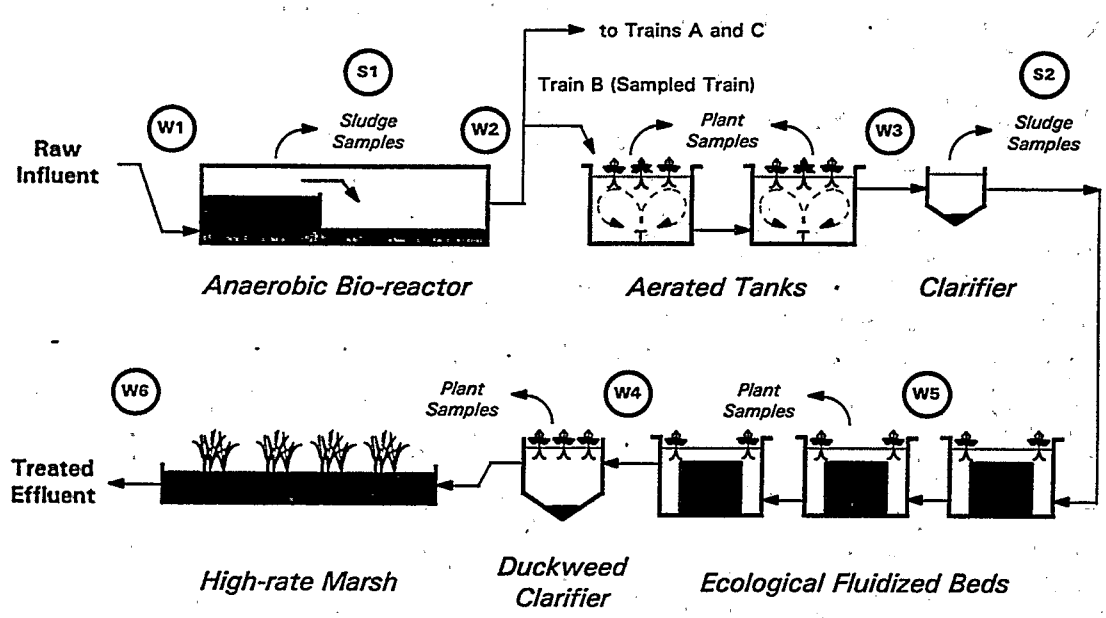
Sample Point	Description of Location
W1	Raw influent into the Anaerobic Bio-reactor, after primary screening
W2	Anaerobic Bio-reactor effluent
W3	Effluent from the 2nd Aerated Tank
W4	Effluent from the 3rd Ecological Fluidized Bed
W5[1]	Effluent from the 1st Ecological Fluidized Bed
W6	Effluent from the High-rate Marsh

(1) The position of sampling location W5 was changed after the first week of the study. Originally, sample point W5 was located at the outlet of the Duckweed Clarifier. However, as noted in the Quality Assurance Project Plan (see Appendix A), little difference existed in water quality between effluent from the 3rd Ecological Fluidized Bed and effluent from the Duckweed Clarifier. In the second week of the study, this sampling location was moved to sample effluent from the 1st Ecological Fluidized Bed, where it remained until the end of the study.

4.2.2 Residuals Sampling Locations

Samples of both sludge and plants were collected during the study. Sludge samples were removed from the Anaerobic Bio-reactor (Sample Location S1) and the clarifier following the 2nd Aerated Tank (Sample Location S2). Plant samples were taken as follows: water hyacinth from the 1st Aerated Tank, pennywort from the 2nd Aerated Tank, and both duckweed and azolla from the 2nd Ecological Fluidized Bed. Figure 4-1 also summarizes these sampling locations.

Figure 4-1 Wastewater and Residuals Sampling Locations



4.3 Sampling Methods

4.3.1 Composite Wastewater Samples

Time-proportioned, composite 24-hour wastewater samples were collected throughout the study using ISCO automatic samplers located at the sampling locations described in Section 4.2. The six samplers used for the study were inspected, cleaned, and calibrated at the beginning of the study and, subsequently, on a routine basis throughout the remainder of the study period. One sample was collected from each location every week for the eleven week duration of the study.

Before each sampling event, the sampler tubing and collection container were rinsed with the wastewater being tested, and the samplers were filled with ice for sample

preservation. The automated samplers were then programmed to take the required number of samples and locked to maintain sample security.

Each automated sampler was programmed to composite 48 ½-hourly samples during the 24-hour sampling period. In addition, the sampler was programmed to flush its sample tubing with fresh wastewater before and after taking each ½-hourly sample. The automated samplers also recorded any abnormalities detected during the sampling period (e.g., inability to take a full sample) which enabled the field team to detect sampling errors that might have occurred.

When the 24-hour composite samples were removed from the automated samplers, the sample temperatures were taken and the collection containers were agitated to distribute any settled solids throughout the sample. The sample was then transferred into sample bottles and preserved in ice before shipment to the laboratory for chemical analysis. Information on the analytical procedures is presented in Section 6.

4.3.2 Grab Wastewater Samples

Grab wastewater samples were also collected for dissolved oxygen, pH, temperature and fecal coliform analysis. These samples were obtained using the same automated samplers used for the composite sampling.

Before collection of a grab sample, the sample collection container was rinsed with fresh wastewater and any remaining ice was emptied from the sampler. The wastewater sample was then taken and transferred to a clean container in preparation for field analysis. Samples that had to be analyzed for fecal coliform were segregated at this stage, and preserved in ice before shipment to the laboratory. Field analyses to determine dissolved oxygen (DO), pH, and temperature were then performed on the grab samples. Information on analytical procedures is presented in Section 6.

4.3.3 Sludge Samples

Sludge samples were collected from the system using a sampling pole and transferred into a clean container prior to field analysis. At this point, samples to be analyzed for Part 503 metals, TKN, total phosphorus, % solids and fecal coliform were segregated and preserved in ice before shipment to the laboratory. Field analyses for DO, pH, and temperature were then carried out on the samples. Information on analytical procedures is presented in Section 6.

4.3.4 Plant Samples

Plant tissue samples were collected by hand from the sampling locations. Samples of water hyacinth and pennywort were dissected into a stem section and a root section using a clean plastic knife, and then placed inside sample containers. These sample containers were preserved in ice before shipment to the laboratory for analysis. Information on analytical procedures is presented in Section 6.

Section 5

Tracer Study

5.1 Introduction

This section describes the methodology used to perform the tracer study at the AEES Facility. The objective of the tracer study was to examine the individual stages of the treatment system in order to determine the actual hydraulic detention times (HDTs) of the process components. Information on the tracer study protocol is provided below.

5.2 Test Locations

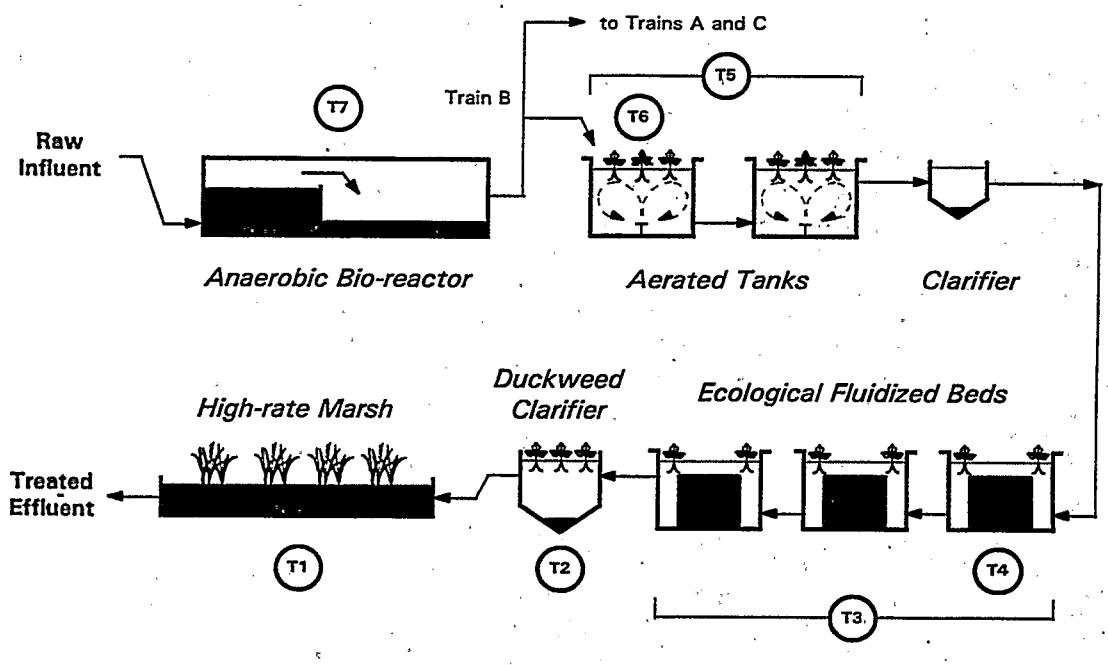
The tracer study was performed at several locations throughout the AEES system. Each sampling location had an injection point for the tracer compound and a water sampling point for sample collection. The stages of the process examined are summarized in Table 5.1 and displayed graphically in Figure 5-1.

Table 5.1 Tracer Study Sampling Locations

Sample Point	Description of Location
T1	Across High-rate Marsh
T2	Across Duckweed Clarifier
T3	Across the three Ecological Fluidized Beds
T4	Across the 1st Ecological Fluidized Bed
T5	Across the two Aerated Tanks
T6	Across the 1st Aerated Tank
T7	Across the Anaerobic Bio-reactor

The tracer study was carried out "in reverse order"; from the end of the process towards the head of the process. The reason for this was to prevent the anomalous detection of previously injected tracer compound in the later stages of the study.

Figure 5-1 Tracer Study Sampling Locations



5.3 Tracer Study Methods

5.3.1 Tracer Compound and Injection

The tracer compound used in this study was lithium chloride. Dyes are more typically used for tracer studies but, in this case, the plants in the AEES might have taken the dye up through their roots. For this reason, it was necessary to use a compound that would not be absorbed by the plants and, consequently, lithium chloride was selected.

The required quantities of lithium chloride for each sample location were calculated and weighed out using calibrated laboratory scales (accurate to 0.1 g). Before each part of the study, the tracer compound was dissolved in deionized water and injected in a single batch solution at the head of the system component being tested. The time of injection was noted so that sampling would be started at the correct time.

5.3.2 Sample Collection

Discrete wastewater samples were collected with an ISCO automatic sampler that was moved to a position downstream of the relevant sampling location at each stage of the

tracer study (T1 through T7). This sampler was inspected, cleaned, and calibrated at the beginning of each stage of the study.

Before each sampling event, the collection containers were cleaned and sample tubing was rinsed with the wastewater being tested. The sampler was then filled with ice for sample preservation. The automated sampler was programmed to take the required number of samples and locked to maintain sample security.

The automated sampler was programmed to take discrete hourly samples during the 24-hour sampling period. In addition, the sampler was programmed to flush its sample tubing with fresh wastewater before and after taking each hourly sample. The automated sampler also recorded any abnormalities detected during the sampling period (e.g., inability to take a full sample).

The first discrete sample for a sample location was always taken one hour after injection of the tracer compound. The last sample was taken at three times the theoretical HDT. These times are summarized in Table 5.2

Table 5.2 Calculated HDT and Sample Times for Tracer Study

Sample Point	Description of Location	Theoretical HDT (1)	Sampling End (2)
T1	High-rate Marsh	9 hours	27 hours
T2	Duckweed Clarifier	7½ hours	23 hours
T3	Three Ecological Fluidized Beds	19½ hours	59 hours
T4	1st Ecological Fluidized Bed	6½ hours	20 hours
T5	Two Aerated Tanks	18 hours	54 hours
T6	1st Aerated Tank	9 hours	27 hours
T7	Anaerobic Bio-reactor	19 hours	57 hours

(1) Calculated by Parsons ES.

(2) Time measured after injection of lithium chloride.

When the discrete samples were removed from the automated sampler, the collection containers were agitated to distribute any settled compounds throughout the sample. Each sample was then transferred into a sample bottle, preserved with nitric acid, and stored in ice before shipment to the laboratory for chemical analysis. Information on the analytical procedures used is presented in Section 6.

5.3.3 Calculation of Hydraulic Detention Times

On receipt of the analytical data, graphs of lithium concentration versus time were plotted. The centroid of each graph was calculated and used to derive the actual HDTs of each system component. As a check on the accuracy of the tracer study, calculations were also performed to confirm the percentage recovery of lithium chloride for each sample location. More information on these calculations is presented in Section 9.

Section 6

Analytical Procedures

6.1 Introduction

The analytical procedures used during this investigation may be separated into two general categories: field analyses and laboratory analyses. The following sections describe the methods used during the study to perform both types of test.

6.2 Field Analyses

Field analyses were carried out on the wastewater and sludge grab samples collected during the study. These analyses were as follows:

- pH;
- dissolved oxygen; and
- temperature.

Sample pH was measured using a portable pH meter and probe; dissolved oxygen was measured using a portable DO meter and probe; and sample temperature was measured using a thermometer. Both the pH and DO meters were calibrated before use and then as required during sampling. Duplicate samples were analyzed according to the Quality Assurance Project Plan (Section 7 and Appendix A).

No field analyses were performed on the plant samples collected.

6.3 Laboratory Analyses

A variety of chemical analyses were performed on the wastewater and residuals samples collected during the study. These analyses, and the USEPA approved methods followed, are summarized in Table 6.1.

6.3.1 Wastewater

The composite wastewater samples obtained for the process evaluation of the AEES were analyzed for a range of water quality parameters (Table 6.1). These parameters were selected as they were considered to be indicative of general water quality. The methods that were used for analyses of these conventional pollutants are the type most commonly specified in National Pollutant Discharge Elimination System (NPDES) permits for municipal wastewater treatment plants. The results of these analyses were used to evaluate the removal efficiencies of the Anaerobic Bio-reactor and the different process components in Train B of the treatment system. Factors such as solids removal, and nitrification and denitrification efficiencies could be estimated using this data. Discrete wastewater samples collected during the tracer study were analyzed to determine lithium concentration. The results of these analyses were used in the calculation of HDTs for the system components. Duplicate analyses and spike samples were analyzed for these wastewater samples according to the Quality Assurance Project Plan (Section 7 and Appendix A).

Table 6.1 Summary of Laboratory Analyses

Measurement	Matrix	Method [1]	Units
Chemical Oxygen Demand (COD), total	Water	410.4 HACH	mg/l
Chemical Oxygen Demand (COD), soluble	Water	410.4 HACH	mg/l
Biochemical Oxygen Demand (BOD), total	Water	405.1	mg/l
Biochemical Oxygen Demand (BOD), soluble	Water	405.1	mg/l
Total Suspended Solids (TSS)	Water	160.2	mg/l
Volatile Suspended Solids (VSS)	Water	160.4	mg/l
Total Kjeldahl Nitrogen (TKN)	Water	351.3 (mod)	mg/l
Total Kjeldahl Nitrogen (TKN)	Sludge/Plant Tissue	351.3 (mod)	mg/l, mg/kg
Ammonia (NH_4)	Water	350.3	mg/l
Nitrate (NO_3)	Water	352.1	mg/l
Total Phosphorus (TP)	Water	365.2	mg/l
Total Phosphorus (TP)	Sludge/Plant Tissue	365.2	mg/l, mg/kg
Fecal Coliform	Water	SM9221E	cfu/100mL
Fecal Coliform	Sludge/Plant Tissue	SM9221E (mod)	cfu/100mL, cfu/g
Lithium	Water	SM3111B	mg/l
Part 503 Metals [2]	Sludge/Plant Tissue	[3]	mg/l, mg/kg
Percent Solids	Sludge	3540	%

(1) USEPA method number unless otherwise noted as HACH or SM (Standard Methods).

(2) Part 503 Metals are: Arsenic, Cadmium, Chromium, Copper, Lead, Mercury, Molybdenum, Nickel, Selenium, and Zinc.

(3) USEPA Methods 206.2, 213.1, 218.1, 220.1, 239.1, 245.1, 246.2, 249.1, 270.2, 289.1, and 200.7.

6.3.2 Residuals

Both the sludge and plant tissue samples collected were analyzed for total phosphorus, total Kjeldahl nitrogen, fecal coliform, and Part 503 metals. The results of these analyses were used to assess the suitability of the process residuals for land application and/or disposal. Duplicate analyses and spike samples were analyzed for residuals according to the QA/QC Plan (Section 7 and Appendix A).

Section 7

Quality Assurance and Quality Control

7.1 Introduction

A quality assurance/quality control (QA/QC) program was established for this study with the objective of gathering sufficiently precise and accurate data for evaluating the AEES facility. A Quality Assurance Project Plan (QAPjP) was prepared prior to data collection to identify and/or establish procedures for the following:

- QA/QC program organization and responsibilities;
- QA/QC objectives for precision, accuracy, completeness, representativeness, and comparability;
- Sampling and analytical procedures;
- Quality control checks and system audits;
- Data validation and calculation of data quality indicators; and
- Corrective action.

In addition to the Project Manager and Technical Directors identified in the Work Plan, the QAPjP identified QA/QC program staff to assume the roles of Quality Assurance Manager (QAM), Quality Assurance Coordinator (QAC), and Laboratory Director (LD). QACs and LDs were identified for both field and analytical activities. The QA/QC responsibilities and lines of authority for each of the QA/QC program staff are summarized in the QAPjP.

A copy of the QAPjP is presented in Appendix A.

7.2 QA/QC Program Implementation and Procedures

7.2.1 Field Activities

Prior to initiating sample collection, the field QAC and LD reviewed and practiced sample collection and handling techniques and instrument calibration procedures. The meters and equipment were calibrated prior to the start of field activities to ensure all were in good working condition and again during field activities, as required in the QAPjP. The field LD, or a designated member of the field team, completed all field QA/QC documentation including chain-of custody forms, sample labels, field data sheets, and logbook notes. Quality control checks for field activities consisted of duplicate analyses on field pH, DO, and temperature measurements.

A field audit was conducted on the second day of sample collection activities. The audit was conducted by the field QAC to evaluate the performance of the field LD, who was the principal sample collector during the study. The audit covered sample collection and handling, as well as calibration and use of field instruments.

7.2.2 Analytical Activities

In addition to following the project specific QA/QC guidelines in the QAPjP, the Parsons ES laboratory in Atlanta, Georgia, adheres to it's own QA/QC protocols described in their Quality Assurance and Quality Control manual (Parsons ES, 1992). Technicians are well qualified and undergo a formal training and certification program for each analytical parameter they perform. The quality of work performed by the laboratory is indicated through successful participation in the USEPA performance check sample program.

The laboratory analyzed a variety of QC samples during the conduct of this study to assess accuracy and precision of the data including: calibration standards, system blanks, laboratory control samples, duplicate samples, and matrix spike samples. Calibration standards, system blanks, and laboratory control samples were performed with each set of samples to ensure that analytical procedures and measurement systems were working properly. Duplicate samples were performed on a minimum of 10% of the samples collected for a specific parameter to assess the data quality objectives for precision. Matrix spike samples were also performed on 10% of the samples collected for TKN, ammonia, nitrate, and total phosphorus to assess the data quality objectives for accuracy.

A laboratory audit was conducted three weeks after initiation of analytical activities. The audit was conducted by the laboratory QAC to evaluate the performance of the laboratory technicians receiving and analyzing samples for the study. The audit covered sample receipt and handling, facilities and general equipment, QA/QC documentation, chemical analysis, and data reduction, validation, and reporting.

The laboratory QAC was responsible for reviewing, validating, and reporting all data generated. The QAC evaluated compliance with method detection limits and calculated precision, accuracy, and completeness values from the data.

7.2.3 Program Activities

Monthly reports were prepared by the QA/QC program staff. The field and analytical LDs reported QA/QC activities using the LD Field Form 1 and LD Lab Form 1, respectively, from the QAPjP. The field and analytical QACs reviewed the monthly reports from the LDs and reported QA/QC activities using the QAC Form 1 from the QAPjP. All of the reports were submitted to the QAM, who reviewed the reports and reported QA/QC activities to the Program Manager using the QAM Form 1 from the QAPjP.

Guidelines for implementation of corrective action procedures are identified in the QAPjP. Documentation of problem conditions was reported on the QAC and QAM Forms 1 and on the cover letters from the laboratory (if applicable).

7.3 QA/QC Program Results

7.3.1 Field Activities

Documentation of field instrument calibrations are provided in the field logbook. No significant problems with equipment calibration were identified. All required field QA/QC documentation, including chain-of custody forms, sample labels, field data sheets, and logbook notes, was recorded and/or prepared daily during field activities. Duplicate analysis on field pH, DO, and temperature measurements were evaluated from April 12,1995, through the end of the sampling period. All duplicate analyses were within 20 percent of the original value as shown in Table 7.1. Duplicates were not performed for the first six

weeks of the study; however, results of duplicates performed later in the study indicated no technique or equipment problems.

Table 7.1 RPDs and PRRs for Analyzed Samples

Parameter	Matrix	RPD (maximum)	RPD Limit	PRR	PRR Limit
COD (total and soluble)	water	3.9%	20%	97-105%	80-120%
BOD (total and soluble)	water	8.6%	20%	90-115%	80-120%
TSS	water	46%(1)	30%	-	-
VSS	water	27%	30%	-	-
TKN	water	12%	20%	87-120%	80-120%
TKN	sludge/plants	9%	30%	111-128%	70-130%
Ammonia	water	4.2%	20%	97-127%(3)	80-120%
Nitrate	water	5.1%	20%	79-109%	70-130%
Total phosphorus	water	12%	20%	85-108%	80-120%
Total phosphorus	sludge/plants	9.1%	30%	80-116%	70-130%
Field pH	water/sludge	0.4%	-	-	-
Field DO	water/sludge	20%	-	-	-
Field temperature	water/sludge	11.1%	-	-	-
Fecal coliform	water/sludge/plants	46%(2)	-	-	-
Part 503 metals	sludge/plants	15%	30%	80-118%	70-130%

RPD Relative Percent Difference

PRR Percent Recovery Range

(1) One duplicate analysis exceeded the control limit for this parameter.

(2) Only one duplicate analysis exceeded 30%, although there was no control limit for this parameter.

(3) One matrix spike exceeded the control limit for this parameter.

Results of the field audit were satisfactory with two minor nonconformities. The stock buffer solutions used for calibrating the pH meter were past the recommended one year expiration date and the thermometer used for field activities had not been calibrated with an NIST (National Institute of Standards in Technology) traceable thermometer.

7.3.2 Analytical Activities

Results of duplicate and matrix spike samples in terms of relative percent difference (RPD) and percent recovery range (PRR), respectively, are presented in Table 7.1. Data quality objectives were met with the exception of one duplicate for TSS and one spike for ammonia. Percent completeness for each sampling location is provided in Table 7.2. The percent completeness is the percent of the total data set that is valid (i.e., that meet the RPD and PRR control limits and are analyzed within the allowable holding time). The objective for this study is 90% completeness. Three sampling points for TSS analyses were slightly below this objective; however, the overall percent completeness for each parameter was $\geq$93.

Results of the laboratory audit were satisfactory with one minor nonconformity. The laboratory does not have a standard operating procedure for data reduction, validation, and reporting. However, the laboratory does address this topic in their QA/QC manual.

Table 7.2 Study Completeness

	% Completeness by Sample Location									% Comp
Parameter	**W1**	**W2**	**W3**	**W4**	**W5**	**W6**	**S1**	**S2**	**Plants**	**Overall**
Total COD	100%	100%	100%	100%	100%	100%				*100%*
Soluble COD	100%	100%	100%	100%	100%	100%				*100%*
Total BOD	93%	93%	93%	93%	93%	93%				*93%*
Soluble BOD	93%	93%	93%	93%	93%	93%				*93%*
TSS	100%	86%	86%	100%	86%	100%				*93%*
VSS	100%	93%	93%	93%	100%	100%				*96%*
TKN	100%	100%	100%	100%	100%	100%	100%	100%	100%	*100%*
Ammonia	100%	93%	93%	100%	93%	100%				*96%*
Nitrate	100%	100%	100%	100%	100%	100%				*100%*
Total phosphorus	100%	100%	100%	100%	100%	100%	100%	100%	100%	*100%*
Field pH	100%	100%	100%	100%	100%	100%	100%	100%		*100%*
Field DO	100%	100%	100%	100%	100%	100%	100%	100%		*100%*
Field temperature	100%	100%	100%	100%	100%	100%	100%	100%		*100%*
Fecal Coliform	100%					100%	100%	100%	100%	*100%*
Part 503 metals							100%	100%	100%	*100%*
Percent solids							100%	100%		*100%*

7.3.3 Program Activities

QA reports were prepared for the months of March, April, May, and June 1995. No major problem conditions were reported that required extensive corrective action. Several minor problems were identified and quickly resolved during the conduct of this study and include the following:

- As discussed in Section 7.3.2, variances to the data quality objectives were observed with two sets of data. The variance observed with the TSS duplicate data

for the March 15 samples was attributed to a non-homogenous sample. The variance observed with the ammonia matrix spike data for the April 12 samples was attributed to matrix interference, since the laboratory control sample run concurrently was well within the control limit.

- A problem condition with BOD analyses was identified and resolved quickly by the QAC when it was discovered that the wrong seed innoculum had been shipped to the laboratory from the supplier.
- During the beginning of the study, some TKN values were determined to be less than the ammonia values for the corresponding samples. The reason for this was judged to be a consequence of the analytical method for TKN when the analyzed sample contained a high percentage of nitrogen as ammonia. The TKN analysis (USEPA Method 351.3) involves refluxing the sample for a period of time which can drive volatile ammonia from the sample before the analysis is complete. This problem was rectified by modifying the analytical method slightly to decrease the reflux period and, consequently, minimize the loss of ammonia from the sample. Where this had occurred, the value for TKN was assumed to equal the value for NH_3.
- It was suggested that analytical variability was the reason that some VSS values were determined to be greater than TSS values. This only occurred when both TSS and VSS were of low magnitude. Where this occurred, the VSS value was assumed to equal the TSS value.
- A review of the field QA report for March revealed that field duplicates were not being performed for pH, DO, and temperature. This field activity was initiated immediately thereafter by the field LD.

7.4 Conclusion

In general, the QA/QC requirements identified in the QAPjP were met during the conduct of this study and all of the required QA/QC documentation is on file. The data quality objectives for accuracy and precision were not achieved in two cases; however, the reason was not attributed to analytical performance. In both cases, the variances were attributed to sample characteristics. For this reason and the fact that the number of samples collected for this study is relatively small, the sample data impacted by these variances are used in the data analysis.

Section 8

Flow Data

8.1 Introduction

The flows of wastewater treated by the AEES Facility were measured for the duration of the eleven week study using influent and effluent flow meters. This section summarizes the results and findings of the flow measurements. The raw data from which this summary is drawn is presented in Appendix B.

8.2 Influent Flows

The recorded Train B influent data demonstrated that mean daily flow rates between 10,000 and 15,000 gpd were being achieved for the duration of the study (not including periods when the plant was shut down). The average of mean daily flows over the course of the study was calculated to be 13,451 gpd which is comparable with the anticipated flow rate into Train B of approximately 13,300 gpd. The weekly mean influent flow rates are summarized in Table 8.1.

There were some instances during the study when accidental power outages and problems with the flow meter and associated computer resulted in "gaps" in the recorded flow data. Where this occurred, the missing flow data were either calculated from daily totalized flow data recorded by hand in the field, or the data were interpolated from the recorded flows. In addition, as noted in the table, on three occasions the AEES Facility was shut down and, consequently, was not receiving influent flow for a period of days. The influent flows for these days have not been included in the calculations of the daily mean flows.

8.3 Effluent Flows

The effluent flow data recorded by the existing OAI flow meter showed a large variability in comparison with the influent flow data. The cause of this could have been the effluent flow meter. For this reason the effluent flow data was deemed to be unreliable and not used in the evaluation. The influent flow totals were considered to be sufficient data for the process evaluation.

Table 8.1 Mean Daily Wastewater Flows into Train B

Study Week	Dates	Mean Daily Flow	Comments
Week 1	2/28/95 to 3/3/95	11,622 gpd	
Week 2	3/4/95 to 3/10/95	13,303 gpd	
Week 3	3/11/95 to 3/17/95	13,870 gpd	The plant was shut down on 3/17/95 owing to a power outage (*this day is not included in the daily mean*)
n/a	3/18/95 to 3/24/95	13,804 gpd	The plant was shut down from 3/18/95 to 3/20/95 owing to a power outage (*these days are not included in the daily mean*)
Week 4	3/25/95 to 3/31/95	13,463 gpd	
Week 5	4/1/95 to 4/7/95	13,238 gpd	
Week 6	4/8/95 to 4/14/95	14,775 gpd	
Week 7	4/15/95 to 4/21/95	13,542 gpd	
Week 8	4/22/95 to 4/28/95	13,456 gpd	
Week 9	4/29/95 to 5/5/95	12,639 gpd	
Week 10	5/6/95 to 5/12/95	13,743 gpd	
Week 11	5/13/95 to 5/19/95	14,239 gpd	
n/a	5/20/95 to 5/26/95	no data	Flow meter malfunction resulted in the inaccurate reading of influent flows
n/a	5/27/95 to 6/2/95	no data	Flow meter malfunction resulted in the inaccurate reading of influent flows. Influent flow was shut down between 5/24/95 and 6/1/95
Week 12	6/3/95 to 6/9/95	no data	Flow meter malfunction resulted in the inaccurate reading of influent flows
Week 13	6/10/95 to 6/16/95	13,009 gpd	
Week 14	6/17/95 to 6/23/95	13,614 gpd	Low influent flows on 6/17/95 and 6/18/95 owing to clogging of influent pump at Ballanger WWTP (*these days are not included in the daily mean*)
Mean of Mean Daily Flows		**13,451 gpd**	

Section 9

System Performance

9.1 Introduction

The data generated during the eleven week wastewater and residuals sampling study (Section 4) was used to evaluate the performance of the AEES Facility. This section summarizes these data and details some observations concerning the AEES process. The raw data on which this section is based is presented in Appendix C.

9.2 Wastewater Characteristics

By the end of the eleven week study, individual water quality samples had been taken from each sample location (W1 to W6) throughout the process. Analysis of these samples yielded the data that was used to assess the process performance of the AEES Facility. However, before these data were used, they were examined and adjusted to remove any spurious points and statistical outliers that might influence the evaluation.

9.2.1 Data Manipulation and Statistical Assessment

The first step of the data manipulation was to review the field notebook and laboratory reports to remove any data points that were known to be invalid. Some values were removed because of a process upset and a sampling mishap that occurred during the study. Additionally, the first week's data for point W5 could not be used since the initial location for sample point W5 was moved after Week 1 of the study (see Section 4). There were also a few cases where, owing to analytical variability, some values for VSS exceeded those for TSS. In these cases, the value for VSS was assumed to equal the TSS value. Similarly, the analyses for ammonia yielded some values that exceeded the TKN values. This was determined to be a consequence of the analytical method for TKN when the TKN comprises mainly ammonia. Consequently, the analytical method was modified slightly to account for this but, where this had already occurred, the TKN was assumed to equal the ammonia value.

After the initial review, the data were examined statistically. This involved testing to identify how the study data were statistically distributed, followed by discordancy testing to remove any "outliers" (points that are outside a data set's normal distribution). Outliers were removed in order that they would not influence the process evaluation, by influencing the mean data either upwards or downwards. Once these statistics had been performed, the data were used to derive means from which the process could be assessed. These means are presented in Section 9.2.2.

Full details of the data manipulation and statistical assessment are presented in Appendix C.

9.2.2 Mean Water Quality Data

The mean water quality data from the eleven week study are presented in Table 9.1. The raw data, indicating the values removed after data manipulation and statistical assessment, are presented in Appendix C.

The mean values for chemical oxygen demand (total and soluble), along with the associated standard deviations, are depicted graphically in Figure 9-1. Most of the COD (total) reduction occurs in the Anaerobic Bio-reactor, even though further treatment takes place downstream. The very slight increase in total COD in the Aerated Tank effluent could be a result of the sludge recycle to the Aerated Tanks from upstream. However, the standard deviations of the data from sample points W2 and W3 overlap to a large degree which indicates the insignificance of this small peak.

Soluble COD appears to increase slightly in the effluent from the Anaerobic Bio-reactor which suggests that some of the total COD reduction is caused by breakdown of compounds into a more soluble form. The major decline in soluble COD appears to take place in the Aerated Tanks, after which the levels fall only slightly throughout the rest of the system.

The mean values for total and soluble BOD, along with the associated standard deviations, are depicted graphically in Figure 9-2. As in the case of COD, the major reduction in total five-day BOD occurs in the Anaerobic Bio-reactor, although additional decreases occur in the subsequent process components. The soluble BOD increases slightly after the Anaerobic Bio-reactor which could be a result of the breakdown of BOD-causing compounds into a more soluble form. The Aerated Tanks appear to remove the remaining BOD from the wastewater before it passes out of the system.

In this case, "soluble" BOD may be a slight misnomer since the fraction of BOD analyzed by the USEPA method (Method 405.1) is actually that which passes through a 0.45μm cellulose-nitrate membrane. Therefore, this BOD fraction is not necessarily "soluble". However, since the Method 405.1 definition of soluble BOD is used by the USEPA, it is a valid one with respect to this process evaluation.

The mean values for suspended solids (total and volatile), along with the associated standard deviations, are displayed graphically in Figure 9-3. Again, the Anaerobic Bio-reactor appears to be responsible for the majority of TSS and VSS reduction taking place in the treatment system. The peak that occurs following the Anaerobic Bio-reactor could possibly be a consequence of the sludge recycle to the Aerated Tanks from upstream (a similar, less-defined peak occurs for total COD). Alternatively, root matter from the plants in the Aerated Tanks may be sloughed off into the system, resulting in an increase in suspended solids; or it could be a combination of these two factors.

Most of the ensuing solids reduction appears to be carried out by the 1st Ecological Fluidized Bed. With respect to suspended solids, there is very little noticeable difference between the effluent from the 3rd Ecological Fluidized Bed and the High-rate Marsh.

The mean values for the nitrogenous components (TKN, ammonia and nitrate), along with the associated standard deviations, are displayed graphically in Figure 9-4. This graph provides an indication of what is occurring with respect to nitrification and denitrification throughout the system. Both TKN and ammonia decrease steadily as they pass through the process. There is a slight peak of TKN that occurs after the Aerated Tanks but this may be a result of the aforementioned sludge recycle from upstream (the overlapping standard deviations between W2 and W3 may mean that this peak is not even significant). There is

Table 9.1

WATER QUALITY SUMMARY FOR AEES FACILITY

ELEVEN WEEK PERFORMANCE EVALUATION

	Parameter	Units	Mean Water Quality Data						AEES Effluent Targets
			Raw Sewage Influent	Anaerobic Bio-reactor Effluent	Aerated Tank Effluent	1st Ecological Fluidized Bed Effluent	3rd Ecological Fluidized Bed Effluent	High-rate Marsh Effluent	
			W1	W2	W3	W5	W4	W6	
Composite Samples	Total COD	mg/l	1,307.0	444.7	399.4	149.8	73.4	53.2	
	Soluble COD	mg/l	157.5	216.2	63.8	50.7	43.2	38.3	
	Total BOD_5	mg/l	468.8	160.0	105.6	49.4	18.4	12.5	10
	Soluble BOD_5	mg/l	70.1	107.7	9.7	6.4	11.3	10.2	
	Total Suspended Solids	mg/l	470.4	78.0	148.0	42.6	9.9	3.5	10
	Volatile Suspended Solids	mg/l	364.0	64.0	122.0	33.6	6.3	2.2	
	Total Kjeldahl Nitrogen	mg/l	55.9	43.3	46.0	29.9	10.0	8.4	
	Ammonia	mg/l-N	25.6	33.8	28.0	22.9	7.5	5.5	1
	Nitrate	mg/l-N	0.16	0.15	0.38	2.12	10.49	5.40	5
	Total Phosphorus	mg/l-P	13.6	8.2	8.5	8.0	7.0	6.8	3
Grab Samples	Fecal Coliform	cfu/100ml	8,109,091					170	
	Field pH		7.98	7.26	7.61	7.47	7.15	7.30	
	Field Dissolved Oxygen	mg/l	2.9	4.9	4.9	5.5	3.5	2.8	
	Sample Temperature	°C	17.3	16.5	17.1	17.7	18.2	18.5	

Figure 9-1
Eleven Week Performance Evaluation
Parameter: *Chemical Oxygen Demand*

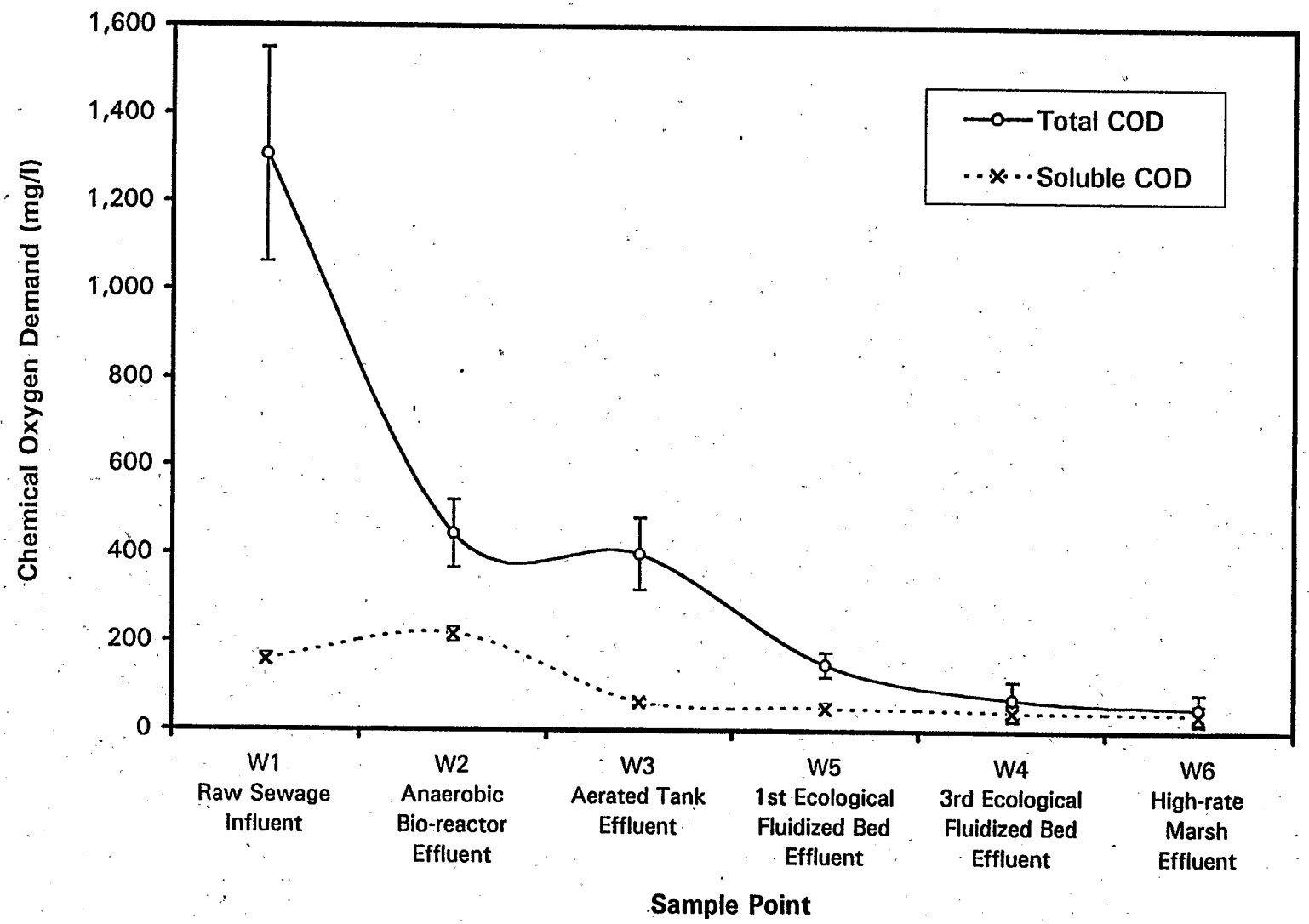


Figure 9-2
Eleven Week Performance Evaluation
Parameter: *Biochemical Oxygen Demand*

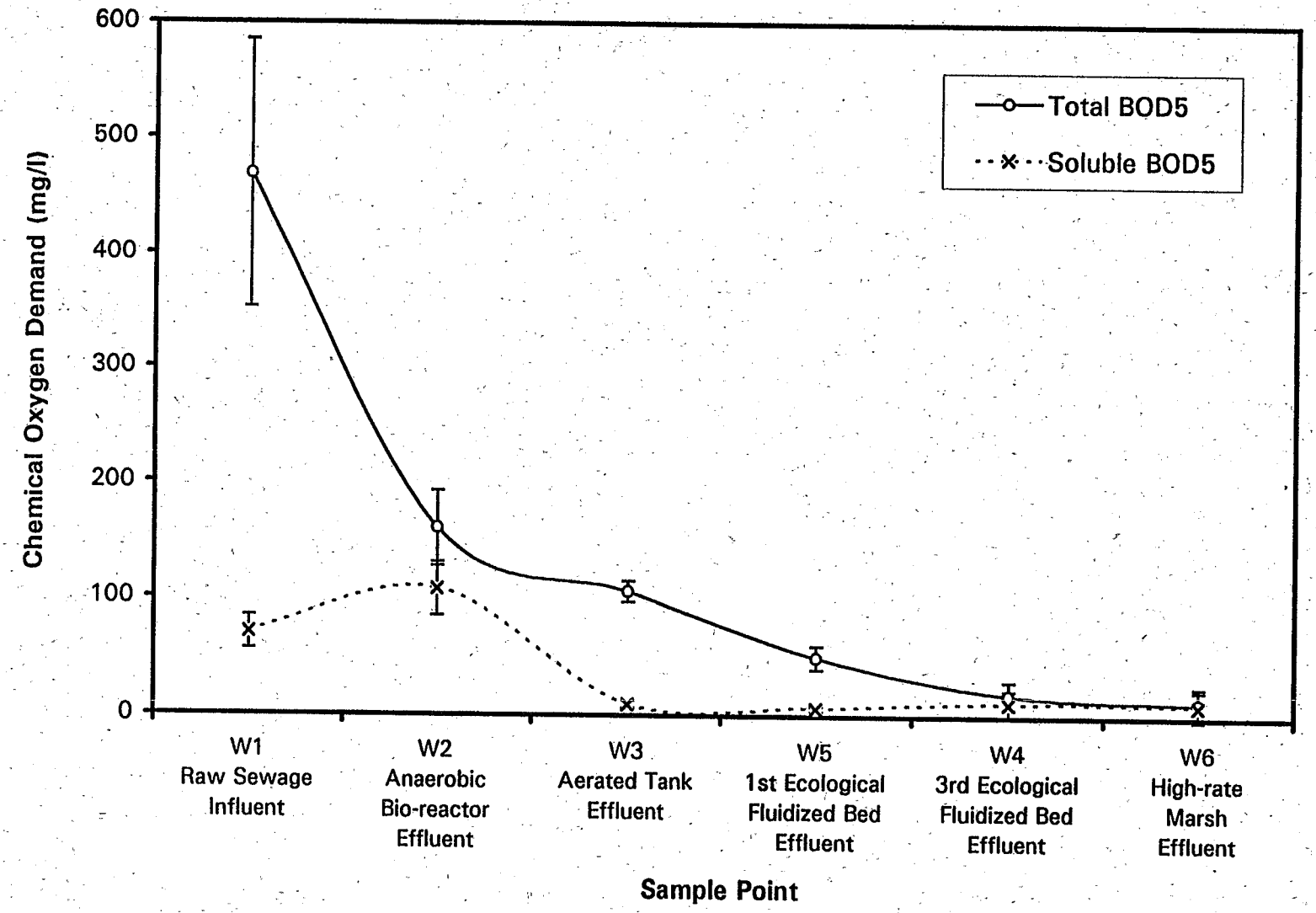


Figure 9-3
Eleven Week Performance Evaluation
Parameter: *Suspended Solids*

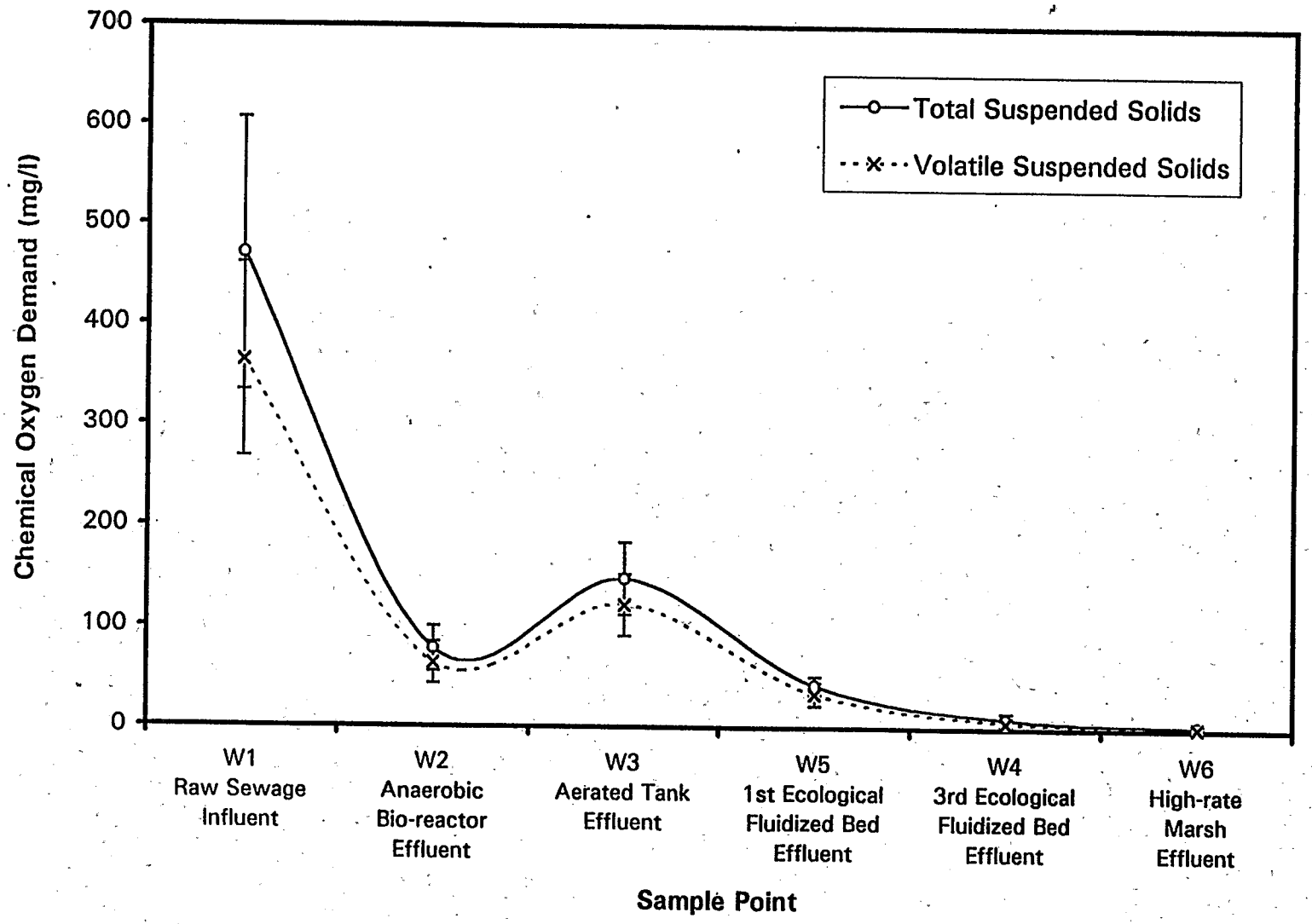
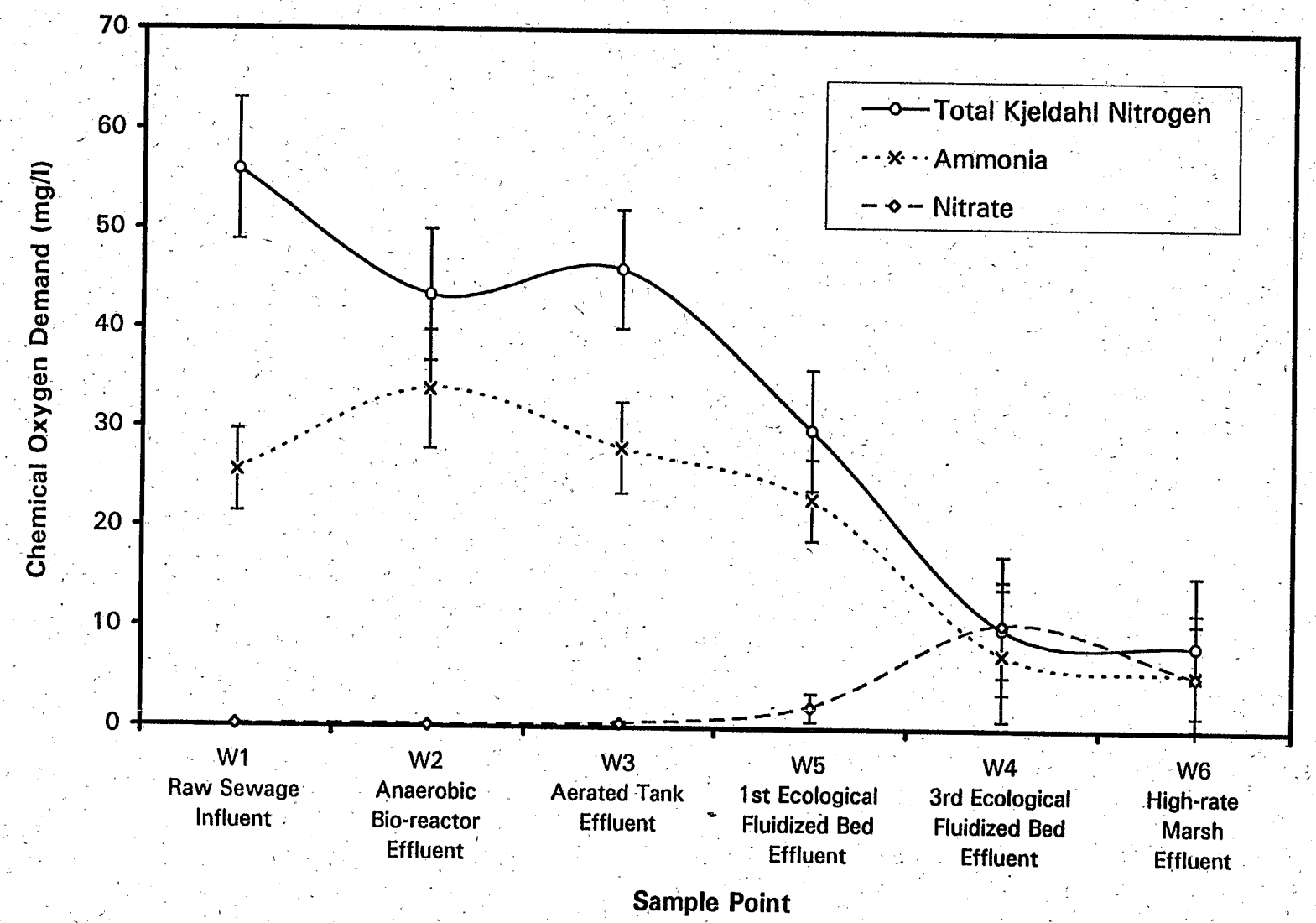


Figure 9-4
Eleven Week Performance Evaluation
Parameters: *TKN, Ammonia and Nitrate*



also a slight increase in ammonia in the Anaerobic Bio-reactor effluent which could indicate that a fraction of the TKN is broken down to ammonia in this component of the process. Alternatively, this could be a result of the sludge recycle into the Anaerobic Bio-reactor. There is very little reduction of TKN or ammonia observed passing through the Duckweed Clarifier and High-rate Marsh.

Nitrate levels begin to increase visibly within the Ecological Fluidized Beds, indicating that most nitrification is occurring in these units. The effluent from the High-rate Marsh demonstrates a reduction in nitrate concentrations, suggesting that dentrification has begun to occur in the last two stages of the process (the Duckweed Clarifier and High-rate Marsh).

The mean values for total phosphorus, along with the associated standard deviations, are displayed graphically in Figure 9-5. As with total COD, total BOD and suspended solids, most of the phosphorus removal occurring in the system appears to take place in the Anaerobic Bio-reactor. Once again, there may be a slight increase occurring within the Aerated Tanks which could be attributed to the sludge recycle. However, the overlapping standard deviations of the data at points W2, W3 and W5 suggest that the increase is not a significant one. There is also a slight decrease in total phosphorus within the Ecological Fluidized Beds.

The mean values for field pH and dissolved oxygen, along with the associated standard deviations, are displayed graphically in Figure 9-6. The pH remains consistently between pH 7 and pH 8 throughout the process, and the small standard deviations of this data suggest that with respect to pH the system is very stable. The level of dissolved oxygen is at approximately the same level in both the influent and the treated effluent. This level increases within the process system in the Aerated Tank and Ecological Fluidized Bed effluents, since these units are both aerated. The increase of DO observed in the Anaerobic Bio-reactor effluent is likely to be the result of the aeration that the wastewater undergoes in the three odor-control tanks following this system component.

Graphs were not plotted for fecal coliform or temperature. The mean fecal coliform count in the raw influent decreases by over 99.9% by the time it has left the treatment system. From the data, it is not possible to tell where in the process most of this reduction is taking place. The field sample temperatures taken at each sample location increased throughout the duration of the study, as the weather got warmer and, therefore, it is doubtful that this data would be useful in the process evaluation. This data was collected purely for QA/QC purposes.

9.3 Treatment Efficiencies

Using the water quality data described in Section 9.2, treatment efficiencies were calculated for the overall process as well as for the individual process components of the AEES Facility. The individual component treatment efficiencies were calculated using the following equation:

$$\text{Component Treatment Efficiency} = [(P_a - P_b)/P_a] \times 100$$

Where: P_a = pollutant concentration in component influent

P_b = pollutant concentration in component effluent

Figure 9-5
Eleven Week Performance Evaluation
Parameter: *Total Phosphorus*

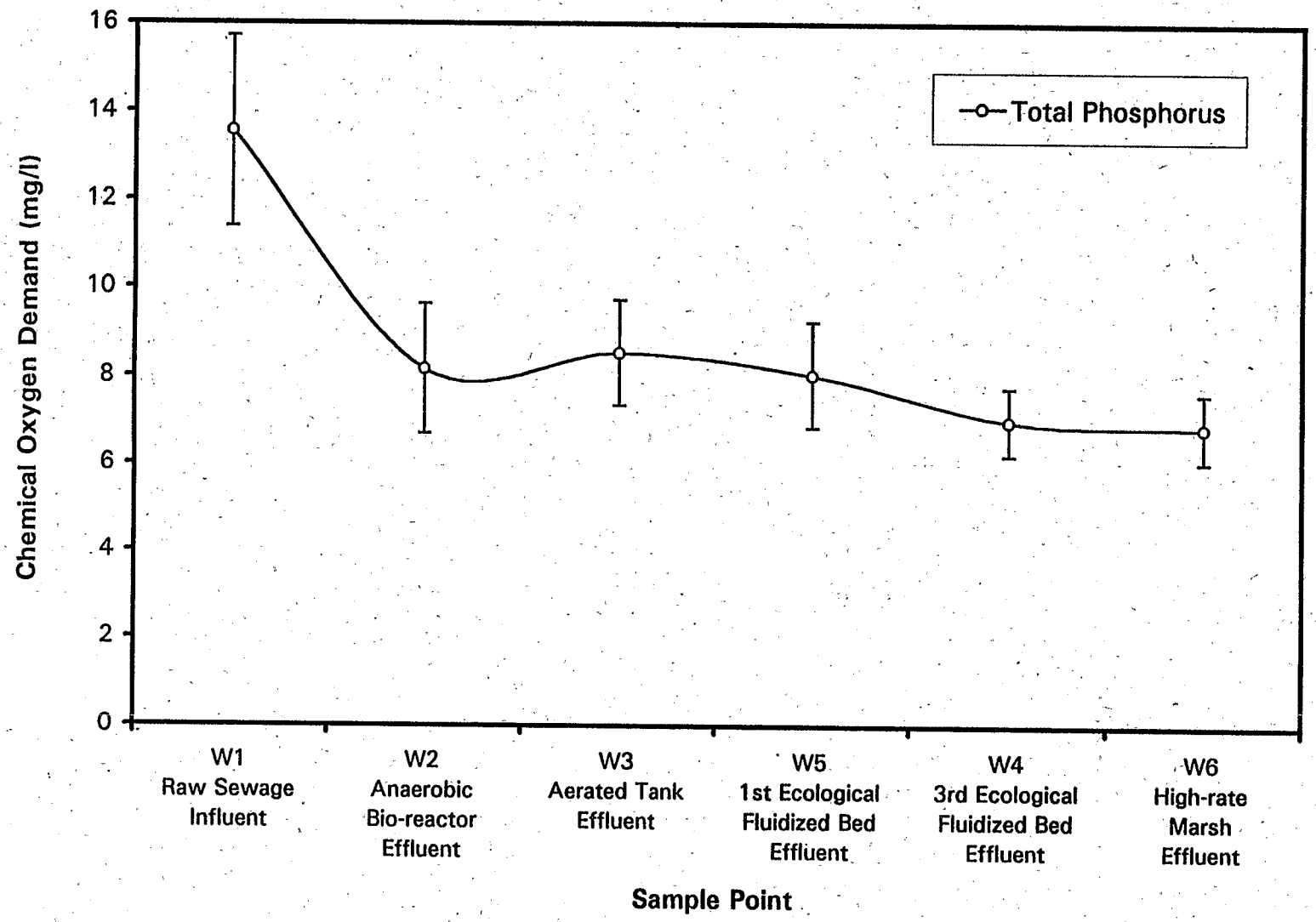
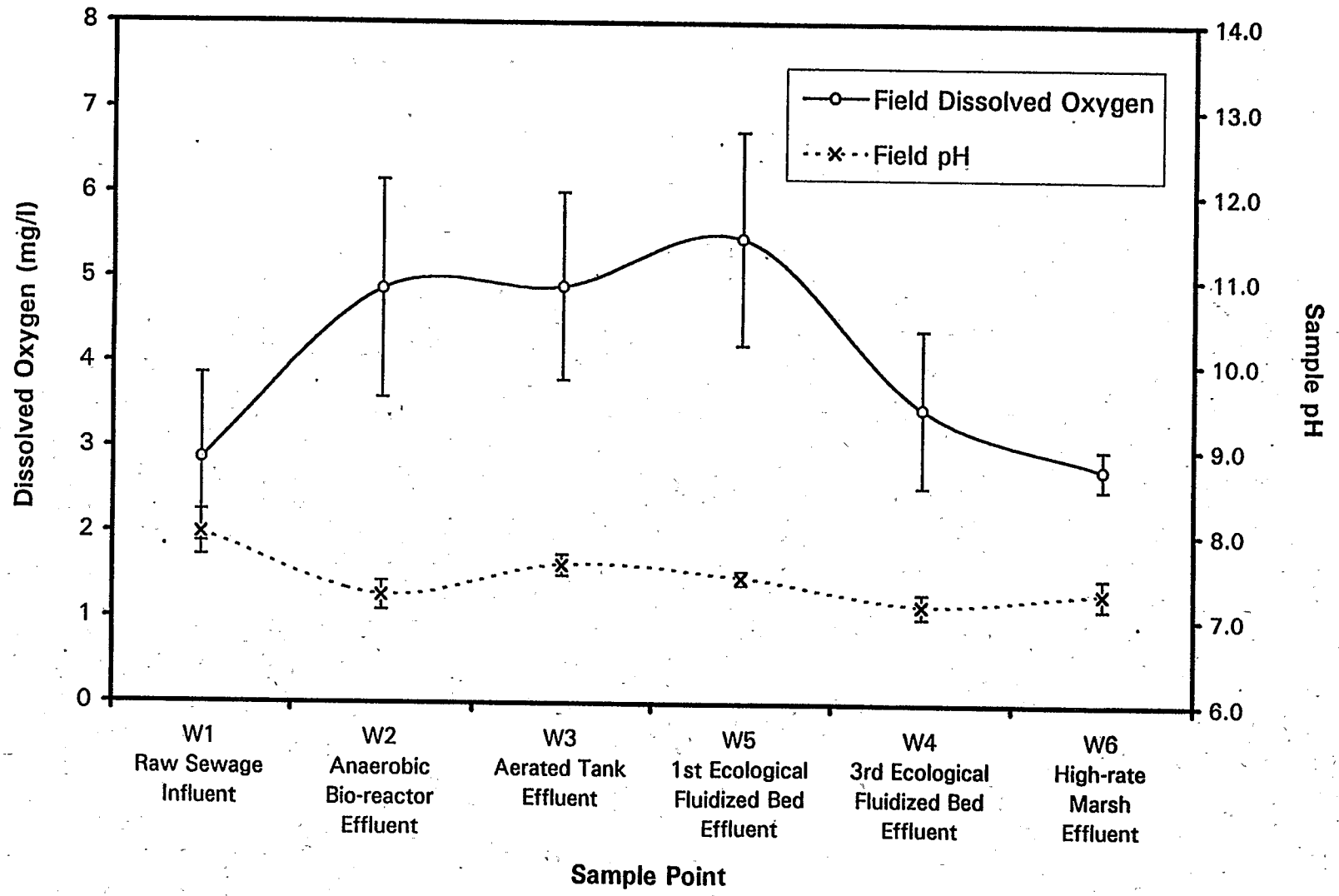


Figure 9-6
Eleven Week Performance Evaluation
Parameters: *Dissolved Oxygen and pH*



The calculation of the system's overall treatment efficiency was based on the following equation:

$$\text{Process Treatment Efficiency} = [(P_i - P_e)/P_i] \times 100$$

Where: P_i = pollutant concentration in raw influent to AEES

P_e = pollutant concentration in treated effluent from AEES

An exception to this formula was used in the case of nitrate treatment efficiency. This pollutant is generated in the process during nitrification and, therefore, the overall treatment efficiency was calculated by looking at the performance of the denitrifying components of the process (the Duckweed Clarifier and High-rate Marsh).

The overall and individual component treatment efficiencies for the selected pollutants are shown in Table 9.2.

In addition to this, the percentage contributions to pollutant removal of each system component was calculated for the major water quality parameters (excluding nitrate). This was calculated using the following equation:

$$\text{Contribution to Pollutant Removal} = [(P_a - P_b)/(P_i - P_e)] \times 100$$

Where: P_a = pollutant concentration in component influent

P_b = pollutant concentration in component effluent

P_i = pollutant concentration in raw influent to AEES

P_e = pollutant concentration in treated effluent from AEES

In some situations, an increase of a given pollutant occurred within a system component. For example, an increase of suspended solids takes place after the Aerated Tanks which, it is suspected, is caused by the sludge recycle. In these instances, system components had to be combined in order to calculate their correct percentage contributions to pollutant removal.

The percentage contributions to pollutant removal for the selected pollutants are shown in Table 9.3 and are also displayed as pie charts in Figures 9-7 through 9-12.

These figures confirm the previous observations that the Anaerobic Bio-reactor is removing the vast majority (65% to 85%) of total COD, total BOD, TSS, and total phosphorus from the wastewater passing through the system. In the case of TKN and ammonia, it is evident from the pie charts that most nitrification is taking place in the 2nd and 3rd Ecological Fluidized Beds, with some occurring further upstream in the 1st Ecological Fluidized Bed and the Aerated Tanks.

9.4 Residuals Characteristics

During the eleven week study, various samples of the process residuals (sludge and plants) were collected from sample locations throughout the process. Analysis of these samples yielded data that were used to assess the quality of the residuals generated by the process. This assessment would examine how suitable the sludge and plants were for land disposal and/or composting.

Table 9.2

POLLUTANT TREATMENT EFFICIENCIES FOR AEES FACILITY

ELEVEN WEEK PERFORMANCE EVALUATION

Parameter	Percentage Pollutant Removal (1)					
	Overall Pollutant Removal	Anaerobic Bio-reactor	Aerated Tanks	1st Ecological Fluidized Bed	Ecological Fluidized Beds (2)	Duckweed Clarifier & High-rate Marsh
Total COD	96%	66%	10%	62%	82%	28%
Soluble COD	76%	-37%	70%	21%	32%	11%
Total BOD_5	97%	66%	34%	53%	83%	32%
Soluble BOD_5	85%	-54%	91%	34%	-16%	9%
Total Suspended Solids	99%	83%	-90%	71%	93%	65%
Volatile Suspended Solids	99%	82%	-91%	72%	95%	65%
Total Kjeldahl Nitrogen	85%	23%	-6%	35%	78%	16%
Ammonia	79%	-32%	17%	18%	73%	27%
Nitrate (3)	49%	11%	-159%	-466%	-2692%	49%
Total Phosphorus	50%	40%	-4%	6%	18%	2%
Fecal Coliform	99.998%					

(1) A negative percent removal indicates an increase of the component through the system.

(2) Percentage removals shown are for all three Ecological Fluidized Beds.

(3) Overall pollutant removal shown for nitrate is taken between the Final Ecological Fluidized Bed and the Treatment Plant Effluent.

Table 9.3

POLLUTANT REMOVAL CONTRIBUTIONS FOR AEES FACILITY

ELEVEN WEEK PERFORMANCE EVALUATION

Parameter	Percentage Contribution to Pollutant Removal				
	Anaerobic Bio-reactor	Aerated Tanks	1st Ecological Fluidized Bed	2nd and 3rd Ecological Fluidized Beds	Duckweed Clarifier and High-rate Marsh
Total COD	68%	4%	20%	6%	2%
Total BOD_5	68%	12%	12%	7%	1%
Total Suspended Solids (1)	84%	8%		7%	1%
Total Kjeldahl Nitrogen (2)	27%	28%		42%	3%
Ammonia (3)	13%			77%	10%
Nitrate (4)	n/a	n/a	n/a	n/a	n/a
Total Phosphorus (5)	80%	2%		16%	2%

(1), (2) and (5) For the purposes of calculation, the contributions of the Aerated Tanks and 1st Ecological Fluidized Bed have to be combined.

(3) For the purposes of calculation, the contributions of the Anaerobic Bio-reactor, Aerated Tanks and 1st Ecological Fluidized Bed have to be combined.

(4) Owing to the nature of the nitrification/denitrification occurring in the system, it is meaningless to calculate the individual contributions of the components to nitrate removal.

Figure 9-7
Contributions of Process Components
Total Chemical Oxygen Demand Removal

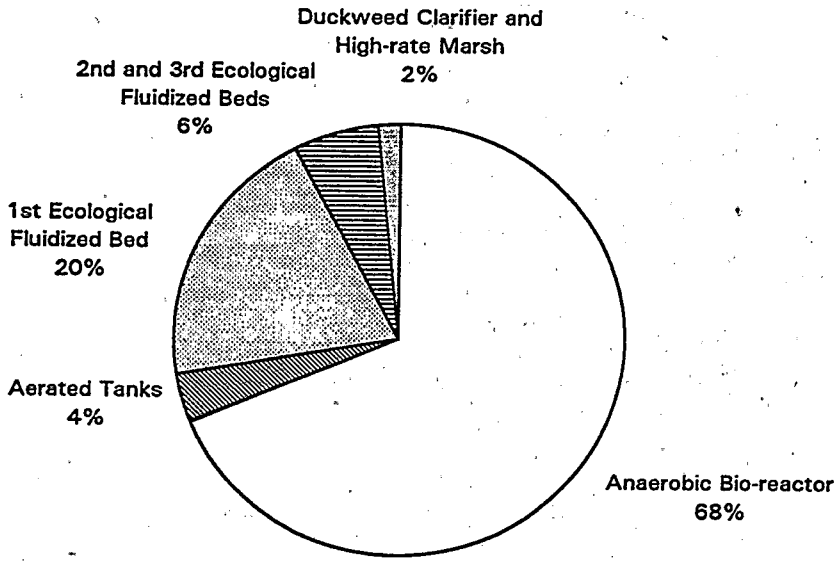


Figure 9-8
Contributions of Process Components
Total Biochemical Oxygen Demand Removal

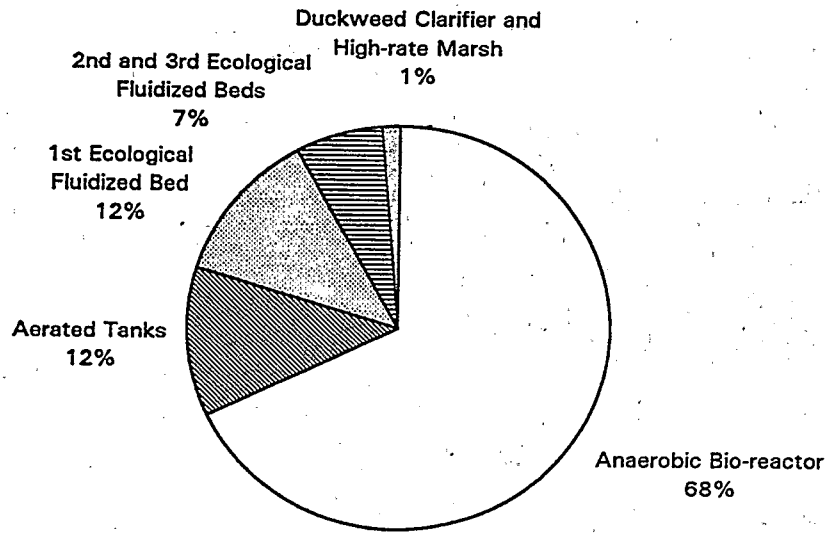


Figure 9-9
Contributions of Process Components
Total Suspended Solids Removal

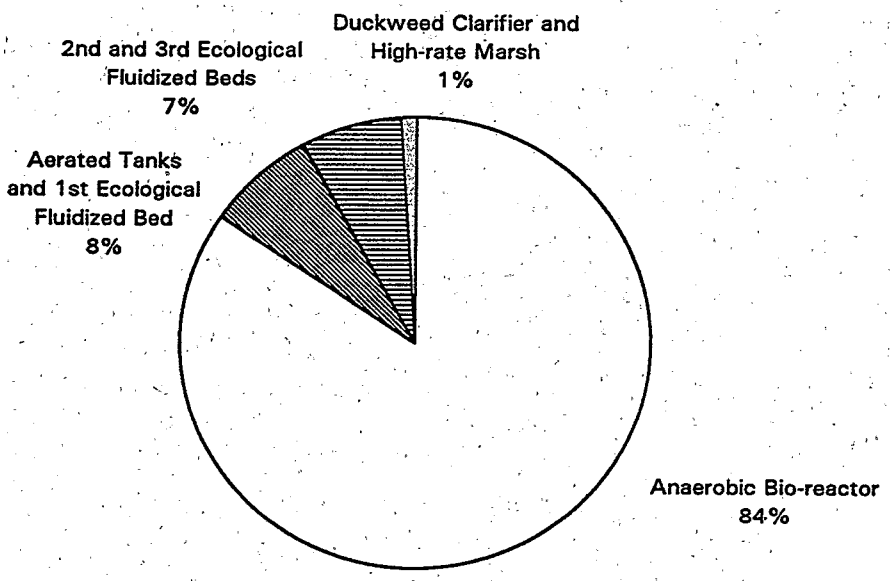


Figure 9-10
Contributions of Process Components
Total Kjeldahl Nitrogen Removal

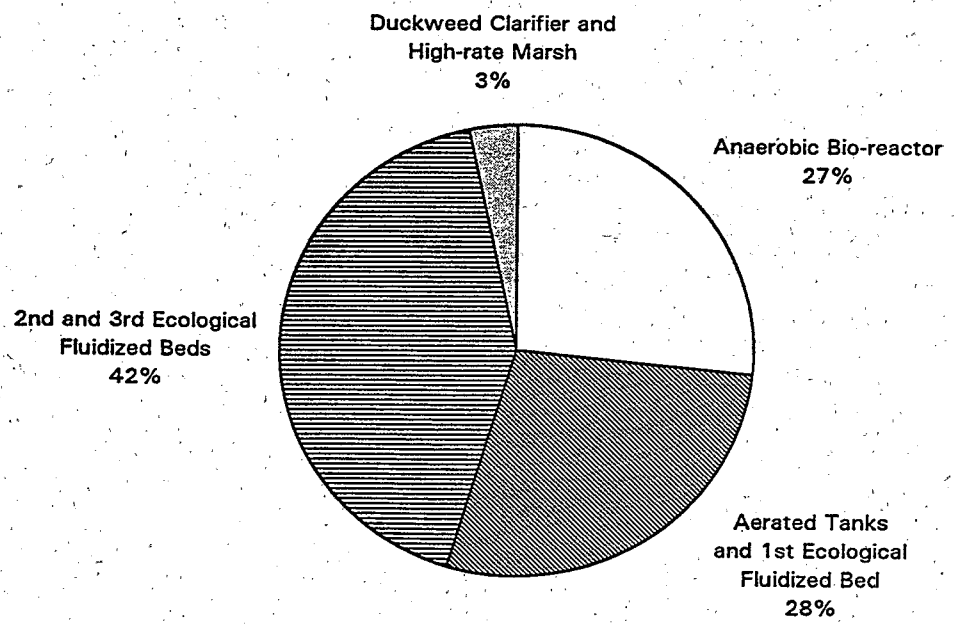


Figure 9-11
Contributions of Process Components
Ammonia Removal

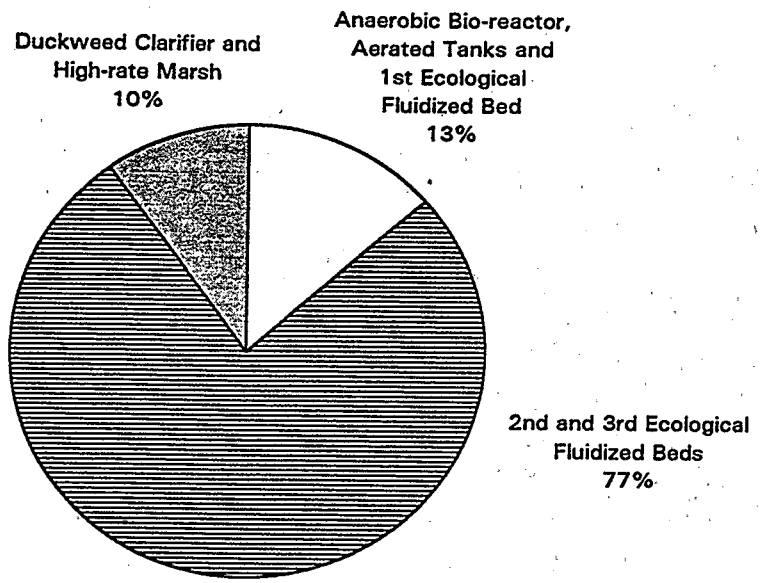
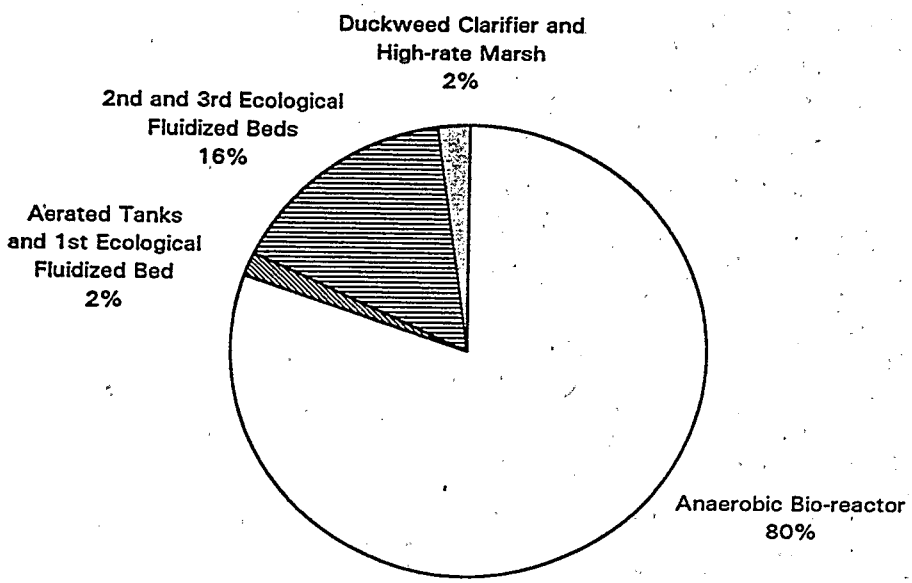


Figure 9-12
Contributions of Process Components
Total Phosphorus Removal



The raw results from the analysis of the sludge are presented in Appendix C. Before these data can be compared with the 503 Regulations for sludge disposal, the concentrations of metal (in mg/l) must be converted to a dry weight basis. The converted data are shown in Table 9.4. Note that this conversion assumes all of the metals are concentrated in the solid fraction of the sludge.

For the sludge samples taken from both sampling locations, there are no concentrations of metals that exceed the limits as described in the 503 Regulations. Therefore, with respect to the current metals regulations, there would be no restrictions on the land application of the sludge generated by the AEES.

However, the fecal coliform count in the sludge from the Anaerobic Bio-reactor would appear to be well in excess of the Land Applicable Minimum Criteria permitted by the 503 Regulations for pathogens. This would preclude the land application of the sludge from this unit unless it had first been treated to reduce the fecal coliform count. The sludge from the clarifier (sample location S2) contains less fecal coliform, although it is still over the limit for exceptional quality (EQ) sludges, meaning that it could only be applied to agricultural land, forests, public contact sites and/or reclamation sites in limited situations by using additional restrictions (e.g., limited site access and crop uses). Its application to sites other than these would be permitted without restriction.

The data from the plant analyses are shown in Table 9.5. These data are compared with the 503 Regulations (for land application of sewage sludge) owing to the absence of other suitable standards for the land application of compostable material. This comparison is made assuming that no metals are lost during composting (e.g., from leaching), and that any compost bulking agents used do not affect the metals content of the product.

The data indicate that the plants contain very low concentrations of the metals controlled by the 503 Regulations and that these concentrations are well below the EQ limit. The general trend appears to be that the plant roots hold more metals than the plant stems which is probably a result of sludge that covers the root systems (i.e., it is the sludge that is the location of most of these metals, not the plants). However, it could also be caused by preferential storage of metals in the roots so further examination of this phenomenon would be required before a definite conclusion could be drawn. Fecal coliform counts on the plants are also less than the pathogen Pollutant Limit and exhibit the trend of being higher for the plants' roots, although the coliform on the composted product would likely be different to that on the plants prior to composting. Therefore, on the basis of the above information, the composted product from these plants could be allowably land applied.

There do not appear to be any major differences between plant type with respect to metals concentration but there was ten times more fecal coliform on the hyacinth root than on the pennywort root. This could be a result of the process since the pennywort sample was taken from the 2nd Aerated Tank whereas the hyacinth was taken from the 1st Aerated Tank. Fecal coliform could, therefore, be reduced between these two tanks. However, once again the difference is more likely to be attributable to sludge accumulation or root storage: the hyacinth roots are significantly larger than those on the pennywort. Consequently, fecal coliform counts would be higher on the hyacinth root.

Table 9.4

SLUDGE DATA SUMMARY

ELEVEN WEEK PERFORMANCE EVALUATION

SAMPLE POINT S1 AND S2 (Anaerobic Bio-reactor and Clarifier After 2nd Aeration Tank)

DATA COMPARISON WITH 503 METALS REGULATIONS

Parameter	Units	503 Regulations		Anaerobic Bio-reactor		Clarifier (after 2nd Aeration Tank)	
		Ceiling Concentration[1] (Land Applicable Minimum Criteria)	Pollutant Concentration[2] (Exceptional Quality Criteria)	High Value (dry weight basis)[3]	Mean Value (dry weight basis)[4]	High Value (dry weight basis)[5]	Mean Value (dry weight basis)[6]
Arsenic	mg/kg	75	41	7.8	6.4	6.5	6.3
Cadmium	mg/kg	85	39	4.7	4.1	3.3	2.6
Chromium	mg/kg	3,000	1,200	45	38	34	23
Copper	mg/kg	4,300	1,500	1,078	953	873	578
Lead	mg/kg	840	300	60	51	38	28
Mercury	mg/kg	57	17	1.8	0.9	1.3	0.9
Molybdenum	mg/kg	75	*suspended*	40	30	25	19
Nickel	mg/kg	420	420	39	38	33	23
Selenium	mg/kg	100	36	3.3	3.3	6.5	6.5
Zinc	mg/kg	7,500	2,800	1,128	1,042	4,817	2,071
Parameter	**Units**	**Class B Sludge[1] (Land Applicable Minimum Criteria)**	**Class A Sludge[2] (Exceptional Quality Criteria)**	**High Value (dry weight basis)[3]**	**Mean Value (dry weight basis)[4]**	**High Value (dry weight basis)[5]**	**Mean Value (dry weight basis)[6]**
Fecal Coliform [7]	cfu/g	2,000,000	1,000	10,000,000	7,700,000	1,400,000	1,350,000

(1) Sewage sludge may not be land applied if the concentration of any parameter exceeds this concentration.

(2) Sewage sludge may land applied with no loading rate restrictions if the concentrations of all parameters are below these concentrations. Application of such sludges would be controlled by annual and cumulative loading limits, or other application restrictions.

(3) This value is calculated by dividing the High metal concentration from Table C.7 by the percent solids from Table C.7 (Appendix C).

(4) This value is calculated by dividing the Mean metal concentration from Table C.7 by the percent solids from Table C.7 (Appendix C).

(5) This value is calculated by dividing the High metal concentration from Table C.8 by the percent solids from Table C.8 (Appendix C).

(6) This value is calculated by dividing the Mean metal concentration from Table C.8 by the percent solids from Table C.8 (Appendix C).

(7) The values for fecal coliform are shown in coliform forming units (cfu) per gram total solids.

Table 9.5

PLANT DATA SUMMARY

HYACINTH, PENNYWORT, AND DUCKWEED/AZOLLA

LABORATORY ANALYSES

Parameter	Units	503 Regulations		Sample Numbers				
		Ceiling Concentration[1] (Land Applicable Minimum Criteria)	Pollutant Concentration[2] (Exceptional Quality Criteria)	P1-0330-1135/ P1-0419-1110	P2-0330-1140/ P2-0419-1115	P3-0330-1150/ P3-0419-1125	P4-0330-1155/ P4-0419-1130	P5-0330-1200/ P5-0419-1215
Plant Type				Hyacinth (leaf & stem)	Hyacinth (root)	Pennywort (leaf & stem)	Pennywort (root)	Duckweed & Azolla
Sample Location				1st Aerated Tank	1st Aerated Tank	2nd Aerated Tank	2nd Aerated Tank	2nd Ecological Fluidized Bed
Total Phosphorus	mg/kg-P	n/a	n/a	973	1,310	614	602	2,350
TKN	mg/kg-N	n/a	n/a	2,090	1,460	1,300	3,350	1,070
Arsenic	mg/kg	75	41	< 2.4	< 2.3	< 2.5	< 2.3	< 2.3
Cadmium	mg/kg	85	39	< 0.25	< 0.22	< 0.24	< 0.25	< 0.25
Chromium	mg/kg	3,000	1,200	2.28	< 1.13	< 1.21	< 1.25	< 1.24
Copper	mg/kg	4,300	1,500	1.22	8.94	0.773	5.62	4.83
Lead	mg/kg	840	300	< 1.25	< 1.13	< 1.21	< 1.25	< 1.24
Mercury	mg/kg	57	17	< 0.10	< 0.10	< 0.09	< 0.10	< 0.10
Molybdenum	mg/kg	75	*suspended*	< 1.2	< 1.2	< 1.2	< 1.2	< 1.2
Nickel	mg/kg	420	420	< 1.25	< 1.13	< 1.21	< 1.25	< 1.24
Selenium	mg/kg	100	36	< 2.4	< 2.3	< 2.5	< 2.3	< 2.3
Zinc	mg/kg	7,500	2,800	5.18	11.1	3.43	10.5	11.3
Parameter	**Units**	**Class B Sludge[1] (Land Applicable Minimum Criteria)**	**Class A Sludge[2] (Exceptional Quality Criteria)**	**P1-0330-1135/ P1-0419-1110**	**P2-0330-1140/ P2-0419-1115**	**P3-0330-1150/ P3-0419-1125**	**P4-0330-1155/ P4-0419-1130**	**P5-0330-1200/ P5-0419-1215**
Fecal Coliform	cfu/g	2,000,000	1,000	4	120	2	12	2

(1) Sewage sludge may not be land applied if the concentration of any parameter exceeds this concentration.

(2) Sewage sludge may land applied with no loading rate restrictions if the concentrations of all parameters are below these concentrations. Application of such sludges would be controlled by annual and cumulative loading limits, or other application restrictions.

9.5 Operations and Maintenance During the Process Evaluation

9.5.1 Chemical/Bacteria Additions

Various bacteria and chemical additions are made to the AEES process stream during the course of normal operations. The purpose of these additions is to maintain the bacterial populations for nitrification and denitrification, and to provide a carbon source and nutrients to the organisms within the system. The quantities of chemicals added to Train B during the eleven week evaluation are shown in Table 9.6.

Table 9.6 Weekly Chemical/Bacteria Additions to Train B

Study Week	Dates	Addition: Bacteria [1]	Carbon Source [2]	Mariah Powder	Kelp Meal
Week 1	2/28/95 to 3/3/95	150 ml	5 lbs	100 lbs [3]	none
Week 2	3/4/95 to 3/10/95	4,250 ml	6 lbs	5 lbs	3 lbs
Week 3	3/11/95 to 3/17/95	2,050 ml	33 lbs	22 lbs	none
n/a	3/18/95 to 3/24/95	300 ml	13 lbs	16 lbs	2 lbs
Week 4	3/25/95 to 3/31/95	300 ml	15 lbs	6 lbs	4 lbs
Week 5	4/1/95 to 4/7/95	350 ml	17 lbs	7 lbs	7 lbs
Week 6	4/8/95 to 4/14/95	2,050 ml	21 lbs	5 lbs	5 lbs
Week 7	4/15/95 to 4/21/95	1,650 ml	13.3 l	5 lbs	5 lbs
Week 8	4/22/95 to 4/28/95	4,250 ml	14.1 l	5 lbs	5 lbs
Week 9	4/29/95 to 5/5/95	2,150 ml	11.2 l	5 lbs	none
Week 10	5/6/95 to 5/12/95	4,050 ml	8.8 l	5 lbs	1 lb
Week 11	5/13/95 to 5/19/95	5,950 ml	10.9 l	5 lbs	5 lbs

(1) Bactapur N and XL were dosed into the system until April 30; the bacteria additions were changed to N-2000, XL and Pond KLEAR on May 1 (during Week 9 of the study).

(2) Until April 14, the carbon source used was sodium acetate; the carbon source was changed to methanol on April 17 (during Week 7 of the study).

(3) The Week 1 addition of Mariah powder was added into the Anaerobic Bio-reactor.

9.5.2 Sludge and Plant Disposal

As part of normal operation of the AEES, quantities of sludge and plant material are removed from the system. Sludge removed is pumped directly back to Ballanger Creek WWTP whereas plant material is composted on site. A log is kept of these activities to record the residuals quantities being produced as a result of the system operation.

Sludge is pumped out of the Anaerobic Bio-reactor, the Ecological Fluidized Beds and the Duckweed Clarifiers. The sludge volumes removed from Train B during the eleven week study are shown in Table 9.7.

Table 9.7 Weekly Sludge Removals

Study Week	Dates	Sludge Removed from: Anaerobic Bio-reactor	Ecological Fluidized Beds(1)	Duckweed Clarifier(2)
Week 1	2/28/95 to 3/3/95	3,600 gallons	none	none
Week 2	3/4/95 to 3/10/95	3,600 gallons	1,400 gallons	none
Week 3	3/11/95 to 3/17/95	3,600 gallons	700 gallons	none
n/a	3/18/95 to 3/24/95	4,200 gallons	1,000 gallons	100 gallons
Week 4	3/25/95 to 3/31/95	6,000 gallons	1,500 gallons	100 gallons
Week 5	4/1/95 to 4/7/95	4,800 gallons	800 gallons	200 gallons
Week 6	4/8/95 to 4/14/95	10,200 gallons	600 gallons	100 gallons
Week 7	4/15/95 to 4/21/95	7,200 gallons	800 gallons	100 gallons
Week 8	4/22/95 to 4/28/95	3,600 gallons	500 gallons	100 gallons
Week 9	4/29/95 to 5/5/95	5,200 gallons	1,000 gallons	100 gallons
Week 10	5/6/95 to 5/12/95	2,400 gallons	700 gallons	none
Week 11	5/13/95 to 5/19/95	2,400 gallons	240 gallons	75 gallons
Total Sludge Removed		56,800 gallons	9,240 gallons	875 gallons

(1) 1st, 2nd and 3rd Ecological Fluidized Beds in Train B only.

(2) Duckweed Clarifier in Train B only.

Plant material is also removed from various parts of the process. This is done in order to stimulate growth among the remaining plants (consequently increasing pollutant uptake), to reduce overcrowding of the tanks, to remove plants that are infected or infested. Plant material is also removed because various plants in the system are grown to be sold to outside customers. The quantities of plant matter removed from Train B during the eleven week study are shown in Table 9.8.

Table 9.8 Weekly Plant Removals from Train B

Study Week	Dates	Total Mass of Plants Removed[1]	Locations from which Plants were Taken
Week 1	2/28/95 to 3/3/95	none	n/a
Week 2	3/4/95 to 3/10/95	93 lbs	1st, 2nd & 3rd Ecological Fluidized Beds, Duckweed Clarifier and High-rate Marsh
Week 3	3/11/95 to 3/17/95	none	n/a
n/a	3/18/95 to 3/24/95	19 lbs	3rd Ecological Fluidized Bed and Duckweed Clarifier
Week 4	3/25/95 to 3/31/95	87 lbs	2nd & 3rd Ecological Fluidized Beds, Duckweed Clarifier and High-rate Marsh
Week 5	4/1/95 to 4/7/95	12 lbs	3rd Ecological Fluidized Bed, Duckweed Clarifier and High-rate Marsh
Week 6	4/8/95 to 4/14/95	none	n/a
Week 7	4/15/95 to 4/21/95	50 lbs	1st, 2nd & 3rd Ecological Fluidized Beds
Week 8	4/22/95 to 4/28/95	7 lbs	High-rate Marsh
Week 9	4/29/95 to 5/5/95	none	n/a
Week 10	5/6/95 to 5/12/95	199 lbs	1st and 2nd Aerated Tanks, 3rd Ecological Fluidized Bed, Duckweed Clarifier and High-rate Marsh
Week 11	5/13/95 to 5/19/95	797 lbs[2]	1st and 2nd Aerated Tanks and High-rate Marsh
Total Plants Removed from Train B		1,264 lbs[2]	

(1) Wet weight.

(2) 795 lbs of this weight was the plants removed from the Aerated Tanks in preparation for the second stage of the study.

9.5.3 Abnormal Operations and Modifications

During the course of the study, events occurred that might have affected the "normal" operating conditions of the AEES. All of these events were recorded by the Parsons ES field team and are presented in Table 9.9.

In situations where these operating abnormalities might have affected the study data, this fact was recognized and spurious data points were noted and removed. For example, on March 7 an operating mishap resulted in 600 gallons of sludge being pumped into the system before sample location W2. This event adversely affected the data for points W2 and W3 during this week of the study (Week 2), so these points were removed during data manipulation (Section 9.2.1).

Table 9.9 Abnormal Operations and Modifications that Occurred During the Study

Date	Event
March 1	Influent flow to the Anaerobic Bio-reactor was off between 0930 and 1030.
March 7	A mishap occurred during sludge removal from the Anaerobic Bio-reactor, resulting in approximately 600 gallons of sludge being pumped into the system after the Anaerobic Bio-reactor (before sample point W2).
March 10	One of the three Air Blowers was repaired (this blower had been inoperative since the start of the study). The repair meant that system aeration would now be increased.
March 10	Approximately 600 gallons of mixed liquor from Ballanger Creek WWTP was added to the 1st Aeration Tank of each train to seed the system.
March 10	Approximately 300 gallons of solids were recycled from the 3rd Ecological Fluidized Bed to the 1st Ecological Fluidized Bed.
March 17	Influent flow to the Anaerobic Bio-reactor was shut off owing to contractors at Ballanger Creek WWTP damaging the inlet line.
March 20	Inlet line was repaired, allowing flows into the AEES to resume (this shutdown resulted in scheduled sampling being suspended for one week).
April 7	A quantity of iron filings were added into the Anaerobic Bio-reactor to induce phosphate precipitation.
April 10	Influent flow to the Anaerobic Bio-reactor was off between 0700 and 1000.
April 11	Influent flow to the Anaerobic Bio-reactor was off between 0400 and 0700.
April 17	Methanol was substituted for sodium acetate as the carbon source for the process.
April 17	A flushing valve to the Anaerobic Bio-reactor was discovered to be malfunctioning. This situation was thought to have existed for up to one month and it had resulted in blockage of one third of the inlets pipes to the Bio-reactor. The valve was subsequently repaired.
April 17	Plants in the Aerated Tanks were cut back.
April 24	Half of the shade cloth was placed on the roof of the greenhouse.
April 26	Influent flow to the Anaerobic Bio-reactor was off between 0830 and 0940.
May 1	The second half of the shade cloth was placed on the roof of the greenhouse.
May 10	At 0800, the 1st Aerated Tank (Train B) overflowed owing to plant matter blocking the outlet pipe. The blockage was later cleared.
May 18	All of the plants (hyacinth and pennywort) were removed from the Train B Aerated Tanks in preparation for the second part of the study.
June 14	Influent flow to the Anaerobic Bio-reactor was off between 1030 and 1200.
June 15	3rd Ecological Fluidized Bed (Train B) was changed to aerobic operation. This filter had been operating anaerobically since the start of the study.
June 17 to 18	Influent flow to the Anaerobic Bio-reactor was off for approximately 24 to 36 hours, owing to clogging of the influent pump at Ballanger STP.
June 17 and 18	Each of the Ecological Fluidized Beds were backflushed for 24 hours each.
June 20	At Parsons ES' request, 3rd Ecological Fluidized Bed (Train B) was changed back to anaerobic operation to maintain process continuity for the study.

Section 10

Hydraulic Detention Times

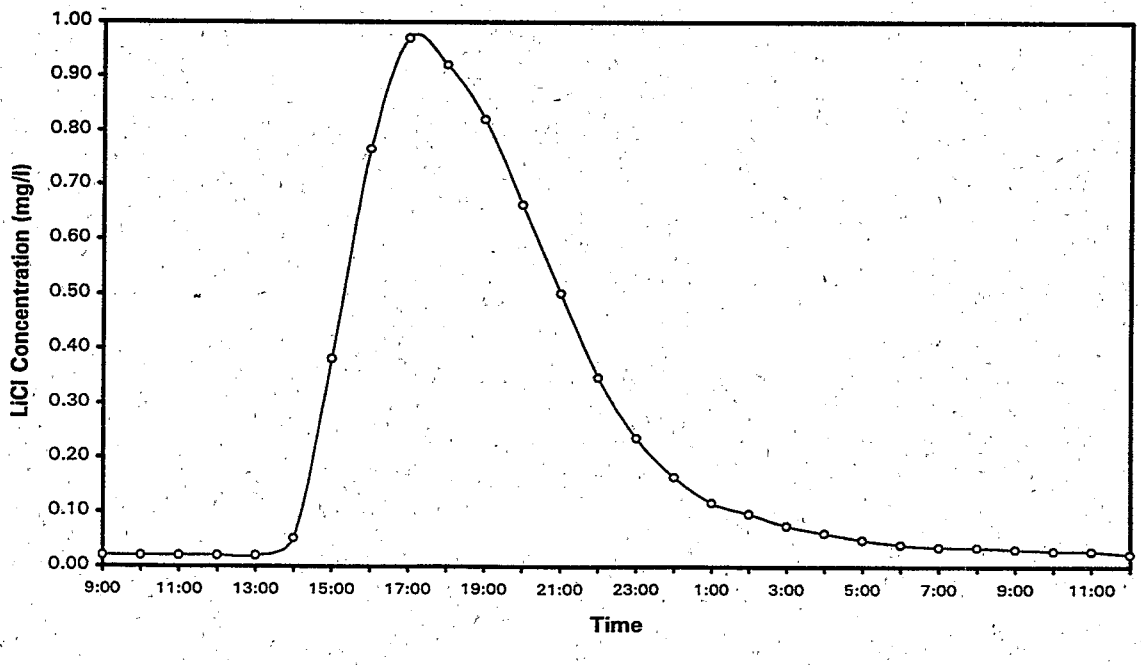
10.1 Introduction

The actual hydraulic detention times of the AEES components were calculated using the data obtained during the tracer study (Section 5). This section summarizes the results of this study and explains how the HDTs were calculated. All of the raw data from the tracer study is presented in Appendix D.

10.2 Tracer Study Results

In most simple flow systems, where there are few branches and no recycling, the concentration of the tracer compound measured at a given point will begin to rise sharply after injection. The compound will then attain a peak concentration that will begin to decrease sharply at first, gradually becoming less severe over time. Plotting the concentration of the tracer compound detected over time will yield a plot such as that shown in Figure 10-1.

Figure 10-1
Tracer Study to Determine HDTs
Location: *Across High-rate Marsh*



The above graph shows the data from the tracer study of the High-rate Marsh at the AEES. Following the completion of the tracer study, data had been obtained that characterized the flows throught the various system components of the "Living Machine".

Using this graphical data, calculations were carried out to establish the actual HDT of each system component. The method used to determine this information is described below.

10.3 Calculation of Hydraulic Detention Times

The actual HDT of the lithium chloride through each system component was calculated in the following manner:

1. The time at which the tracer material was first injected was identified. This established the zero-time benchmark for that sample location.
2. The HDT is defined as the x-axis ("time" axis) coordinate of the centroid of the area under the curve. The "centroid" of the area under the curve is the area's geometric center.
3. The first step of determining this x-axis coordinate is to find the partial area under the curve between two data points and applying the concept of discrete integration.
4. The area beneath the curve between two points is estimated by assuming a straight line between the two points and finding the partial area of the region as though it were a true trapezoid. A small amount of error is introduced here since the actual function defining the concentration over time is, more than likely, not a straight line between any two consecutive points. However, the closer the data points are together, the less error is introduced.
5. After the entire curve is separated into discrete "smaller" areas, the moment arm about the y-axis for each smaller area is computed by finding the distance from the y-axis to the midpoint of the smaller area.
6. The problem is then solved, borrowing from statics, using the following equation:

$$C_y = \Sigma[M \times d(A)] / \Sigma[d(A)]$$

Where:

C_y	=	Centroid of time (x-axis centroid coordinate)
M	=	Moment arm distance of each d(A) from the y-axis
d(A)	=	Partial area under the curve between each two consecutive data points

The difference in hours between the time of lithium chloride injection and the calculated x-axis centroid coordinate is, therefore, the actual HDT of that system component.

Table 10.1 Actual and Theoretical HDTs for the AEES

System Component	Time of Injection (date/time)	Calculated Centroid (date/time)	Actual HDT (hours:mins)	Theoretical HDT [1] (hours:mins)
Anaerobic Bio-reactor	5/9/95 @ 10:30	5/10/95 @ 4:58	18:28	18:30
1st Aerated Tank	5/2/95 @ 9:30	5/2/95 @ 18:57	10:52	8:30
2 Aerated Tanks	4/25/95 @ 10:00	4/26/95 @ 6:57	20:57	17:00
1st Ecological Fluidized Bed	4/24/95 @ 10:00	4/24/95 @ 15:04	6:15	7:00
3 Ecological Fluidized Beds	6/20/95 @ 10:00	6/21/95 @ 10:55	24:55	21:00
Duckweed Clarifier	4/12/95 @ 9:50	4/12/95 @ 22:02	12:12	8:30
High-rate Marsh	4/4/95 @ 9:00	4/4/95 @ 19:24	10:24	9:00
TOTAL HDT [2]			86:56	74:00

(1) Theoretical HDTs were calculated by OAI and are based on a flow of 37,000 gpd into the Anaerobic Bio-reactor, and 13,300 gpd into Train B.

(2) The total HDT is calculated by adding the HDTs of the Anaerobic Bio-reactor, both Aerated Tanks, all three Ecological Fluidized Beds, the Duckweed Clarifier and the High-rate Marsh.

The calculated HDTs for the various individual process components of the AEES are shown in Table 10.1. It is apparent from this data that most of the detention times determined by the tracer study are within 1 to 3 hours of the theoretical times. The exception to this, among the individual units measured, is the Duckweed Clarifier which has an actual HDT of 12 hours and 12 minutes; 3 hours and 42 minutes above the theoretical HDT. With respect to the total system detention time, the estimated HDT of the system is approximately 3½ days whereas the theoretical HDT is closer to 3 days.

Calculations were also performed to estimate the percentage recoveries of lithium chloride in each part of the tracer study. These were done as a test of the tracer study accuracy since, a suitably substantial recovery (approximately 90%) of lithium is typically required to make the test valid. A summary of the lithium percentage recoveries is provided in Table 10.2.

All but two of the calculated recovery percentages was in excess of 100%. The excess was attributed to analytical variability and so it was still considered that the lithium recovery was satisfactory to validate the tracer study results. The study on the three Ecological Fluidized Beds and the single Ecological Fluidized Bed yielded lithium recoveries of 90% and 88%, respectively. These percentages are considered sufficient to validate the calculated HDTs, however, the less-than-total recoveries might suggest that the calculated HDTs should be of slightly longer duration than the tracer study showed.

Table 10.2 Percentage Lithium Recoveries for the Tracer Study

System Component	Percentage Recovery of Lithium [1]
Anaerobic Bio-reactor	>100%
1st Aerated Tank	>100%
2 Aerated Tanks	>100%
1st Ecological Fluidized Bed	88%
3 Ecological Fluidized Beds [2]	90%
Duckweed Clarifier	>100%
High-rate Marsh	>100%

(1) Occurrences where the lithium recovery is in excess of 100% is attributed to analytical variability.

(2) The first time this sampling location was tested, the lithium recovery was only 65%. This was attributed to an instance when sludge was pumped out of the Ecological Fluidized Beds during that part of the tracer study. The tracer study of the three Ecological Fluidized Beds was subsequently repeated and a sufficiently high recovery was attained.

Section 11

Comparison of Study Data with Ocean Arks' Data

11.1 Introduction

In addition to the water quality sampling carried out by Parsons ES during the study period, sampling was also performed by OAI staff at the AEES. The samples collected by OAI were analyzed both at the OAI on-site laboratory and at a local certified laboratory. Potentially, this additional data could be used to increase the size of the data set for the process performance evaluation if it was found to be statistically similar to the Parsons ES study data.

Consequently, parametric statistical testing was performed on all three sets of data to assess their statistical similarity. In addition, a simple visual comparison of the data's summary statistics was also performed. The details of these comparisons are described in this section.

11.2 Comparison of Data Sets

11.2.1 Statistical Comparison of Data

After data manipulation and statistical assessment (Section 9.2.1), parametric testing was carried out on the study data. The data from OAI were not altered in any way before this testing since it was assumed that any necessary data manipulation (such as removal of spurious data or statistical outliers) would have been performed by OAI themselves.

Two-tailed T-tests (which assumed equal variances between the study data) were the parametric tests performed on the data. These tests generated a factor that represented the probability that the two data sets tested had come from populations having the same mean, therefore indicating the statistical similarity of the data. Since not all of the Parsons ES and OAI data were collected on the same date and time, this T-testing assumed that there were no significant variations between these data owing to different sample dates and times. To verify this assumption, as well as T-testing all of the study data, tests were also carried out that only examined the data that were taken on the same days. The results of these T-tests are shown in Tables 11.1 through 11.7.

The two-tailed T-tests performed on the data showed similarities and differences between the various Parsons ES study data, and the data generated at OAI's on-site and certified labs. Assuming that a T factor of 0.5 (50% probability that the data are similar) is reasonable, 11 out of the 30 data sets compared between Parsons ES and the OAI on-site lab were statistically similar. Comparisons between Parsons ES' and the OAI certified lab's data showed that 7 out of 12 of the sets were similar (using the 0.5 T factor). The parameters that display the best similarities between laboratories are TSS, TKN, ammonia and total phosphorus.

Table 11.1 T-test Results for Total Chemical Oxygen Demand

Laboratory	Sample Location	T-test Result	
		All Data	Same Day Data
Parsons ES vs OAI Site Lab	W1	0.211	0.339
Parsons ES vs OAI Site Lab	W2	0.034	n/a
Parsons ES vs OAI Site Lab	W3	0.000	0.012
Parsons ES vs OAI Site Lab	W4	0.256	n/a
Parsons ES vs OAI Site Lab	W6	0.334	0.443
Parsons ES vs OAI Certified Lab	W1	n/a	n/a
Parsons ES vs OAI Certified Lab	W6	n/a	n/a

Table 11.2 T-test Results for Total Suspended Solids

Laboratory	Sample Location	T-test Result	
		All Data	Same Day Data
Parsons ES vs OAI Site Lab	W1	0.502	0.132
Parsons ES vs OAI Site Lab	W2	0.512	n/a
Parsons ES vs OAI Site Lab	W3	0.459	0.857
Parsons ES vs OAI Site Lab	W4	0.645	n/a
Parsons ES vs OAI Site Lab	W6	0.134	0.470
Parsons ES vs OAI Certified Lab	W1	0.192	n/a
Parsons ES vs OAI Certified Lab	W6	0.059	n/a

Table 11.3 T-test Results for Volatile Suspended Solids

Laboratory	Sample Location	T-test Result	
		All Data	Same Day Data
Parsons ES vs OAI Site Lab	W1	0.265	0.090
Parsons ES vs OAI Site Lab	W2	0.543	n/a
Parsons ES vs OAI Site Lab	W3	0.338	0.494
Parsons ES vs OAI Site Lab	W4	0.559	n/a
Parsons ES vs OAI Site Lab	W6	0.251	0.871
Parsons ES vs OAI Certified Lab	W1	0.140	n/a
Parsons ES vs OAI Certified Lab	W6	0.000	n/a

Table 11.4 T-test Results for Total Kjeldahl Nitrogen

Laboratory	Sample Location	T-test Result	
		All Data	Same Day Data
Parsons ES vs OAI Site Lab	W1	n/a	n/a
Parsons ES vs OAI Site Lab	W2	n/a	n/a
Parsons ES vs OAI Site Lab	W3	n/a	n/a
Parsons ES vs OAI Site Lab	W4	n/a	n/a
Parsons ES vs OAI Site Lab	W6	n/a	n/a
Parsons ES vs OAI Certified Lab	W1	0.615	n/a
Parsons ES vs OAI Certified Lab	W6	0.857	n/a

Table 11.5 T-test Results for Ammonia

Laboratory	Sample Location	T-test Result	
		All Data	Same Day Data
Parsons ES vs OAI Site Lab	W1	0.627	0.567
Parsons ES vs OAI Site Lab	W2	0.506	n/a
Parsons ES vs OAI Site Lab	W3	0.159	0.131
Parsons ES vs OAI Site Lab	W4	0.482	n/a
Parsons ES vs OAI Site Lab	W6	0.126	0.906
Parsons ES vs OAI Certified Lab	W1	0.708	n/a
Parsons ES vs OAI Certified Lab	W6	0.857	n/a

Table 11.6 T-test Results for Nitrate

Laboratory	Sample Location	T-test Result	
		All Data	Same Day Data
Parsons ES vs OAI Site Lab	W1	0.042	0.038
Parsons ES vs OAI Site Lab	W2	0.000	n/a
Parsons ES vs OAI Site Lab	W3	0.064	0.189
Parsons ES vs OAI Site Lab	W4	0.144	n/a
Parsons ES vs OAI Site Lab	W6	0.277	0.820
Parsons ES vs OAI Certified Lab	W1	0.016	n/a
Parsons ES vs OAI Certified Lab	W6	0.916	n/a

Table 11.7 T-test Results for Total Phosphorus

Laboratory	Sample Location	T-test Result All Data	T-test Result Same Day Data
Parsons ES vs OAI Site Lab	W1	0.429	0.165
Parsons ES vs OAI Site Lab	W2	0.699	n/a
Parsons ES vs OAI Site Lab	W3	0.726	0.589
Parsons ES vs OAI Site Lab	W4	0.840	n/a
Parsons ES vs OAI Site Lab	W6	0.735	0.596
Parsons ES vs OAI Certified Lab	W1	0.831	n/a
Parsons ES vs OAI Certified Lab	W6	0.617	n/a

For the data taken on the same days, the probability of similarity increased in 10 out of 18 cases (and decreased in the remaining 8 cases). Only in 4 of the 10 cases where there was an increase in the probability did the T factor change to suggest that the data were similar. The parameters showing the best similarities in this case were ammonia and total phosphorus.

Therefore, although the testing indicated some similarity between the data, it was inconclusive with respect to showing total statistical similarity or dissimilarity between the laboratories and sampling methods used in this study.

11.2.2 Simple Comparison of Data

Following the inconclusive results of the statistical comparison of the data, a less complex method was chosen to perform a general comparison of the study data. Descriptive statistics (mean, median, standard deviation, and variance) were generated for the individual data sets and a "visual" comparison of these parameters was performed. This method involved looking at the descriptive statistics and making an informed judgment on their similarity based upon knowledge of reasonable laboratory error and sample variability. Although subjective, this comparison was thought to be appropriate for identifying whether the data sets were really as dissimilar as the T-testing had suggested. The descriptive statistics for the Parsons ES and the OAI data are shown in Tables 11.8 through 11.14.

This comparison of the study data revealed that, despite the results of the T-tests, the Parsons ES data and the OAI data were actually quite similar. For example, T-tests of the total COD data for sample location W1 did not indicate similarity between the data sets (T factor of 0.211) but the descriptive statistics did show some similarity (10% difference between means, 2% difference between standard deviations). Comparable cases can also be observed for a number of other parameters at various sample locations.

Based on these comparisons, it is considered that the Parsons ES data and the OAI data are not as different as the T-testing implied. This is not surprising since analytical and sample variability will inevitably lead to discrepancies between data which may be interpreted by the T-tests to be a result of greater differences than they actually are.

Table 11.8 Descriptive Statistics for Total Chemical Oxygen Demand

Laboratory	Sample Location	Descriptive Statistics				
		Mean	Median	Standard Deviation	Variance	Count
Parsons ES	W1	1,307	1,290	243	59,147	11
OA Site Lab	W1	1,193	1,109	240	57,337	21
Parsons ES	W2	445	429	76.1	5,796	10
OA Site Lab	W2	377	368	80.9	6,552	21
Parsons ES	W3	399	415	81.4	6,632	10
OA Site Lab	W3	292	275	58.5	3,424	18
Parsons ES	W4	73.4	60.8	39.1	1,530	10
OA Site Lab	W4	59.8	53.0	25.9	673	21
Parsons ES	W6	53.2	58.4	33.0	1,089	11
OA Site Lab	W6	42.3	35.0	26.8	721	19

Table 11.9 Descriptive Statistics for Total Suspended Solids

Laboratory	Sample Location	Descriptive Statistics				
		Mean	Median	Standard Deviation	Variance	Count
Parsons ES	W1	470	493	136	18,602	10
OA Site Lab	W1	536	530	150	22,490	21
OA Certified Lab	W1	564	535	175	30,475	11
Parsons ES	W2	78.0	82.1	22.6	513	10
OA Site Lab	W2	84.0	85.0	25.1	628	20
Parsons ES	W3	148	152	36.2	1,313	10
OA Site Lab	W3	143	142	33.9	1,150	18
Parsons ES	W4	9.9	9.6	6.3	40	10
OA Site Lab	W4	11.4	10.0	7.0	50	21
Parsons ES	W6	3.5	2.0	2.4	6	9
OA Site Lab	W6	2.2	1.7	1.4	2	18
OA Certified Lab	W6	1.8	1.5	1.2	2	11

Table 11.10 Descriptive Statistics for Volatile Suspended Solids

Laboratory	Sample Location	Descriptive Statistics				
		Mean	Median	Standard Deviation	Variance	Count
Parsons ES	W1	364	362	96.4	9,284	10
OA Site Lab	W1	410	410	108	11,555	21
OA Certified Lab	W1	442	425	131	17,041	11
Parsons ES	W2	64.0	60.7	20.7	426	10
OA Site Lab	W2	69.0	71.5	20.9	436	20
Parsons ES	W3	122	121	30.8	948	10
OA Site Lab	W3	112	106	25.6	657	19
Parsons ES	W4	6.3	5.0	5.5	30	10
OA Site Lab	W4	7.3	7.2	4.0	16	23
Parsons ES	W6	2.3	2.0	0.5	0	9
OA Site Lab	W6	1.8	1.3	1.3	2	17
OA Certified Lab	W6	1.2	1.0	0.5	0	11

Table 11.11 Descriptive Statistics for Total Kjeldahl Nitrogen

Laboratory	Sample Location	Descriptive Statistics				
		Mean	Median	Standard Deviation	Variance	Count
Parsons ES	W1	55.9	58.4	7.1	50.3	11
OA Certified Lab	W1	54.2	54.2	8.8	77.9	11
Parsons ES	W6	8.4	5.0	7.0	48.6	11
OA Certified Lab	W6	7.9	5.4	6.7	44.4	10

Table 11.12 Descriptive Statistics for Ammonia

Laboratory	Sample Location	Descriptive Statistics				
		Mean	Median	Standard Deviation	Variance	Count
Parsons ES	W1	25.6	25.1	4.2	17	11
OA Site Lab	W1	26.3	25.9	3.1	10	20
OA Certified Lab	W1	26.2	24.9	2.8	8	11
Parsons ES	W2	33.8	33.8	5.9	35	10
OA Site Lab	W2	35.1	35.0	4.8	23	21
Parsons ES	W3	28.0	28.1	4.6	21	10
OA Site Lab	W3	30.2	30.3	3.8	14	20
Parsons ES	W4	7.5	4.4	6.6	44	11
OA Site Lab	W4	5.9	4.1	5.9	34	21
Parsons ES	W6	5.5	2.6	6.3	39	11
OA Site Lab	W6	2.5	0.4	4.0	16	18
OA Certified Lab	W6	6.0	3.3	6.1	37	10

Table 11.13 Descriptive Statistics for Nitrate

Laboratory	Sample Location	Descriptive Statistics				
		Mean	Median	Standard Deviation	Variance	Count
Parsons ES	W1	0.2	0.1	0.1	0	11
OA Site Lab	W1	1.3	0.8	1.8	3	21
OA Certified Lab	W1	0.1	0.1	0.1	0	11
Parsons ES	W2	0.1	0.1	0.1	0	10
OA Site Lab	W2	1.3	1.1	0.5	0	21
Parsons ES	W3	0.4	0.3	0.2	0	9
OA Site Lab	W3	0.7	0.7	0.4	0	20
Parsons ES	W4	10.5	9.0	6.9	47	11
OA Site Lab	W4	14.1	12.0	6.5	42	23
Parsons ES	W6	5.4	5.7	5.2	27	10
OA Site Lab	W6	8.0	7.3	6.4	41	20
OA Certified Lab	W6	5.2	5.3	5.1	26	11

Table 11.14 Descriptive Statistics for Total Phosphorus

Laboratory	Sample Location	Descriptive Statistics				
		Mean	Median	Standard Deviation	Variance	Count
Parsons ES	W1	13.6	13.4	2.2	5	10
OA Site Lab	W1	12.9	12.4	2.2	5	21
OA Certified Lab	W1	13.8	13.8	2.7	7	11
Parsons ES	W2	8.2	8.4	1.5	2	10
OA Site Lab	W2	8.0	8.0	0.9	1	21
Parsons ES	W3	8.5	8.2	1.2	1	9
OA Site Lab	W3	8.4	8.2	1.0	1	20
Parsons ES	W4	7.0	7.1	0.8	1	10
OA Site Lab	W4	6.9	6.8	0.8	1	23
Parsons ES	W6	6.8	6.9	0.8	1	11
OA Site Lab	W6	6.7	6.6	0.8	1	20
OA Certified Lab	W6	7.0	6.6	1.0	1	11

Section 12

Investigation of the System Without Plants

12.1 Introduction

At the request of USEPA, an additional investigation was performed on the AEES to determine the extent to which the plants in the Aerated Tanks affected the process performance of the system. This study was carried out over a three week period before which all of the plants (water hyacinths and pennywort) were removed from the Train B Aerated Tanks. As with the main process performance study, composite and grab wastewater samples were collected from the system during the study period. Information concerning the methods and results of this investigation is presented below. The raw data for this section is presented in Appendix E.

12.2 Wastewater Sampling

12.2.1 Sampling Locations

The wastewater sampling locations used for this part of the study were the same as those used in the eleven week study. The locations of these sample points may be found in Table 4.1 and Figure 4-1.

12.2.2 Sampling Methods

As in the previous stage of the study, time-proportioned, composite 24-hour wastewater samples were collected for the study duration using ISCO automatic samplers. The samplers were located at the sampling locations identical to those described in Section 4.2.1. One sample was collected from each location every week for the three week duration of the study. The same sampling, cleaning, and maintenance protocols were followed as was used for the eleven week process performance evaluation (Section 4.3.1).

The wastewater grab samples collected for field analysis were also collected in an identical manner to those gathered for the process performance study (Section 4.3.2).

12.3 Analytical Procedures and QA/QC

Identical field and laboratory analyses were performed on the samples collected during this part of the study as were carried out during the process performance evaluation (Section 6). The QA/QC procedures and requirements were also identical to those previously used (Section 7).

12.4 Process Performance Without Plants

This part of the study yielded three weeks of water quality data by which the performance of the AEES without plants could be assessed. Sample collection and laboratory analysis went ahead without incident for this part of the study so data

manipulation was not required. Additionally, detailed statistical analyses of these data were not performed owing to the small sample size; it was considered inappropriate to identify outliers from a sample size of three samples. Simple summary statistics were calculated, however. The mean water quality data for the three week evaluation of the process without plants are presented in Table 12.1.

As before, treatment efficiencies were calculated for the overall process as well as for the individual process components of the AEES Facility. This was done using the equations detailed in Section 9.3. The calculated efficiencies are summarized in Table 12.2.

12.5 Comparison to Process Performance With Plants

The data generated during the three week process evaluation (without plants) were then compared with that from the eleven week evaluation (with plants). Owing to the small sample size from the three week study, statistical comparison of the two data sets was considered to be inappropriate as it would not yield conclusive results. Therefore, the comparison was limited to using graphs to visually contrast the data.

Figures 12-1 through 12-12 show how the various water quality parameters are reduced throughout the AEES, with and without plants in the Aerated Tanks. The standard deviations of the data are also displayed on the graphs to show the variability of the data sets and to provide an indication of the true extent to which the the data points are "different".

For the parameters COD (total and soluble), BOD (total and soluble), TSS, VSS, and phosphorus (Figures 12-1 to 12-6, and 12-10), there does not appear to be a significant difference between the process with and without plants in the Aerated Tanks. Neither is a significant difference apparent between the parameters for pH and DO (Figures 12-11 and 12-12).

However, there do seem to be some differences between the graphs for TKN, ammonia, and nitrate (Figures 12-7 through 12-9). Both TKN and ammonia in the system effluent are lower, and nitrate is higher, when the system is operating with plants in the Aerated Tanks. This suggests that nitrification may be more effective when the plants are present in the system. The lower nitrate levels in the effluent from the system without plants would seem to be a result of the reduced nitrification upstream, rather than improved denitrification in the latter part of the process system.

However, these differences could be regarded as slight when the closeness and/or overlap of the standard deviations are taken into account. Additionally, the differences for these parameters are most marked downstream of the 1st Ecological Fluidized Bed whereas the plants were removed upstream of that process component.

None of this is to say that there is no difference at all between the performance of the AEES with and without plants. Additional water quality data would be required in order to observe more subtle differences between the two modes of operation. What this part of the study appears to have demonstrated is that no *major* differences are apparent when the process is operating without plants in the Aerated Tanks.

Table 12.1

WATER QUALITY SUMMARY FOR AEES FACILITY

TREATMENT FACILITY WITHOUT PLANTS

	Parameter	Units	Mean Water Quality Data					
			Raw Sewage Influent	Anaerobic Bio-reactor Effluent	Aerated Tank Effluent	1st Ecological Fluidized Bed Effluent	3rd Ecological Fluidized Bed Effluent	High-rate Marsh Effluent
			W1	W2	W3	W5	W4	W6
Composite Samples	Total COD	mg/l	1,203.3	470.3	438.3	149.7	53.2	26.6
	Soluble COD	mg/l	191.7	190.0	62.2	57.8	39.6	25.8
	Total BOD_6	mg/l	316.7	156.7	98.0	37.7	15.6	4.8
	Soluble BOD_6	mg/l	94.0	89.0	9.2	7.1	9.8	4.0
	Total Suspended Solids	mg/l	597.0	105.7	142.0	37.1	6.6	2.9
	Volatile Suspended Solids	mg/l	443.3	69.7	103.4	27.4	4.6	2.0
	Total Kjeldahl Nitrogen	mg/l	51.0	37.4	38.7	27.9	19.3	15.6
	Ammonia	mg/l-N	25.9	30.3	25.5	27.3	16.4	14.3
	Nitrate	mg/l-N	0.12	0.10	0.16	0.78	2.95	0.70
	Total Phosphorus	mg/l-P	13.8	10.1	7.6	6.8	7.6	7.3
Grab Samples	Fecal Coliform	cfu/100ml	19,333,333					637
	Field pH		7.82	7.13	7.66	7.51	7.40	7.32
	Field Dissolved Oxygen	mg/l	2.3	3.1	6.3	5.0	3.8	2.9
	Sample Temperature	°C	21.0	21.3	21.8	21.9	22.5	22.7

Table 12.2

POLLUTANT TREATMENT EFFICIENCIES FOR AEES FACILITY

TREATMENT FACILITY WITHOUT PLANTS

Parameter	Percentage Pollutant Removal (1)					
	Overall Pollutant Removal	Anaerobic Bio-reactor	Aerated Tanks	1st Ecological Fluidized Bed	Ecological Fluidized Beds (2)	Duckweed Clarifier & High-rate Marsh
Total COD	98%	61%	7%	66%	88%	50%
Soluble COD	87%	1%	67%	7%	36%	35%
Total BOD_5	98%	51%	37%	62%	84%	69%
Soluble BOD_5	96%	5%	90%	23%	-7%	59%
TSS	99.5%	82%	-34%	74%	95%	56%
VSS	99.5%	84%	-48%	74%	96%	57%
TKN	69%	27%	-3%	28%	50%	19%
Ammonia	45%	-17%	16%	-7%	36%	13%
Nitrate (3)	76%	14%	-63%	-378%	-1708%	76%
Total Phosphorus	47%	27%	25%	10%	-1%	4%
Fecal Coliform	99.997%					

(1) A negative percent removal indicates an increase of the component through the system.

(2) Percentage removals shown are for all three Pumice Stone Filters.

(3) Overall pollutant removal shown for nitrate is taken between the Final Pumice Stone Filter and the Treatment Plant Effluent.

Figure 12-1
Comparison of System Treatment With and Without Plants
Parameter: *Total Chemical Oxygen Demand*

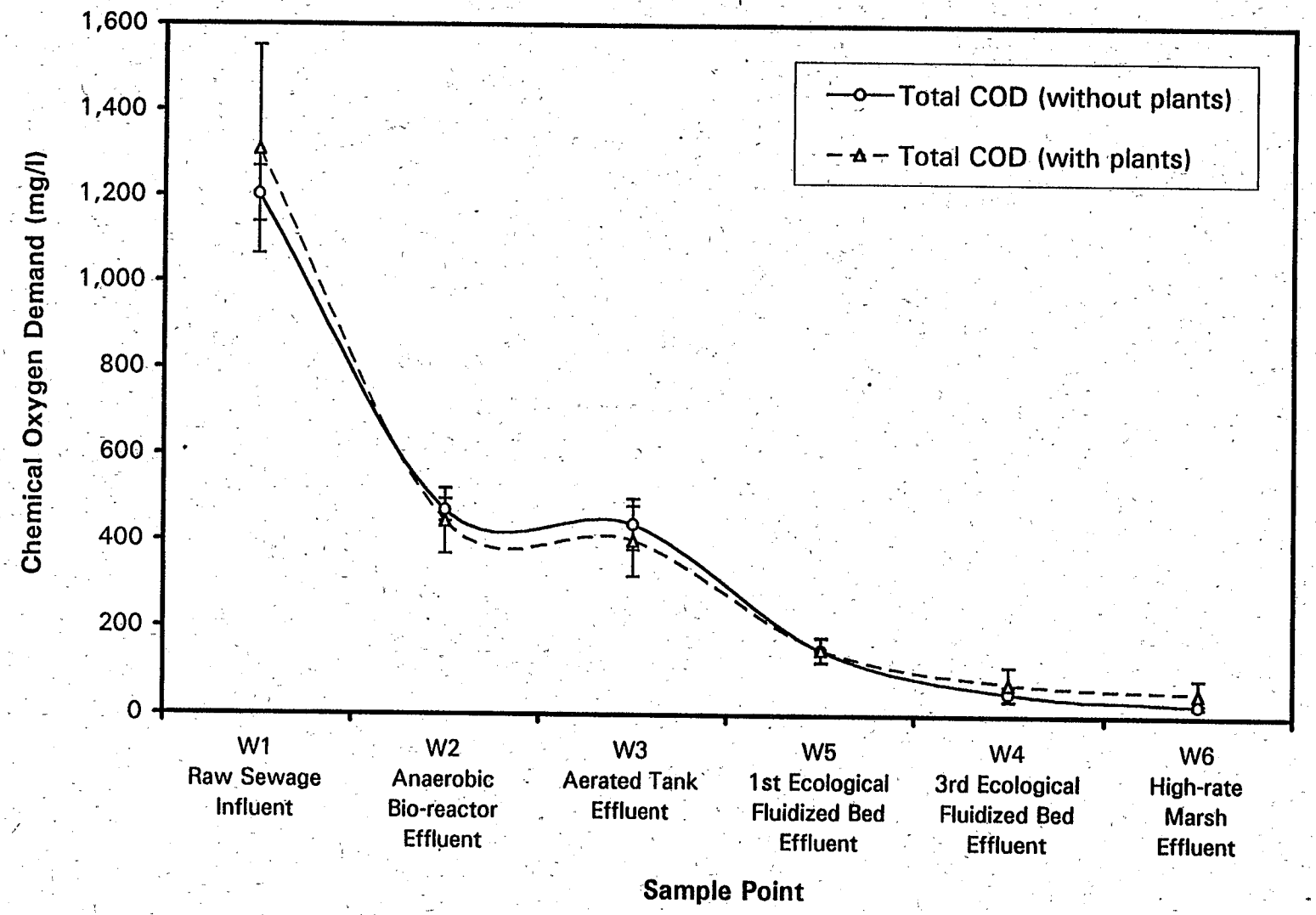


Figure 12-2
Comparison of System Treatment With and Without Plants
Parameter: *Soluble Chemical Oxygen Demand*

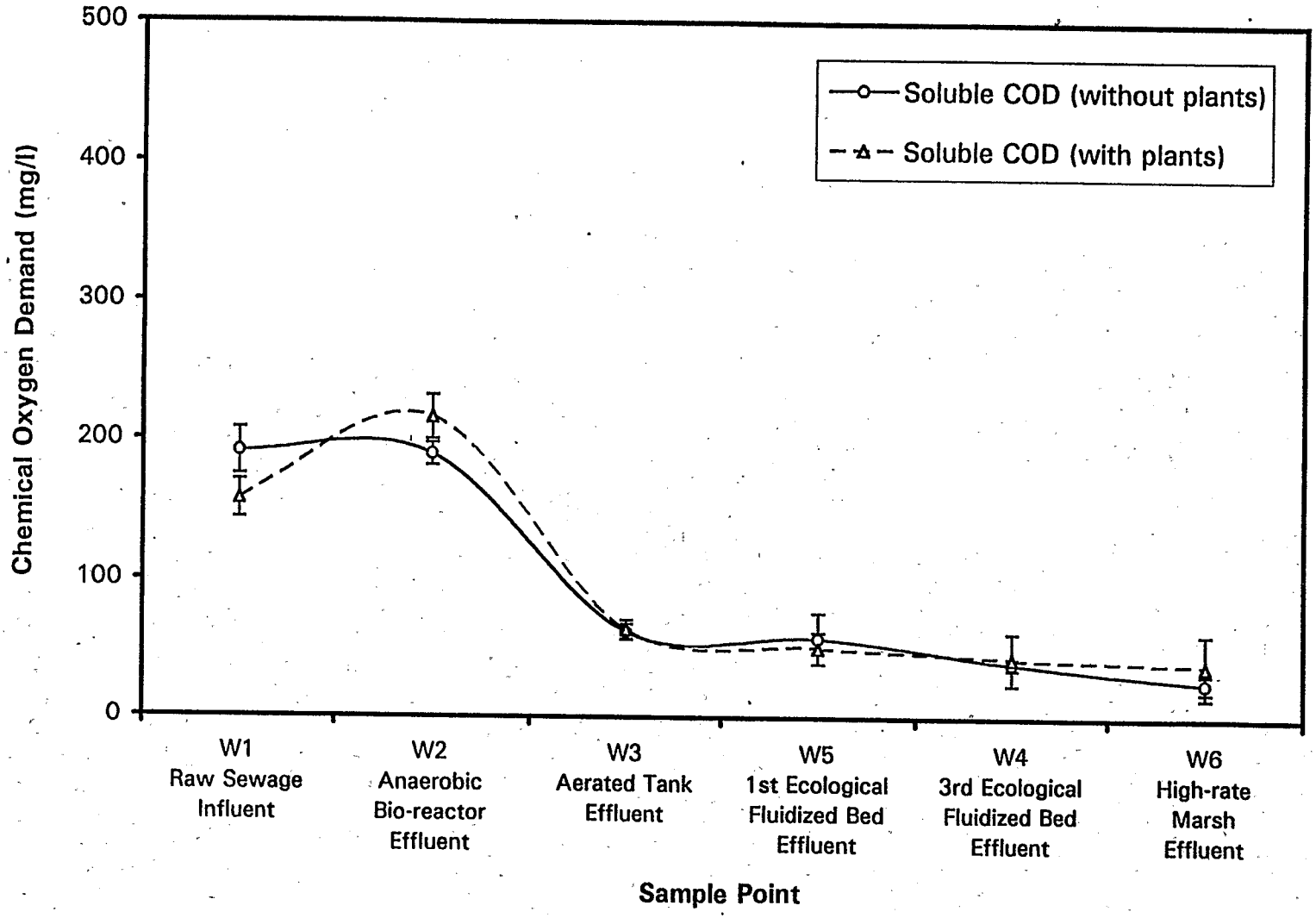


Figure 12-3
Comparison of System Treatment With and Without Plants
Parameter: *Total Biochemical Oxygen Demand*

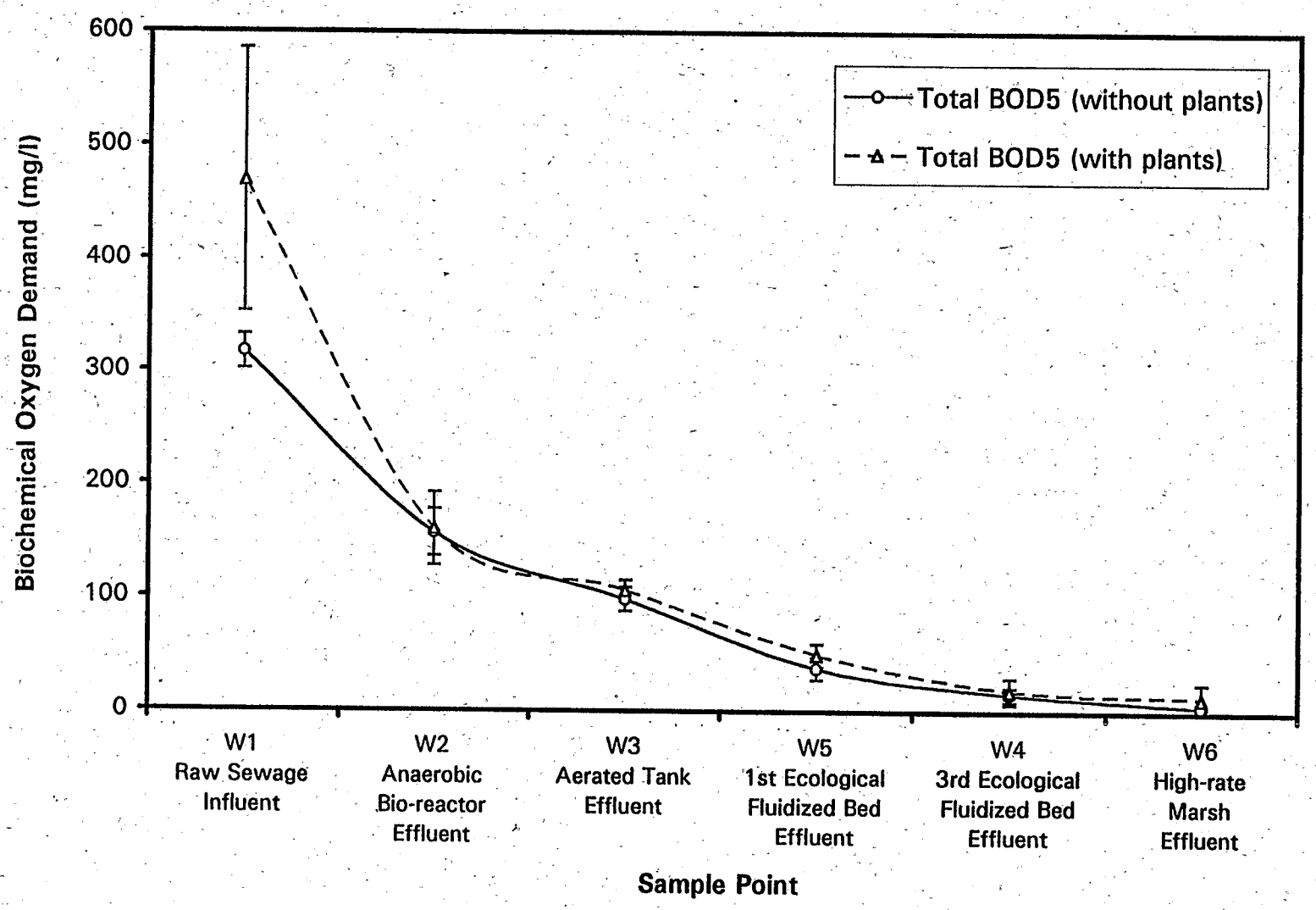


Figure 12-4
Comparison of System Treatment With and Without Plants
Parameter: *Soluble Biochemical Oxygen Demand*

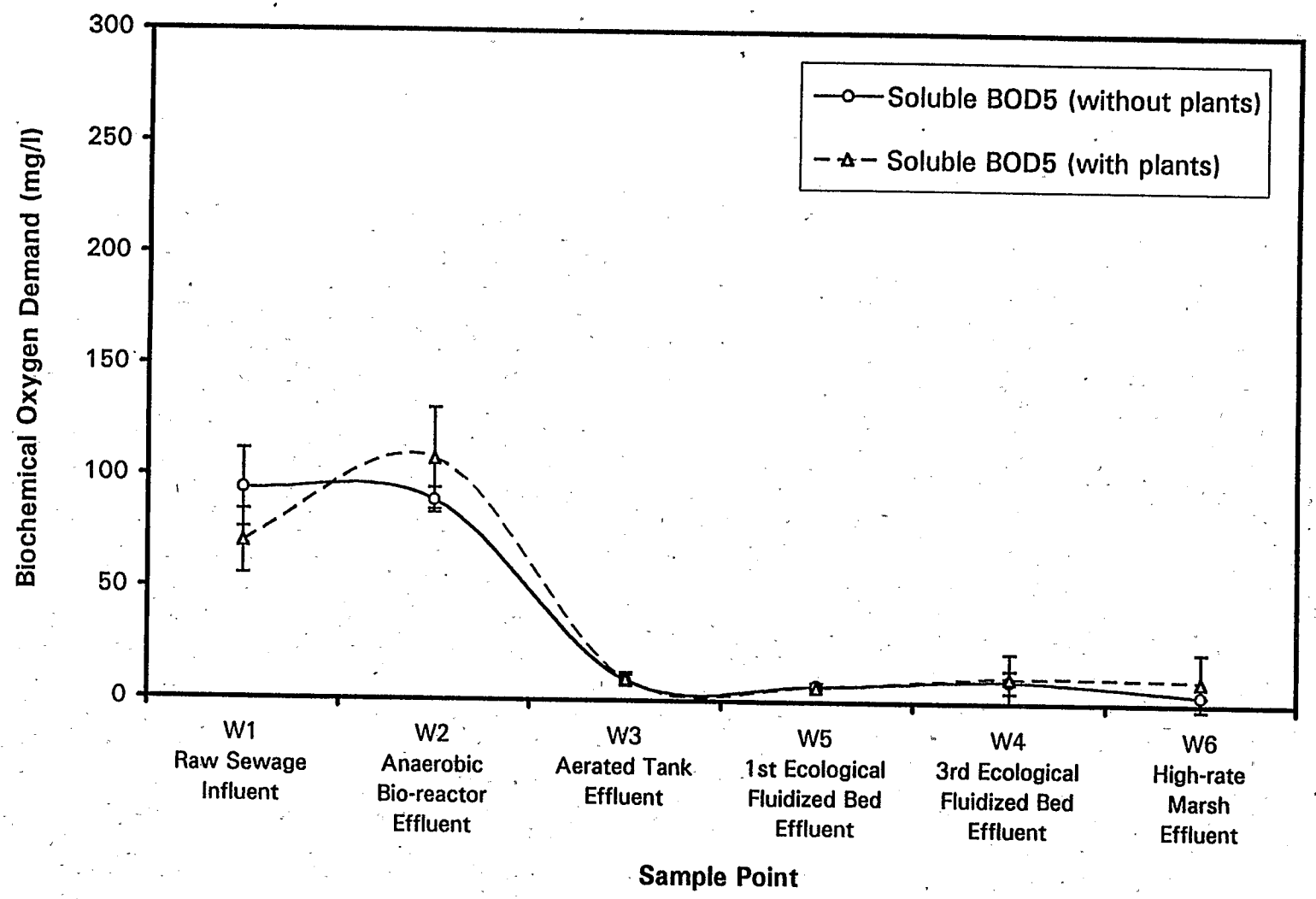


Figure 12-5
Comparison of System Treatment With and Without Plants
Parameter: *Total Suspended Solids*

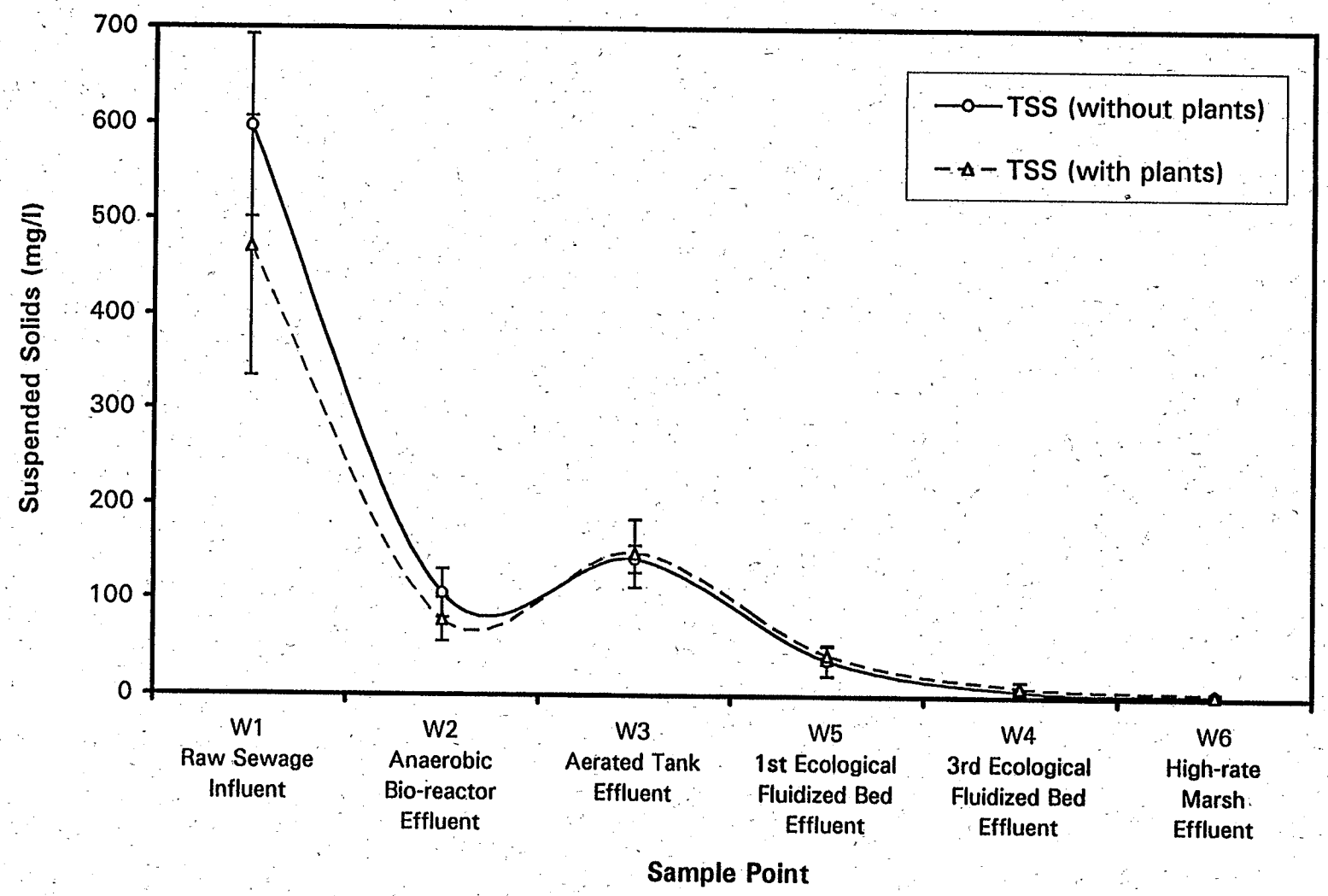


Figure 12-6
Comparison of System Treatment With and Without Plants
Parameter: *Volatile Suspended Solids*

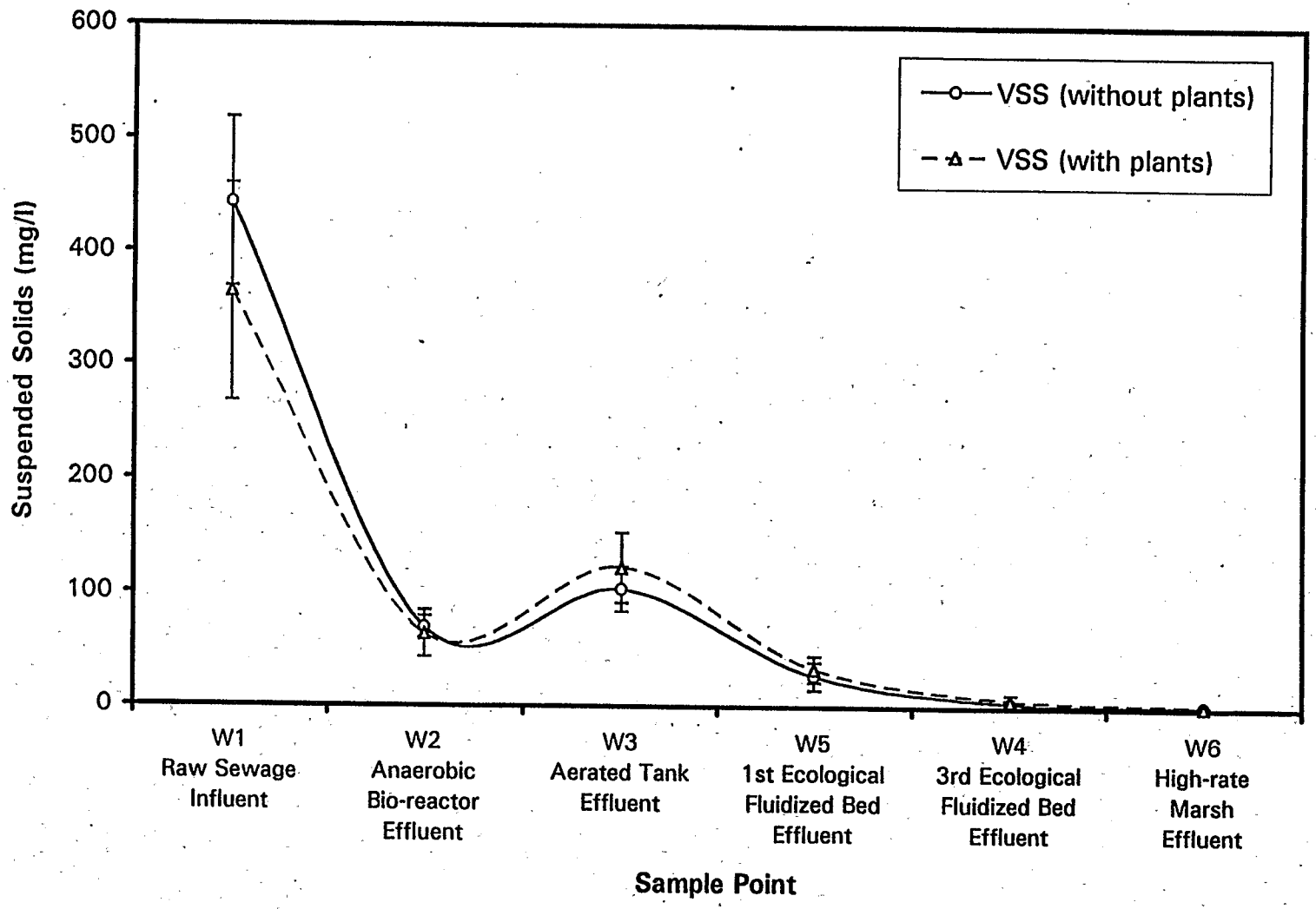


Figure 12-7
Comparison of System Treatment With and Without Plants
Parameter: *Total Kjeldahl Nitrogen (TKN)*

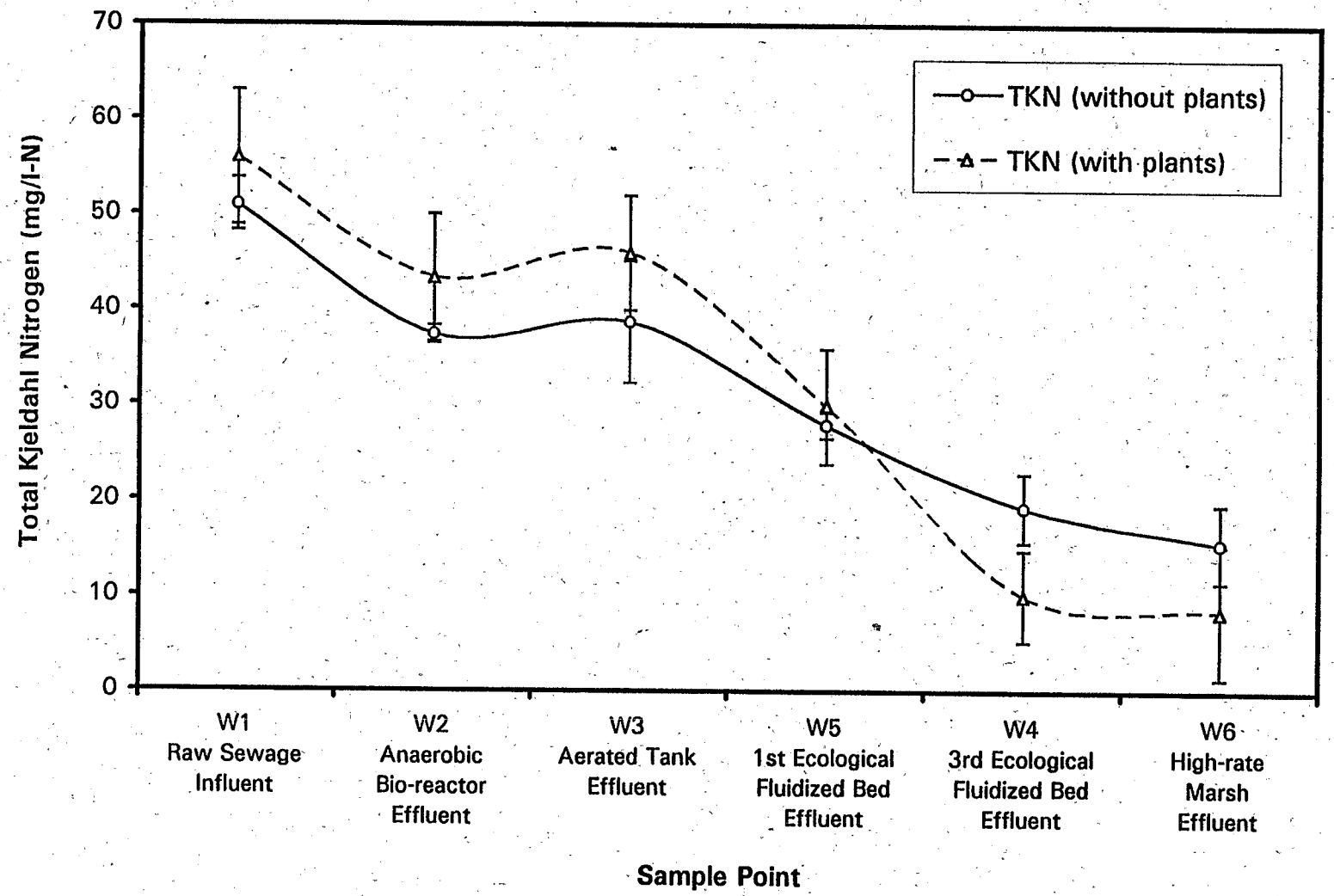


Figure 12-8
Comparison of System Treatment With and Without Plants
Parameter: *Ammonia*

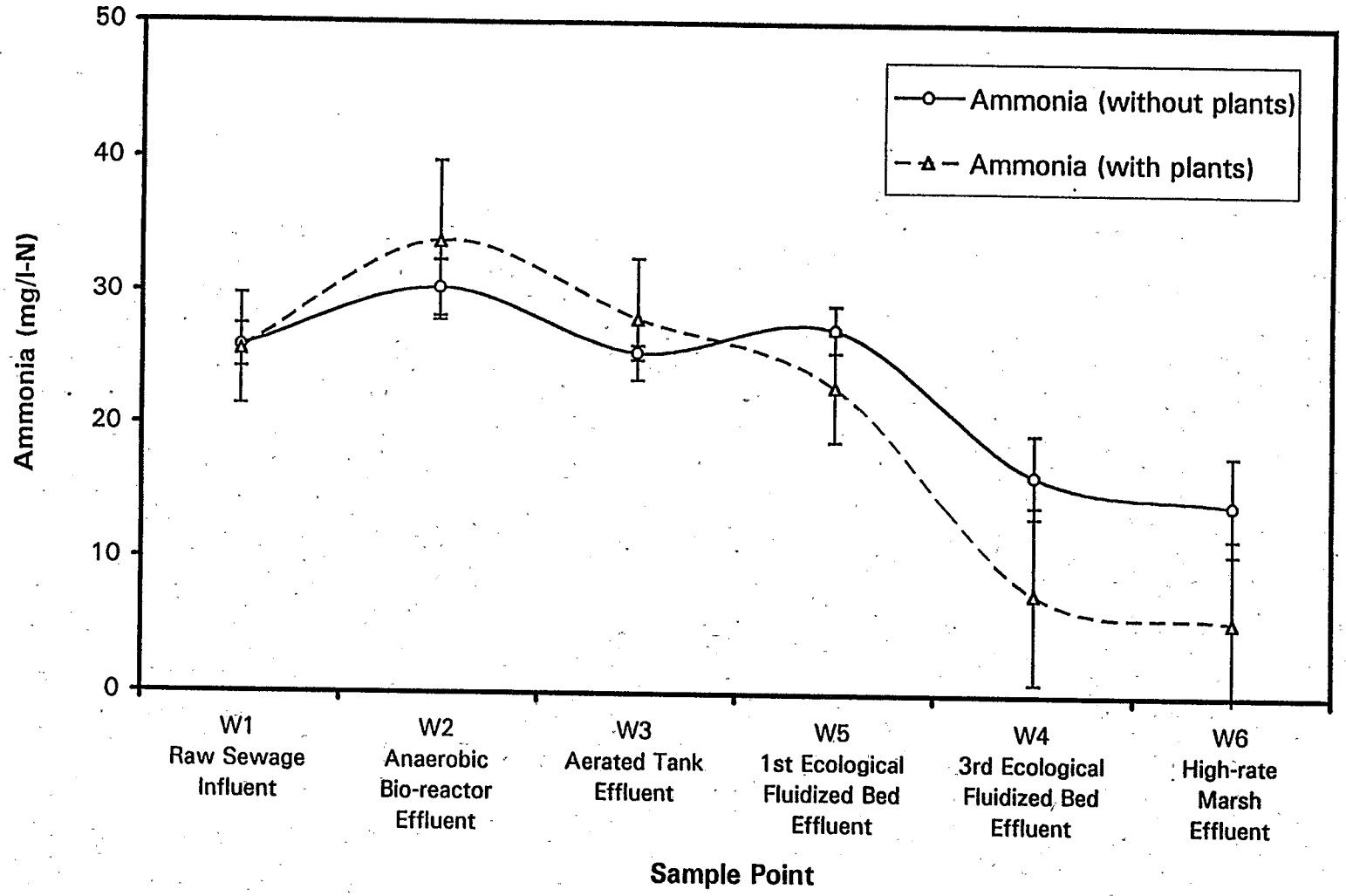


Figure 12-9
Comparison of System Treatment With and Without Plants
Parameter: *Nitrate*

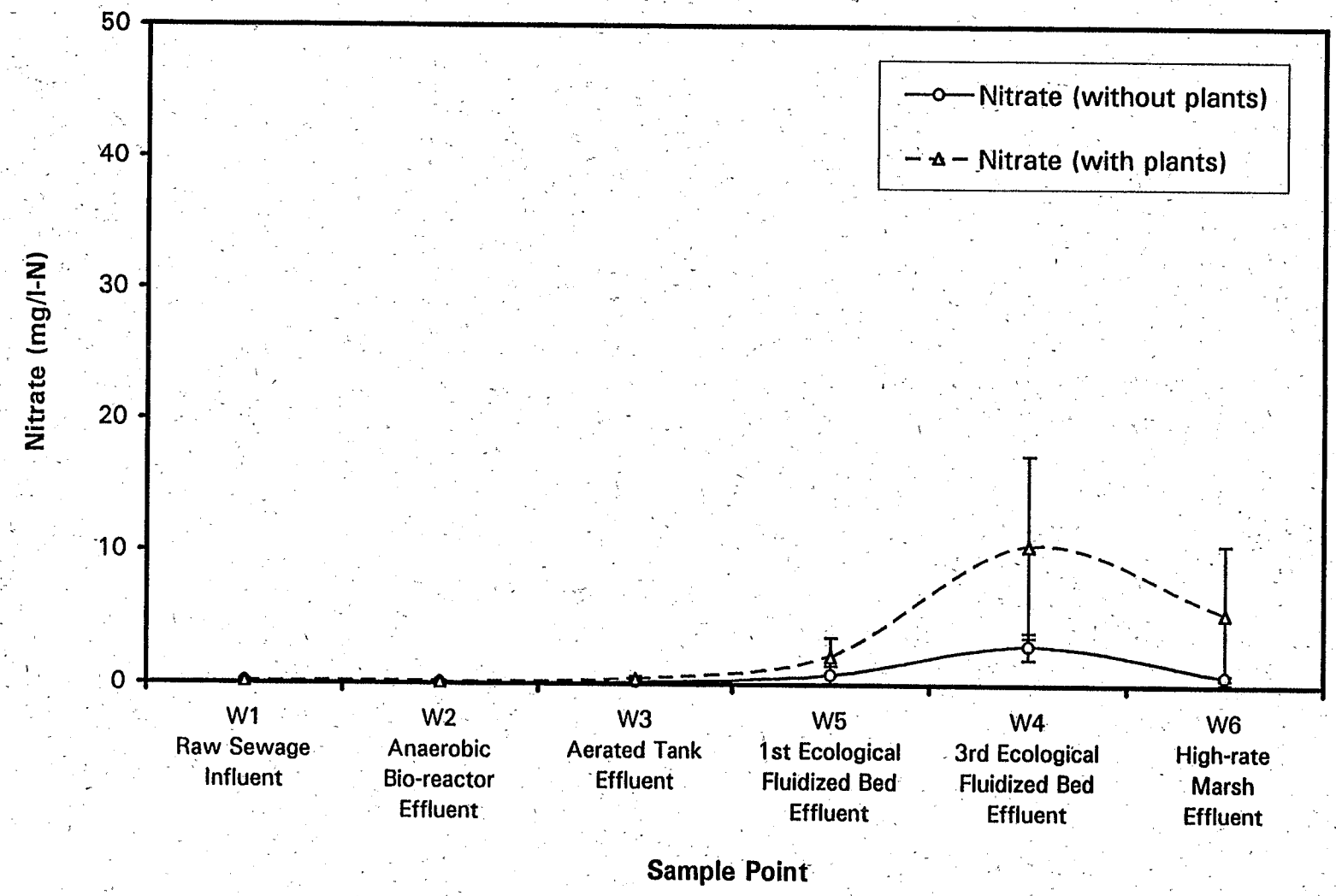


Figure 12-10
Comparison of System Treatment With and Without Plants
Parameter: *Phosphorus*

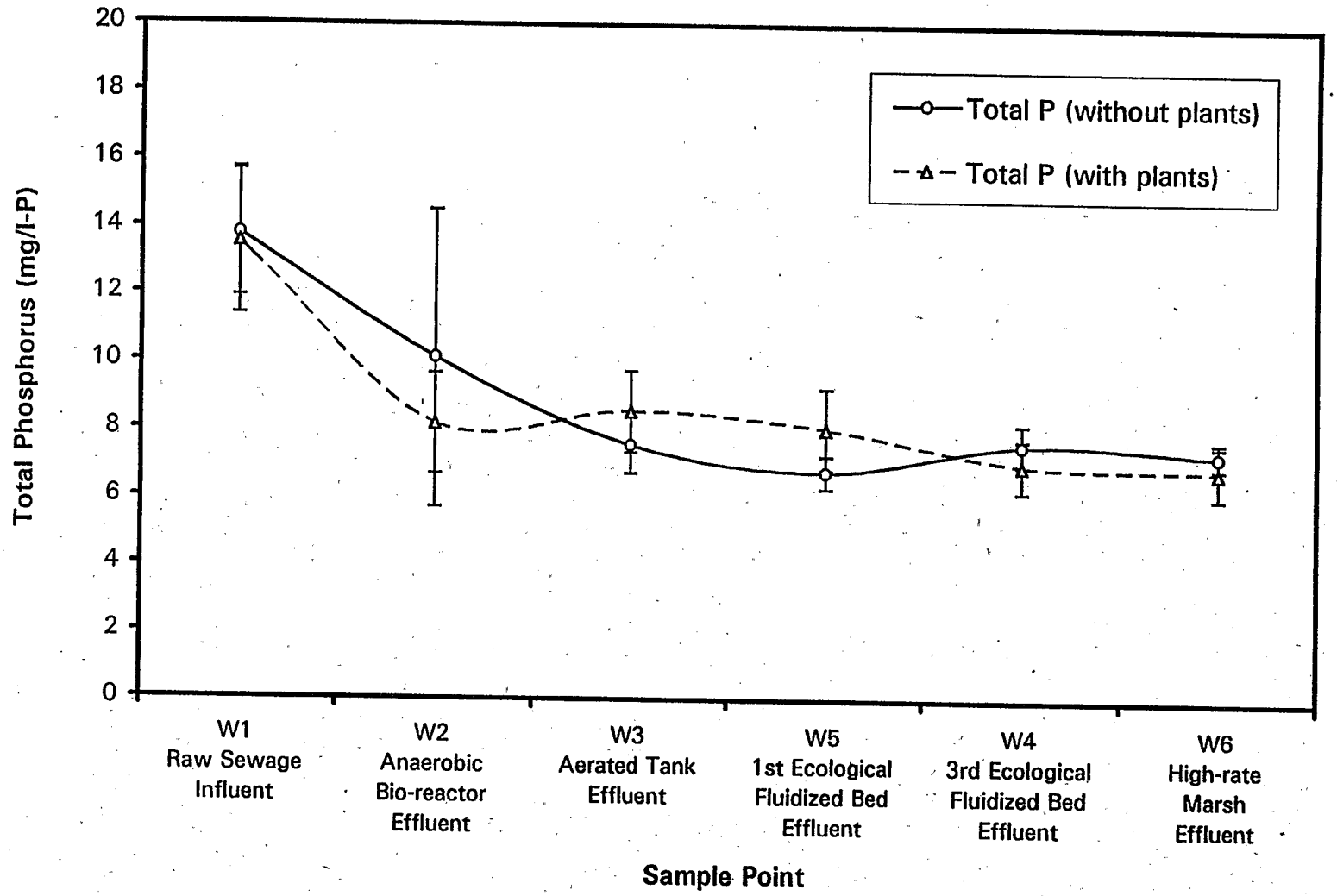


Figure 12-11
Comparison of System Treatment With and Without Plants
Parameter: *pH*

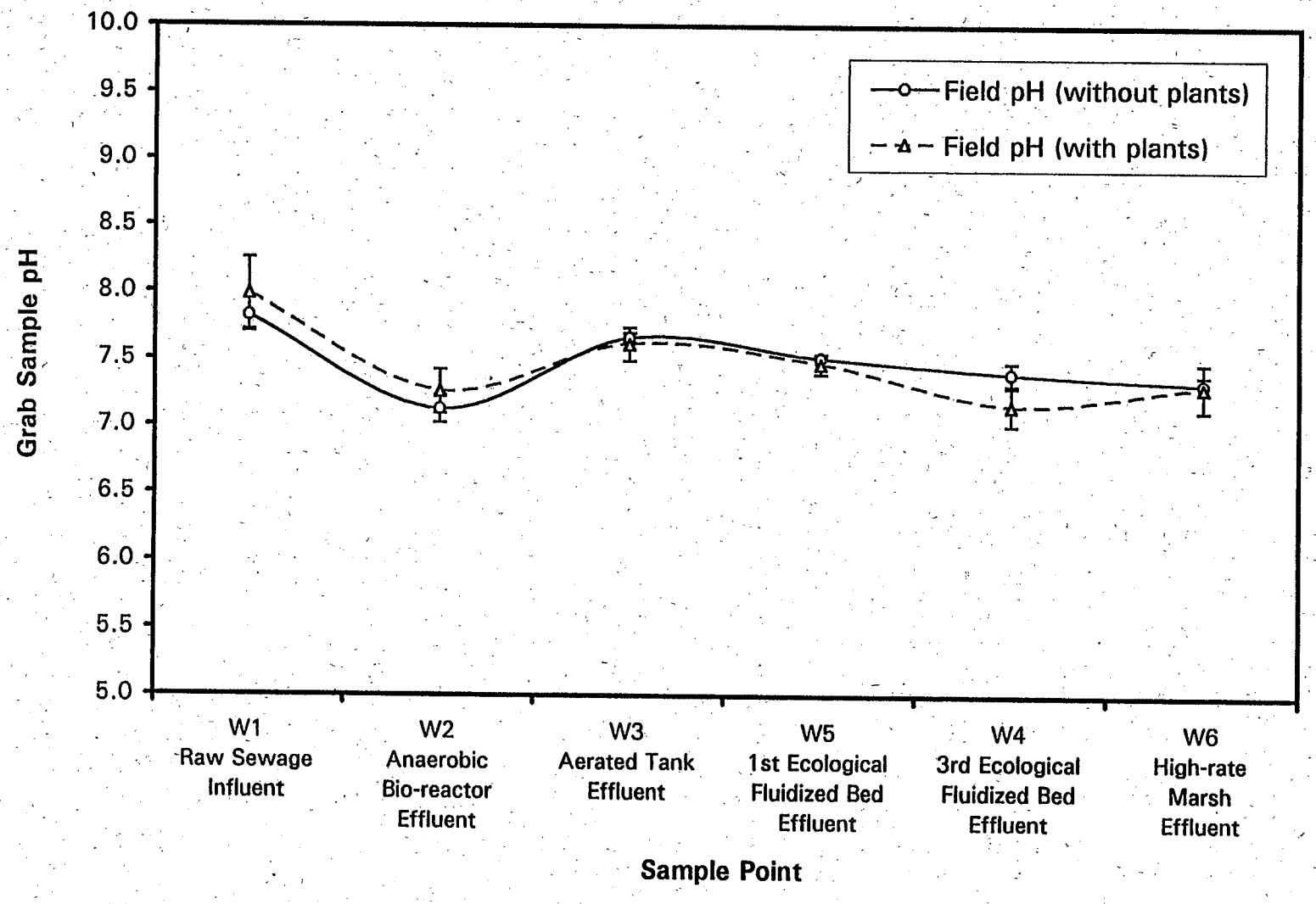
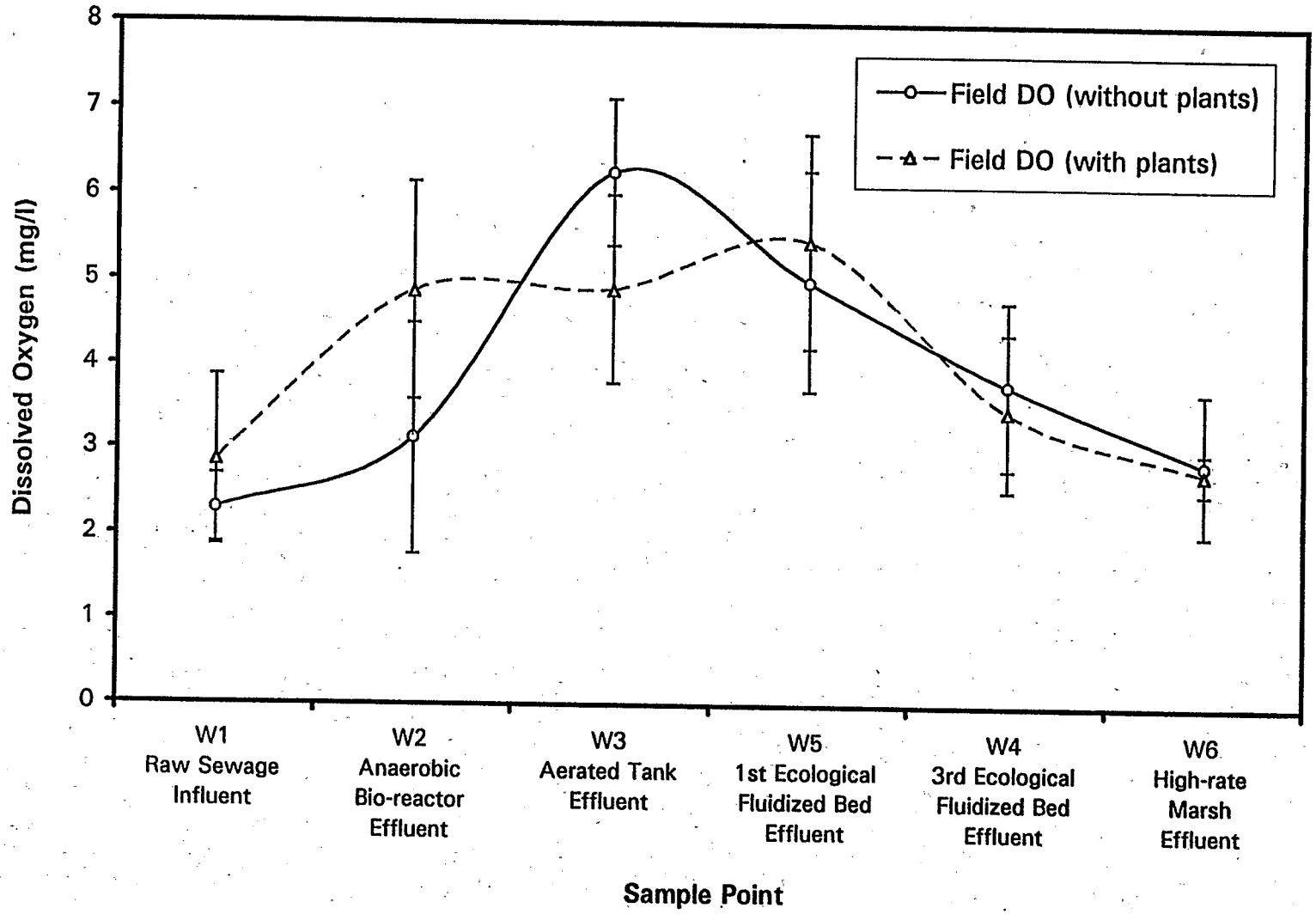


Figure 12-12
Comparison of System Treatment With and Without Plants
Parameter: *Dissolved Oxygen*



Section 13

Interim Evaluation Of The AEES Facility In Frederick, MD

13.1 Introduction

Previous sections of this report have described, and presented the results of, the independent monitoring program performed at the AEES in Frederick, MD. This section will present an evaluation of these data, which were the major objectives of this study. These objectives were to:

- Evaluate the performance of the individual treatment components and the overall AEES process, through monitoring of flow, characterization of wastewater and residuals, and determination of HDTs.
- Compare the capital costs and operation and maintenance (O&M) costs of the AEES process with equivalent conventional wastewater treatment technologies.
- Carry out a statistical comparison of the water quality data generated by this study to that produced by OAI, both from their on-site laboratory and their certified testing laboratory (at Ballenger Creek WWTP). The purpose of this exercise was to validate the OAI procedures and results, thereby reducing the requirement for independent testing in future evaluations of this type.
- Evaluate the performance of the "Living Machine" with and without plants in the treatment units in order to quantify and document the contribution of the floating macrophyte plant species to the AEES wastewater treatment process.

This report is based on the evaluation of the data collected during the February to June 1995 EPA study period. Conclusions based on this short study period are considered to be interim. The AEES continued in operation through 1995 and into 1996 with data collection by the OAI staff. It is intended, if funding is available, to conduct a final, complete evaluation in 1996 based upon all 1995/96 performance data. A cursory examination of data collected since June 1995 indicates that the AEES process has not yet solved all problems with respect to nitrogen and phosphorus removal which are discussed later in this section.

13.2 Process Performance

The performance goals established by Ocean Arks for the Frederick "Living Machine" are compared below to the mean water quality values observed during the 11 week EPA study period. These observed values were measured at the end of the process. A summary of all of the water quality observations can be found in Table 9.1 in Section 9, and in Appendix C.

Table 13.1 Performance of the Frederick AEES During the Study Period

Parameter	Unit	Performance Goal	Actual Mean Performance
BOD_5	mg/l	10	12.5
TSS	mg/l	10	3.5
Ammonia	mg/l-N	1	5.5
NO_3	mg/l-N	5	5.4
TN (1)	mg/l	<10	13.8
TP	mg/l-P	3	6.8

(1) The value for TN (total nitrogen) is derived by taking the sum of TKN and NO_3 from the system effluent in Section 9, Table 9.1.

It is apparent from this comparison that the "Living Machine" did not meet any of its established performance goals during the study period, with the exception of the goal for TSS. Consequently, it could be concluded that the process has not achieved its intended objectives and/or that more modest performance goals should be defined. However, this is not a completely valid conclusion if both the influent wastewater characteristics and the status of the Frederick AEES during the study period are taken into account.

It was the premise of Ocean Arks when establishing these goals that the wastewater at Frederick would have "typical" moderate strength characteristics, i.e.: $BOD_5 \approx 220$ mg/L, TSS ≈ 220 mg/L, TN ≈ 40 mg/L, TP ≈ 8 mg/L. The actual wastewater characteristics at Frederick could instead, be considered a "strong" wastewater, i.e.: $BOD_5 \approx 469$ mg/L, TSS ≈ 470 mg/L, TN ≈ 56 mg/L, TP ≈ 14 mg/L. Consideration was given, prior to the EPA study period, to reducing the flow rate into the AEES facility so that loadings on the system would more closely match the original Ocean Arks expectations. It was finally decided, with EPA concurrence, that the system should be operated at the design flow rate of 40,000 gpd so the system did have to contend with higher than expected wastewater strength.

It was the premise of EPA, in planning this study, that the Frederick facility was truly in "steady state" operation with all of the "bugs" eliminated and all of the components and procedures operating at their optimum potential. This expectation proved not to be valid. The "Living Machine" technology is still evolving so that procedural and operational changes continued to be made during the EPA study period. Typical examples of these changes included variations in the backflushing frequency and duration for the pumice filter beds, and the type and dose of carbon source used for denitrification. As shown on Table 9.6 sodium acetate was the carbon source in use at the beginning of the study, and this continued until the 7th week. The change to methanol had a very significant impact on the characteristics of the final effluent. The average effluent during the first six weeks was: BOD_5 7.4 mg/L, and NO_3 6.9 mg/L; after these modifications the effluent concentrations in the last four weeks of the study averaged: BOD 23 mg/L, and NO_3 2 mg/L. It is clear that denitrification improved due to the change to methanol as the carbon source but the

effluent BOD increased due the presence of the residual methanol. In this case, it is believed that as operational experience with methanol improves the procedure will be optimized to yield both a low effluent nitrate and a low BOD_5 .

It is believed that when the AEES "Living Machine" process is fully optimized and truly operating at steady state conditions it should be capable of satisfying all of the specified treatment goals except phosphorus. Effective phosphorus removal may require the addition of suitable chemicals and/or filtration through suitable media. This opinion regarding the potential capability of the "Living Machine" still needs to be demonstrated. Unfortunately, the process demonstration at Frederick, MD is not well suited for this ultimate purpose, since wastewater is pumped into the AEES facility at a uniform rate so the system is not exposed to the normal diurnal flow variations or the peak flows which occur in response to storm events. In addition, sludges are returned to the adjacent municipal treatment plant without processing. Dewatering on reed beds is proposed for future applications of the "Living Machine". In this case, the leachate from these reed beds would have to return to the AEES facility for treatment. The need to include treatment of this very strong leachate with the normal wastewater stream might reduce the claimed capacity of the system by about 5 percent (i.e.: a 40,000 gpd unit could only treat 38,000 gpd of wastewater and 600 gpd of very strong sludge leachate). The AEES facilities in Frederick and South Burlington are well suited to demonstrate the capabilities of the process under "ideal" operating conditions.

13.2.1 Anaerobic Bio-reactor

It is clear from examination of Figures 9-7 to 9-12 that the anaerobic bio-reactor was a critical component in the successful performance of the AEES system at Frederick. It removed more BOD_5, COD, TSS, and phosphorus than all of the other system components combined. The effective removal of BOD_5, COD, and TSS was essential for the operation of the system since the greenhouse components could not contend with the untreated wastewater if applied directly. This reactor was also very effective for solids removal as evidenced by the 84 percent removal of TSS. It is also apparent that at least some anaerobic digestion is occurring in the reactor since the volatile TSS was reduced while ammonia and soluble COD and soluble BOD_5 increased significantly. It is believed the major mechanism responsible for removal of phosphorus, BOD, and COD in this unit is effective removal of the solids in the incoming wastewater and in the recycled sludges. The BOD and COD can undergo further reduction due to digestion of the solids but most of the phosphorus will remain with the sludge removed from the unit. It has been estimated that a solids reduction of at least 20 percent is accomplished by the anaerobic digestion in this reactor. As shown in Table 10.1 the theoretical and measured detention time in this unit are the same at about 18.5 hours at design flow. Table 9.1 shows a positive dissolved oxygen concentration in the effluent from this reactor; that is due to the small aeration tanks prior to the greenhouse which were discussed in Section 2 of this report.

The observed advantages of this anaerobic unit would seem to favor its continued use with future applications of the AEES technology. Anaerobic reactors can deal effectively with high organic **loads** and organic compounds which might not be easily treated by the units inside the greenhouse. Using such a reactor as the initial treatment step protects the greenhouse processes from upsets and disruptions even with low to moderate strength wastewaters. Its use would be essential for high strength wastewaters. It does require odor control for any exhaust gasses and the digestion process is temperature dependent and would be less efficient in cold climates. These constraints seem a small price

to pay for the advantages of the anaerobic technology. Even if the digestion process was negligible during the cold winter month the solids wasting requirements might not increase more than 20 percent based on the experience at Frederick. It might be possible to sustain a significant level of digestion by adding extra layers of insulation around the perimeter of the tank in cold climates, and possibly heating the sludge wasted from the greenhouse before it is returned to the reactor. It has, however, been decided to replace this anaerobic reactor by increasing the aerated tanks in the greenhouse from two to five, per train, in the system under construction in Vermont.

Sludge is routinely wasted from this unit to the Ballenger Creek WWTP, and sludge is routinely added with sludge from the pumice filter beds (sludge from the final clarifier is also wasted to the Ballenger Creek, WWTP). Similar arrangements are planned for the 80,000 gpd system now under construction in South Burlington, VT. In future applications of the AEES technology where it cannot depend on an adjacent treatment plant it will be necessary to add suitable headworks for screening and grit removal to protect the anaerobic bio-reactor. It might also be necessary to increase the volumetric capacity of the unit to accommodate all of the sludge from all of the greenhouse clarifiers and to achieve further stabilization and solids reduction via anaerobic digestion.

13.2.2 Aerated Tanks

The measured detention time in the two aerated tanks is about 21 hours (Table 10.1). This is comparable to the detention time commonly used in the extended aeration activated sludge process. There are however, two major differences with the AEES tanks: a layer of vegetation floats on the water surface of the tank, and the suspended solids concentration maintained in these tanks is quite low. The uptake of nutrients and other pollutants, by the plants, is minimal but the plant roots are expected to provide a substrate for support of the microorganisms providing treatment of BOD and for nitrification of ammonia nitrogen.

As might be expected with a long detention time, these tanks provide a 91 percent removal of soluble BOD_5 and a 70 percent removal of soluble COD. Much of this removal occurs via generation of new microbial solids and the volatile solids increase by 91 percent in the tank effluent, and the TSS also increases by 90 percent. There is a small reduction in ammonia (17 %) in these tanks but the Kjeldahl nitrogen (TKN) increases by about seven percent. The small ammonia removal is probably due to a lack of sufficient nitrifying organisms in the tank environment. The small increase in TKN is probably due the increase of microbial solids mentioned previously and the associated uptake of ammonia nitrogen.

The average effluent TSS from the second tank was 140 mg/L. Since the tank was completely mixed that would also be the concentration of solids contained in the tank (mixed liquor suspended solids (MLSS)). That is a much lower concentration than typically maintained in conventional activated sludge processes and may be one reason for the low ammonia removal efficiency. In the general case, the nitrifying organisms cannot compete with the heterotrophic organisms which consume the BOD, that is why many conventional treatment processes are two stage systems. However, in long detention time activated sludge systems the soluble BOD reaches low levels and the nitrifiers can compete if they are present in high enough concentrations. In order to keep the population of nitrifiers at high levels it is necessary to recirculate some of the sludge removed by clarification to the aeration tank and to maintain a MLSS concentration of about 2000 mg/L. The AEES aeration units at Frederick provide neither significant sludge return or maintenance of

sufficient MLSS to achieve significant nitrification which could be expected in the complete mix mode of operation.

The roots of the floating macrophytes on these tanks are also intended to serve as the substrate for the nitrifying organisms which allows their retention in an otherwise mixed tank. In this case the mixing action brings the wastewater into contact with the organisms attached to the plant roots. This activity is apparently not very effective at the Frederick facility, and there may be two contributing reasons. It is possible that the roots are covered with accumulated TSS so that oxygen and the wastewater ammonia cannot get to the root surfaces and the accumulated organic matter would discourage occupation by the nitrifiers. The major reason is that there are just not enough plants in the Frederick AEES facility. The amount of root matter available is a function of the number of plants present and that in turn is a function of the surface area of the container. The volume, or depth of water in the container then influences the number of opportunities for wastewater ammonia to come into contact with the plant roots. At the Frederick AEES facility the ratio of depth to surface area is about 1 ft:20 ft^2. Treatment basins using floating macrophytes are typically about three feet deep and have a depth to surface area ratio of at least 1ft:140 ft^2. It is obvious that the latter system can have many more plants and therefore many more contact opportunities between roots and circulating wastewater. These macrophyte basins are typically used in subtropical and tropical climates, without greenhouse protection. The AEES system at Frederick is constrained by the costs required to provide the greenhouse and it is not possible to provide enough water surface and plants to depend on the use of microorganisms attached to the plant roots for significant nitrification.

The aeration tank technology as used at Frederick, MD is therefore a hybrid concept with minimal capability for nitrification by either complete mix or attached growth microbial processes. The nitrification potential of this system component can only be improved if one or both of these mechanisms are optimized. The complete mix pathway could be improved by maintaining a higher concentration of MLSS in these tanks. That would require improved clarification after the aeration tanks and routine return of a portion of that sludge to the first tank in series. These high MLSS concentrations would probably result in the plant roots becoming completely ineffective for nitrification because of sludges trapped in the roots. The plants would still survive and grow but their function would largely be aesthetic. Substrate for attached growth nitrification could be provided with the use of commercially available submerged plastic media. It is also possible to continue the present mode of operation and design these tanks for only BOD_5 removal and depend on the "ecological fluidized beds" for nitrification. This approach would still require improved clarification after the aeration tanks to reduce the solids load on the filter beds.

13.2.3 Ecological Fluidized Beds

These beds are a unique and imaginative attempt to solve several treatment issues: 1. the need to provide a media that can effectively trap solids and also serve as the substrate for microbial nitrification and denitrification, and 2. a media which can be cleaned easily without excessive use of energy or large volumes of water for backwashing. The pumice gravel used in these units would seem to be an ideal choice for these purposes. The first pumice bed achieves a 71 percent removal of TSS, 53 percent removal of BOD_5, and a 31 percent removal of TN. The three pumice beds in series produce a 93 percent removal of TSS, 83 percent removal of BOD_5, and a 56 percent removal of TN.

As described in Section 2, the final bed in the set is operated as an anoxic upflow reactor to accomplish denitrification of the nitrates produced in the earlier process units. As shown on Table 9.1 the average effluent nitrate from this third bed was 10.5 mg/L during the study period. This, however is somewhat misleading since the carbon source addition was changed to methanol at about the 2/3 point in the study period, and in the final sample the nitrate concentration was down to 4.2 mg/L. This suggests that very effective denitrification is possible once the use of the methanol addition is optimized.

The removal of accumulated TSS from the pumice bed is accomplished by aeration which reverses the flow in the inner ring and "fluidizes" or suspends the pumice gravel in the upflowing water. This flushes the retained TSS out of the bed and into the annular space outside the pumice container. A perforated pipe was added at the bottom of that annular space for sludge wasting but that has not proven to be very effective and a manual vacuum operation is routinely used to remove this sludge. A hopper bottom on the entire tank with a suitable airlift might be a more effective method for sludge management in these units.

It is believed that effective management of TSS is the key to successful operation of these pumice bed filters. Rapidly accumulating sludges in the beds require very frequent cleaning and the oxygen demand from the sludge tends to reduce the effectiveness of nitrification. It is suggested that a full sized, and more effective clarifier between the aeration tanks and these filters would significantly improve the performance of the entire AEES process. The small clarifier installed at this point in the Frederick facility was an "after-thought." The 80,000 gpd "Living Machine" now under construction in South Burlington, VT has a specifically designed clarifier at this point.

The pumice gravel seems, at first glance, to be an ideal choice for this service. The gravel provides a high surface area for microbial growth and its low density allows suspension with minimal airlift energy input. However, the softness of pumice creates a problem for operation of the units. The inter-particle abrasion occurring during the backflushing operation causes significant degradation of the gravel particles and loss of the abraded fines. The loss has been equivalent to almost a one foot depth of gravel in some of these tanks during the first year of operation. As a result of these losses, a higher density, harder volcanic stone has been selected for use in the 80,000 gpd facility under construction in Burlington, VT. At the Frederick facility it might be possible to reduce the rate of loss if more effective clarification ahead of the pumice beds would reduce the frequency of backflushing required.

13.2.4 Duckweed Clarifier

The Frederick, MD facility has a "Duckweed" clarifier after the final pumice bed. The "Duckweed" portion of the unit name is due to the presence of a mat of floating duckweed (*Lemna sp.)* on the water surface of this tank. In its present location in the flow path at Frederick this clarifier is not a very effective component in the process and does not contribute significantly to treatment. This is primarily due to the the very effective TSS removal in the pumice filter beds. A sampling point was originally planned for the EPA study after this clarifier. Data collected by the Ocean Arks staff indicated that there was an insignificant change in water quality between the effluent from the third pumice bed and the effluent from this clarifier so the sampling point was moved to the third pumice bed outlet as shown on Figure 4-1. This clarifier is not needed in this position at Frederick since the high rate marsh is there for final effluent polishing, but as noted below the marsh

provides a marginal level of further water quality improvement. As a result, both this clarifier and the final marsh unit have been eliminated from the 80,000 gpd unit now under construction in South Burlington, VT.

A significant improvement in performance at the Frederick facility should be possible using this clarifier, but significant piping changes would be necessary. The effluent from the final pumice bed could bypass this clarifier and flow directly to the high rate marsh. Effluent from the second aeration tank could bypass the pumice beds and flow directly to this clarifier. A small 10 gpm pump would then be required to return the clarified effluent to the inlet of the first pumice filter bed. This arrangement would then replicate to flow path intended for South Burlington and would keep the existing high rate marsh in service.

13.2.5 High-Rate Marsh

This unit was intended for final effluent polishing via physical filtration by the gravel media, by microbial action of the contained organisms, and by contact with the roots of the plants growing in the marsh. The measured detention time in this unit was about 10.5 hours, and is the reason for the term "high-rate" since the detention time in marshes of this type is usually measured in term of days. Space and cost limitations for the enclosing greenhouse would preclude the use of a larger marsh. The marsh produced an additional 65 percent removal of TSS but TSS was already at the project goal in the effluent from the pumice bed filters. A 32 percent further removal of BOD was achieved but the final marsh effluent still exceeded the 10 mg/L goal, on average. A 27 percent ammonia removal was achieved, and nitrate removal averaged 48 percent confirming that an anoxic environment exists in the gravel marsh bed. Removal of total nitrogen (TN) averaged 33 percent but the final effluent (14 mg/L) still exceeded the 10 mg/L Ocean Arks goal. The nitrogen removal in the bed is believed due to the combination of solids removal and denitrification; uptake by the plants growing on the bed is a negligible contribution.

To provide a major contribution to wastewater treatment this marsh would have to have a significantly larger area and/or improved control over denitrifiction carbon sources. as a rule-of-thumb at least five pounds of BOD_5 are required to denitrify one pound of wastewater nitrate. At 18 mg/L it is clear that the marsh influent contains insufficient BOD_5 to support complete denitrification and the short detention time may not be sufficient. In most marsh systems the plant litter is allowed to accumulate and becomes an additional carbon source for denitrification. At the Frederick facility, the marsh surface is managed as a horticultural nursery so the plants are removed before they can develop deep root systems and litter is not allowed on the bed surface.

It is believed that performance at the Frederick facility can meet treatment goals for BOD_5, TSS, and nitrogen forms with improved clarification and methanol management in the upstream units. This would reduce the function of the present marsh to a horticultural role. A gravel bed marsh may still be a useful final polishing unit for the AEES concept, and a larger bed could be located outside the greenhouse, even in cold climates. However, such a marsh would be intended for treatment and have minimal horticultural use.

13.2.7 Phosphorus Removal

The performance goal for phosphorus was set by Ocean Arks at 3 mg/L. During the EPA study period the final effluent phosphorus averaged 7 mg/L, or 50 percent removal for the overall process. The untreated wastewater had an unusually high organic strength but

the phosphorus concentration at 14 mg/L was typical of most municipal wastewaters. Most of the phosphorus removed in the system was taken out in the anaerobic bio-reactor, the next largest contribution was from the pumice filter beds. Neither of these processes have an inherent affinity for phosphorus, the likely removal pathway is with the sludge which was separated from the liquid in these units and then wasted.

None of the biological pathways available in the current AEES process can be expected to remove large quantities of phosphorus. Biological phosphorus removal is possible in specially designed and operated treatment plants. The patented *Bardenpho* process is one example; these processes tend to induce biological uptake of phosphorus by the microorganisms and result in the production of large quantities of sludge. The other commonly used phosphorus removal pathway in wastewater treatment is chemical additions to precipitate the phosphorus; these also produce large quantities of sludge. It is possible to remove significant amounts of phosphorus via plant uptake and harvest but the plant density and harvesting program at the AEES facilities are not sufficient to account for significant amounts of phosphorus. Based on the data presented in Tables 9.1, 9.5 and 9.8 it can be calculated that about 751 kg/yr of phosphorus enters the AEES with the incoming wastewater, at a flow rate of 40,000 gpd. Approximately 0.44 kg/yr of phosphorus would leave the facility with the routinely harvested and composted plant material. Additional phosphorus is removed during the horticultural operations but it is unlikely that the total annual phosphorus for all plants leaving the greenhouse exceeds 1 kg/yr. The plants in the Frederick AEES system can therefore, account for about 0.1 percent of the phosphorus entering the system. **Either significant phosphorus removal should be dropped as an AEES performance claim or more positive methods for removal incorporated in the system.**

13.2.8 Fecal Coliforms

Fecal coliforms were only measured in the untreated wastewater and the final effluent. QA/QC procedures require a grab sample so the data only represent a specific point in time during the sampling day. The apparent removal by the over all system was quite good. The untreated wastewater had a typical concentration of 8×10^6 cfu/100 ml, and the final effluent 170 cfu/100 ml for a four log reduction. Final disinfection of this effluent would not be required for most discharge or reuse purposes. The San Francisco AEES is intended to produce 2.2 cfu/100 ml which is the "Title 22" water quality requirement by the State of California for unrestricted irrigation use.

13.3 Process Residuals

The residuals leaving the AEES process include sludges from the anaerobic bio-reactor and sludges from the final duckweed clarifier and the plants removed from the water surfaces on the various tanks. The plants removed during the horticultural operations are not included in the "residuals" estimate since they are intended for replanting and not disposal. The sludge removed from the pumice filter beds is returned to the anaerobic reactor and are accounted for in the sludge wasted from that unit. The volume of sludge and the weight of plants removed during the EPA study period are given in Tables 9.7 and 9.8 respectively.

Samples of sludge and plant material were collected on several occasions and tested for nitrogen, phosphorus and the metals of concern for land application of sludge (503 regulations). The plant material showed no unusual concentrations of any material and the final compost could be used for any agricultural or horticultural purposes. The sludges from

the system met all of the 503 limits except for fecal coliforms, and these limits could be met with additional stabilization and treatment of the sludges.

The total amount of residual materials removed from the AEES facility in Frederick can be estimated from the data in Tables 9.7 and 9.8. Based on the data in Table 9.7 an average of 4434 gallons of sludge per week were wasted from the anaerobic bio-reactor; at 2.8 percent solids; that is about 472 kg/wk of dry solids, the final clarifier would contribute about 2 kg/wk, and the plant residuals about 1 kg/wk of dry material. On an annual basis, the residuals production would be about 12 dry tons (metric) per year. A comparable 40,000 gpd extended aeration package plant, with a final denitrification filter, would waste about 1000 gallons of sludge per day with about 2 percent solids, this would equal 76 kg/d of dry solids or 14 dry tons (metric) of sludge per year. **The AEES system produces slightly less sludge than a conventional extended aeration treatment process, which also includes final filtration, and the effluent characteristics of the two systems are comparable.** This should not be surprising since the process functions in each system are also similar. The difference in residuals production between the two systems is probably due to the estimated 20 percent solids reduction achieved in the AEES anaerobic bio-reactor.

13.4 Cost Comparisons

Previous discussion in this section evaluates the performance of the AESS process and compares that performance and residuals production to conventional wastewater treatment technology. It is the intent of this section to compare costs for construction, operation, and maintenance of the AEES process to conventional treatment processes capable of delivering the same effluent quality. Cost comparisons at three flow rates were developed: 40,000 gpd (Frederick, MD flow rate), 80,000 gpd (S. Burlington, VT flow rate) and 1,000,000 gpd. The cost estimates for the AEES process were prepared by Living Technologies, Inc., in Burlington, VT; the costs for comparable conventional technologies were developed by process specialists and staff at Parsons Engineering Science, Fairfax, VA. All of the individuals contributing to this effort are listed in the Acknowledgements for this report.

Great care has been taken in the development of these comparisons to be sure that "apples are compared to apples" with respect to process capabilities, residuals management requirements and the inclusion or exclusion of particular items in the cost estimates. An example is the level of phosphorus removal. The original specification given to Parsons Engineering Science required the conventional processes to achieve all of the original Ocean Arks performance goals. However, the AEES facility at Frederick, MD does not satisfy this goal so it was dropped from the second iteration of cost estimates for the conventional systems.

All of the costs cited are essentially for the process components, ancillary facilities such as headworks, administration and laboratory buildings, roads and fences, power transmission, telephone service, etc will vary with the size of the treatment plant. All of these features would probably be included in a 1 mgd capacity treatment plant but none of these elements, or land costs are included in either set of cost estimates at any of the three flow rates. All costs are given in 1995 dollars, the calculations of present worth value and total annual cost are based on 7 percent interest and a 20 year recovery period.

13.4.1 AEES Process Costs

The costs for construction, operation, and maintenance of the AEES system at 40,000, 80,000 and 1,000,000 gpd are given in Table 13.2. The original data were provided by Living Technologies, Inc. at Burlington, VT. The cost estimates at the 80,000 and 1,000,000 gpd flows are for a location in Maryland with a similar climate to Frederick, not the low temperature environment expected in Burlington, VT. As a result, the proposed process train for 80,000 gpd has four aeration tanks instead of the five under construction at South Burlington, VT. The costs for the 40,000 gpd system are based on actual costs for the Frederick, MD system with some deductions for a special railroad crossing and landscaping; it does include the cost of the anaerobic bio-reactor. The AEES projections for 80,000 gpd and 1 mgd do not utilize an anaerobic reactor, extra aeration tanks are provided instead. It was necessary for the senior author of this report to make some adjustments and modifications to these costs based on the actual operational experience at Frederick, MD with respect to labor and utilities, residuals production and management, and horticultural revenues. Adjustments were also made so that the unit costs for labor rates, and power, etc, were compatible between the Parsons and AEES cost estimates. The costs are presented for an AEES system, with and without a greenhouse since the greenhouse should not be required in warm, frost-free, southern climates. The original cost estimates prepared by Living Technologies can be found in Appendix G.

The reed bed included in Table 13.2 is, in essence, a sand bed planted with reeds (*Phragmites*). The bed provides for sludge dewatering and long term stabilization since cleaning and sludge removal are only required every 5 to 7 years. The leachate draining from this sludge is returned to the basis treatment process for treatment. **This consideration has not been included in the proposed AEES design capacity flows.** For example, a 40,000 gpd AEES system might only have the capacity to treat 38,000 gpd of municipal wastewater plus this leachate. An O&M cost will occur every 5 to 7 years for removal and disposal of sludge from these beds. This estimated cost is included in Table 13.3 as a pro-rated annual cost.

Table 13.3 presents operation and maintenance costs for the AEES system at 40,000 gpd, 80,000 gpd and 1 mgd. The original, and a revised second set of estimates were provided by Living Technologies, Burlington, VT. Some line items have been modified by the senior author of this report to reflect actual costs for energy and horticultural revenue at Frederick, MD and also adjusted so the labor rates, etc would be the same for both the AEES and Parsons ES estimates. For example, the potential horticultural revenue claimed in the first AEES cost estimate was $5,411 (at the 40,000 gpd system), this increased to $17,472 in their revised estimate even though the revised system would be in a smaller greenhouse and without a marsh component. The actual horticultural revenues during 1995 at the Frederick, MD facility was about $2,400 and 75 percent of that came from the plants grown on the marsh component, the remainder ($600) came from potted plants suspended in the annular space on the pumice filter beds. It was assumed (by the senior author of this report) that the $600 revenue from potted plants could be increased by a factor of four so $2,400 was entered in Table 13.3. The revenue for 80,000 gpd and 1 mgd was then calculated based on the ratio of greenhouse areas available. Similar procedures were used to scale up other 40,000 gpd costs to the other two flow rates. The unmodified revised cost estimate prepared by Living Technologies, Inc. is given in Appendix G.

Table 13.2 AEES Process, Capital Costs

	40,000 gpd		80,000 gpd		1 mgd	
	w/ g-house	*w/o g-house*	*w/ g-house*	*w/o g-house*	*w/ g-house*	*w/o g-house*
Facility Description						
Size of Anaerobic Bio-reactor (ft^2)	635	635	none	none	none	none
Size of "Living Machine" (ft^2)	2,184	2,184	3,000	3,000	31,584	31,584
Power (kwh/d)	409	409	624	624	5,728	5,728
Operator (hr/wk)	20	20	30	30	126	126
Residuals (dt/yr)	12	12	24	24	300	300
Reed Bed Area (ft^2)	5,280	5,280	10,560	10,560	132,000	132,000
Facility Costs						
AEES Facility (1)	$402,475	$348,414	$560,457	$485,289	$4,043,026	$3,554,987
Reed Beds (2)	$26,400	$26,400	$52,800	$52,800	$660,000	$660,000
TOTAL COST (3)	**$428,875**	**$374,814**	**$613,257**	**$538,089**	**$4,703,026**	**$4,214,987**

(1) Assumed to include bonds, insurance, mobilization, overhead & profit, and contingencies.

(2) Sized at 0.22 ft^2/kg/yr dry solids, cost $5/$ft^2$ w/all overhead, etc, sizing ratio and unit cost provided by Living Technology, Inc.

(3) Total cost does not include disinfection since fecal coliform < 200cfu/100 ml at Frederick.

Table 13.3 Annual O&M Costs for the AEES System

Item	40,000 gpd		80,000 gpd		1 mgd	
	w/ g-house	*w/o g-house*	*w/ g-house*	*w/o g-house*	*w/ g-house*	*w/o g-house*
Energy [1]	$9,000	$9,000	$13,666	$13,666	$125,443	$125,443
Materials & Supplies						
Bioaugmentation	$4,300	$4,300	$5,450	$5,450	$31,500	$31,500
Methanol	$2,901	$2,901	$5,802	$5,802	$10,800	$10,800
Contingencies [2]	$1,080	$1,080	$1,688	$1,688	$15,604	$15,604
Gas	$3,231	$0	$4,438	$0	$70,088	$0
Labor [3]	$26,000	$26,000	$78,000	$78,000	$327,600	$327,600
Sludge Disposal [4]	$2,000	$2,000	$4,000	$4,000	$50,000	$50,000
Maintainance [5]	$4,288	$3,748	$6,132	$5,380	$47,030	$42,150
Hort. Revenue [6]	($2,400)	($2,400)	($3,300)	($3,300)	($35,000)	($35,000)
TOTAL O&M COSTS	**$50,400**	**$46,629**	**$115,876**	**$110,686**	**$643,065**	**$568,097**

(1) Electrical power at $0.06/KWH

(2) Contingencies = 15% of Materials and supplies

(3) Labor at $25/hr including benefits

(4) Sludge disposal, at $500/dt every 7 years, assume 2/3 reduction of mass on bed during 7 years. This is the cost every seventh year/7.

(5) Maintenance at 1% of capital cost

(6) Horticultural revenue, based on 4 times the 1995 actual return at Frederick, MD

Table 13.4 summarizes capital and O&M costs for the AEES process and presents the present worth and total annual costs.

Table 13.4 AEES System, Present Worth and Total Annual Costs

Item	40,000 gpd		80,000 gpd		1 mgd	
	w/ g-house	*w/o g-house*	*w/ g-house*	*w/o g-house*	*w/ g-house*	*w/o g-house*
Capital Costs	$428,875	$374,814	$613,257	$538,089	$4,703,026	$4,214,987
O&M Costs	$50,400	$46,629	$115,876	$110,686	$643,065	$568,097
Present Worth	$960,500	$866,700	$1,835,600	$1,705,700	$11,486,700	$10,207,800
Total Annual	**$90,900**	**$82,000**	**$173,800**	**$161,500**	**$1,087,000**	**$966,000**

13.4.2 Costs of Conventional Treatment Technologies

These cost estimates were prepared by process specialists at Parsons Engineering Science. They have provided capital and O&M cost estimates for conventional wastewater treatment processes recieving the same influent characteristics as the present AEES system in Frederick, MD, with the capability to produce the same quality effluent (i.e.: BOD_5 < 10 mg/L, TSS < 10 mg/L, Ammonia < 1 mg/L, and TN <10 mg/L. Since low levels of phosphorus are not achieved by the AEES facility at Frederick this requirement was also dropped from the Parsons alternatives. However, all of the Parsons alternatives can remove phosphorus to comparable levels (≈ 50%). As indicated previously, these estimates only include the direct process costs and related O&M, the ancillary facilities and activities typically found at larger treatment plants are not included. These omissions are to insure compatibility with the AEES estimates.

This section presents a brief discussion and summary tables. The detailed Parsons cost estimates and related discussion can be found in Appendix F. The comparisons are at the 40,000 gpd, 80,000 gpd, and 1 mgd flow rates to again be compatible with the AEES estimates. The process specialist developed costs for the most cost effective conventional process at each of these flow rates. As a result, the process selected varies with the flow rate. The systems are:

1. 40,000 gpd: A prefabricated packaged extended aeration plant with a final anoxic filter for denitrification and filtration, followed by ultraviolet (UV) disinfection. The only chemical addition is methanol as a carbon source for denitrification.

2. 80,000 gpd: A sequencing batch reactor (SBR) followed by a filter with backwash and UV disinfection. Methanol is not needed in this case since the wastewater BOD_5 provides sufficient carbon in an anoxic period which is developed during the SBR operational sequence. Two options were developed: a prefabricated package plant, and on-site constructed concrete tanks.

3. 1,000,000 gpd: Two options were developed for this flow rate: A prefabricated extended aeration package plant with a cylindrical steel tank erected on a concrete pad, the system includes an anoxic filter for denitrification, and UV disinfection; methanol is used as a carbon source. The second alternative is a *Carrousel*

oxidation ditch process with typical concrete aeration/anoxic zone tanks, final clarifiers and sludge return pumping, a polishing filter and UV disinfection. Methanol is not needed in this case because the wastewater BOD_5 provides sufficient carbon for denitrifiaction in the anoxic zone of the oxidation ditch.

The costs for residuals management and final disposal are included in the estimates. At the 40,000 and 80,000 gpd flow rates sludge disposal is via a contract septic/sludge tank truck hauler which convey the sludge to an off-site facility for final treatment and disposal. Such a procedure is commonly used at these lower flow rates. The 1 mgd systems include on-site sludge management and stabilization procedures. The 1 mgd package plant includes digestion and contract land application for final disposal. Digestion is not required for the 1 mgd oxidation ditch since there is no primary sludge. The sludge management costs for this alternative are derived from actual process costs for the Downington WWTP in Pennsylvania.

The O&M costs are based on manufacturers data on power requirements, manpower, and chemicals. The unit O&M cost for sludge processing, stabilization, and disposal at the 1 mgd flow rate is based on historical data from *ALCOSAN Diversified Residuals Management Program (1994)* and *Sludge Management Alternatives Evaluation Report (1994).* This unit cost at $500 per dry ton includes belt press filter dewatering, lime stabilization and contract land application. The costs for the smaller flow rates is based on a $95/hr rate for the sludge hauler. This cost, converted to $/dry ton (metric) is $1,000 per dry ton produced by the WWTP at the 40,000 and 80,000 gpd flow rates. A $500/dt cost was also added for the final sludge disposal operations in the AEES cost estimates. Tables 13.5 and 13.6 present summary data for the three flow rates.

Table 13.7 compares the total present worth costs of the AEES process and the Parsons ES alternatives for the three flow rates. The cost differences at the 40,000 gpd and 80,000 gpd are within 15 percent and therefore not significant. The cost difference at 1,000,000 gpd is very significant and favors either of the two conventional treatment alternatives. It can be tenatively concluded that the AEES process will cost about the same as conventional technology at flow rates less than about 100,000 gpd; at flow rates of 100,000 gpd or higher conventional wastewater technology is apparently more cost effective. This is probably due to economy of scale issues. An oxidation ditch at 100,000 or 1,000,000 gpd can usually be a single process unit whereas the AEES system must have several replications of greenhouses and process tanks.

Neither the conventional or the AEES costs represent a complete treatment system. Some items not included are: headworks, roads, fences, administrative and laboratory facilities, chemical storage, and redundant treatment units. As a result, these costs cannot be compared to treatment system costs published elsewhere. Addition of these costs would increase the costs of both the AEES and conventional processes.

13.5 USEPA-Ocean Arks Data Comparison

It was the intent of this part of the study to compare the data produced by the EPA study team during the 11 week study period to that produced by Ocean Arks staff in their on-site laboratory at Frederick and by their QA/QC certified laboratory at the Ballenger Creek WWTP. The purpose of the comparison was to validate, if possible, the Ocean Arks data

Table 13.5 Capital and O&M Costs for the 40,000 and 80,000 gpd Alternatives

Item	40,000 gpd	80,000 gpd, Steel	80,000 gpd, Concrete
Capital Costs			
Construction	$266,289	$450,149	$416, 802
Bonds, Insurance, 3%	$7,989	$13,504	$12,504
Mobilizaton, @ 4%	$10,652	$18,006	$16,672
Misc. Costs, @ 10%	$26,629	$45,014	$41,680
Subtotal	$311,559	$526,674	$487,659
OH & P[1], 15%	$46,734	$79,000	$73,149
Contingency, 15%	$46,734	$79,000	$73,149
Total Capital Costs	**$405,025**	**$684,676**	**$633,956**
Annual O&M Costs			
Energy[2], $0.06/KWH	$7,931	$7,493	$7,493
Methanol[3], $0.23/lb	$2,902	$0	$0
Contingencies[4], 15%	$435	$0	$0
Labor[5], $25/hr	$36,500	$54,750	$54,750
Sludge Management[6]	$13,140	$26,280	$26,280
Maintenance, 1% of Capital Costs	$4,050	$6,847	$6,340
Total O&M Costs	**$64,958**	**$95,370**	**$88,119**
Total Present Worth	$1,093,200	$1,695,000	$1,567,500
Total Annual Cost	**$103,192**	**$160,000**	**$148,000**

(1) Construction contractor's overhead and profit.

(2) Electrical power for process and UV disinfection.

(3) Methanol at 35 lb/d.

(4) A percentage of chemicals and supplies.

(5) Includes fringe benefits.

Table 13.6 Capital and O&M Costs for the 1,000,000 gpd Alternatives

Item	1 mgd, Packaged	1 mgd, Carrousel
Capital Costs		
Construction	$2,111,460	$2,100,227
Bonds, Insurance, 3%	$63,344	$63,007
Mobilizaton, @ 4%	$84,458	$84,009
Misc. Costs, @ 10%	$211,146	$210,023
Subtotal	$2,470,408	$2,457,266
OH & P[1], 15%	$370,561	$368,590
Contingency, 15%	$370,561	$368,590
Total Capital Costs	$3,211,530	$3,194,446
Annual O&M Costs		
Energy[2], $0.06/KWH	$88,053	$42,304
Methanol[3], $0.23/lb	$10,786	$0
Contingencies[4], 15 %	$1,618	$0
Labor[5], $25/hr	$146,000	$146,000
Sludge Management[6]	$164,250	$196,188
Maintenance, 1% of Capital Costs	$32,115	$31,944
Total O&M Costs	$442,822	$416,436
Total Present Worth	**$7,902,800**	**$7,606,169**
Total Annual Cost	**$746,000**	**$718,000**

(1) Construction contractor's overhead and profit.

(2) Electrical power for process and UV disinfection.

(3) Methanol at 130 lb/d.

(4) A percentage of chemicals and supplies.

(5) Includes fringe benefits.

Table 13.7 Present Worth Comparison, AEES and Conventional Systems

System Size	40,000 gpd	80,000 gpd	1,000,000 gpd
AEES			
w/ Greenhouse	$960,000	$1,835,600	$11,486,700
w/o Greenhouse	$866,700	$1,705,700	$10,207,800
Conventional System			
Package Plant	$1,093,200		$7,902,800
SBR			
w/ steel tanks		$1,695,000	
w/ concrete tanks		$1,567,500	
Carrousel			$7,606,200

sources so that in continued or future evaluations of the AEES process the EPA study team would not have to continue to produce an independent water quality data set for performance evaluation.

Although some of the data sets were considered to show statistical similarities, the T-test results did not suggest that these similarities existed throughout the data. The best similarities were found between the USEPA data sets and those produced by the certified laboratory at the Ballenger Creek WWTP. Similarities between analytical parameters were best between the results for TSS, TKN, ammonia and total phosphorus. The lack of statistical similarity between the different data sets are almost certainly a result of sampling and analytical variations between the USEPA and OAI data. A simple visual inspection of the data sets indicated that the data were more similar than the T-tests had implied.

Therefore, although statistical dissimilarities exist, an objective examination of any one of the three data sets will lead to the same conclusions regarding performance capabilities of the AEES process. Consequently, it can be concluded that the data generated by OAI are reliable and could be used in the future for an objective assessment of system performance.

13.6 Role of Plants in the AEES Process

As shown on Figure 2-1, prepared by Ocean Arks, plants supported by solar energy are included on almost every unit in the AEES system and their contribution is believed essential to the performance of the process. Having committed to plants and solar energy the design logic then requires the use of a greenhouse when colder seasonal climates prevail, for protection and continued year-round growth of the plants. A commitment to a greenhouse then creates a design dilemma since the high cost of the space enclosed by a

greenhouse then requires deep high rate treatment units for cost effective use of that space. Such high rate units then minimize the surface areas available for utilization of plants so the role of the plants is diminished as is the original highly desirable intent to utilize plants and solar energy as major components in the system. A treatment system based on the use of plants and solar energy as major components must provide sufficient surface area so the plants are in fact a major physical presence in the system.

Plants were utilized on all of the treatment units at the AEES facility in Frederick, MD and are intended for similar use at the 80,000 gpd facility under construction in South Burlington, VT. The plants are considered essential for treatment on some units and for horticultural purposes on others, depending on the plant species used. Regardless of their purpose, the presence of these plants in the AEES greenhouse creates an aesthetically pleasing and often beautiful environment unlike any other conventional wastewater treatment system.

As discussed in a previous section, at the plant density and harvesting schedule used in the Frederick AEES facility the plant uptake of pollutants and then removal via harvesting accounts for a negligible fraction of pollutant removal in the system. The major removal mechanisms are believed to be microbial activity and physical separation of particles via settling and filtration. It is believed that the floating plants can contribute to this microbial activity through colonization of their root systems by the organisms responsible for treatment and this was the intent of the floating macrophytes used on the two aeration tanks at Frederick, MD.

The plants were present, and completely covered the water surfaces in the aeration tanks during the first 7 weeks of the EPA study period, so their contribution to treatment is included, but cannot be separately defined, in the performance data collected during that period. At the suggestion of the EPA study team and with the concurrence of Ocean Arks all of the plants were removed from these tanks for the second phase of the study (the disposal of these plants is not included in the residuals balance discussed in a previous section). The system was allowed to come to equilibrium and then sampling and testing of system performance without these plant continued for the remainder of the period. Although wastewater characteristics might vary during the two study periods it was hoped that a comparison of the "plants" versus " no plants" operational periods might help define the treatment contribution of the plants. A detailed discussion and data comparisons can be found in Section 12 of this report.

There is no significant difference, without the plants, for removal of COD, BOD_5, TSS, VSS and phosphorus when the data in Table 12.2 (without plants) is compared to Table 9.2 (with plants), for either the final system effluent or just the effluent from the aerated tanks. There are slight, but significant differences for the nitrogen forms. The TKN and ammonia are lower and the nitrate levels are higher when the aerated tanks contain plants. The nitrate concentrations leaving the aerated tanks is somewhat higher with plants on the tanks, suggesting that the microbial activity on the plant roots does contribute to nitrification. However, this diminished nitrification capacity without the plants can apparently be compensated by nitrification in the pumice filters so there is no major difference in performance of the overall system with or without plants on the aeration tanks. This observation has been confirmed by continued operation without the plants after the end of the EPA study period. **As a result, it can be concluded that the floating macrophytes used on the aeration tanks do not contribute significantly to treatment.** The

potential is there, but the limited surface area available on these deep tanks does not permit a sufficient number of plants to make a significant difference in performance.

The duckweed and azolla floating on the surface of the final clarifier may make a contribution to treatment by their physical presence on the water surface. Their presence on the water surface adsorbs most of the solar radiation and prevents development of algae in this tank. Such algae would be removed in the final high rate marsh at Frederick, but at the South Burlington AEES facility without a marsh this algae could have an adverse impact on final effluent quality.

Section 14

Conclusions and Recommendations

14.1 Conclusions

These conclusions are based on the evaluation of data collected during the EPA study period extending from February through late June 1995. Operation of the AEES process at Frederick, MD is expected to continue into at least mid 1996. If funding is available, a final evaluation will be conducted at that point and will consider all data. Some of the conclusions given below with respect to system performance may be modified somewhat in this final evaluation.

1. During the 11 week USEPA study period, the AEES at Frederick, MD did not, on an average basis, meet its performance goals for BOD_5, ammonia, NO_3, TN or TP. However, the removal of TSS was significantly better than the 10 mg/l performance goal.

2. Based on the data collected during this study, it is believed that the AEES has the potential to produce an effluent with: $BOD_5 < 10$ mg/l, TSS < 10 mg/l, Ammonia ≤ 1 mg/l, $NO_3 \leq 5$ mg/l, TN < 10 mg/l, and fecal coliform < 200 cfu/100ml. Optimization of methanol feed, and of the aerobic and anoxic Ecological Fluidized Beds will be required to realize this potential.

3. During the EPA study period, the concentrations of BOD_5, COD, TSS, and VSS entering the AEES process were higher than expected and this may have had some impact on system performance. On a mass basis, the system removed about twice the amount of organic pollutants it was designed for. Most of this removal occurred in the preliminary Anaerobic Bio-reactor.

4. The AEES, as presently configured and operated, cannot remove phosphorus to the desired level (≤ 3 mg/l). Some additional process modification will be necessary to achieve low phosphorus levels in the system effluent, or phosphorus removal claims for the process should be abandoned.

5. The AEES was not at true "steady state" operation during the entire study period and procedural changes by OAI staff took place during the study which were intended to improve the performance of the facility. For example, the carbon source for denitrification was changed to methanol about two thirds of the way through the study which had a significant impact on the effluent BOD_5 and nitrate levels. Functional changes at the Ballenger Creek WWTP, beyond the control of OAI, also impacted significantly on the influent wastewater characteristics at the AEES facility.

6. The Anaerobic Bio-reactor, designed by Sunwater Systems, Inc. was essential to the successful performance of the Frederick "Living Machine". It removed more COD, BOD_5, TSS and phosphorus than all of the other system components combined and also contributed significantly to solids reduction.

7. The floating macrophytes in the Aerated Tanks were shown to contribute in a minor way to nitrification, probably through microbial activity in the plant root zone. However, the AEES could achieve suitable levels of nitrification in the Ecological Fluidized Beds without any plants in the Aerated Tanks. The emergent plants on the High-rate Marsh do not appear to contribute significantly to treatment in this unit either.

8. The issue is not the basic capability of plants in providing a contribution to treatment, but rather that there are insufficient numbers of plants in the AEES greenhouse to contribute significantly. In the current AEES design there is not enough available water surface on the tanks to support the number of floating plants required. Shallow tanks with a much larger water surface area would be required, and the cost of a greenhouse to cover this increased area would be prohibitive. The main value of the plants presently used in the AEES is aesthetic, although they also have economic value as a horticultural nursery if plant species with some market value are used.

9. The High-rate Marsh at the Frederick AEES facility is also not large enough to contribute significantly to treatment. It might be possible to construct a marsh with a larger area, outside the greenhouse, and depend on the plant residues in the marsh as the carbon source for denitrification whereas, in the current process, it is necessary to add methanol as a carbon source to achieve denitrification. Denitrification can be achieved in the final, anoxic Ecological Fluidized Bed which means that the High-rate Marsh is not really necessary except for horticultural purposes.

10. The pumice gravel used in the Ecological Fluidized Beds is too soft to withstand inter-particle abrasion and particle loss during the backflushing operations that are used to clean the beds. These losses have reduced the depth of pumice by almost a foot, in some tanks, during the first year of system operation. More effective clarification ahead of these beds would reduce the filtration and backflushing requirements and, additionally, the use of a low density, abrasion-resistant material should be considered as the media in these beds.

11. The Duckweed Clarifier located after the final Ecological Fluidized Bed does not contribute significantly to treatment at the Frederick AEES. However, in future systems, a final clarifier may be necessary if the marsh is not used. The clarification provided after the Aerated Tanks at Frederick is inadequate and results in too frequent backflushing of the first Ecological Fluidized Bed. The Duckweed Clarifier could be put to use for this purpose at Frederick, if some piping changes were made.

12. The sludge and other residuals produced by the AEES at Frederick, MD are slightly less than that from a conventional extended aeration process, designed for the same performance goals and flow rates. The digestion occurring in the Anaerobic Bio-reactor at the Frederick facility is believed responsible for this difference since digestion in this unit results in a 15 to 20 percent solids reduction. If this Anaerobic Bio-reactor is not used in future "Living Machines" then residuals production would be at least comparable to conventional technology.

13. The present worth and total annual costs of the AEES process are approximately the same as conventional wastewater treatment technology at flow rates of 80,000 gpd or less. At higher flow rates the conventional processes are likely to be more economical to build and operate.. At 1,000,000 gpd, for example, the AEES

process with greenhouses would have a present worth value of $11,500,000, while a conventional oxidation ditch process would have a present worth value of $7,600,000. Both of these costs represent only the key treatment components and not a complete treatment facility. Common items such as roads, administration and laboratory facilities are excluded from both estimates. The higher AEES costs at the higher flow rates are probably a result of the need to utilize several replicates of tankage and greenhouse structures, as compared to a few large tanks for conventional systems.

14. The detention times in the AEES unit processes as measured during the USEPA study were comparable to the theoretical detention times calculated by OAI. The total detention time for the process (including the Anaerobic Bio-reactor) was 3.6 days at a flow rate of 37,000 gpd. The total detention time for the components inside the greenhouse was 2.8 days. The detention time in the Aerated Tanks was 21 hours which is comparable to conventional extended aeration activated sludge processes.

15. Statistical analysis of the USEPA study data and the OAI performance data for the Frederick facility did not suggest that, in the main, the two data sets were statistically similar. However, when the data's summary statistics were compared visually, general similarities were noted between the data sets. It was also considered that an objective assessment of either data set would reach the same conclusions regarding system performance.

16. Sludges wasted from the AEES facility in Frederick, MD are returned to the Ballenger Creek WWTP and have no further impact on operations of the AEES system. Future "stand-alone" applications of the AEES technology propose the use of reed beds for sludge dewatering and stabilization. No such system has been constructed so the impacts cannot be evaluated. It is believed that operator time will have to increase, and the necessary return of the leachate from the reed beds to the AEES process for treatment may reduce the claimed treatment capacity of the system.

17. The corrugated metal and plastic lined tanks used at Frederick are not the best choice for this service and are likely to require high costs for repair and liner replacement during a 20-year design life. A different type of tank will be used at the new facility in Vermont. This tankage, based on farm silo concepts, is bolted steel with an integral inner waterproof coating of plastic or glass. The cost effectiveness of the AEES process will be improved as the number of separate tanks required is reduced.

18. A variety of bacterial supplements and mineral and organic additives are routinely used in the AEES facility at Frederick in addition to the methanol used as a denitrification carbon source. The value of these other additives is not clear and was not evaluated during this study. Based on experience with conventional wastewater technology, effective nitrification in the AEES process should not require the continuous addition of bacterial supplements.

19. The OAI "Living Machine" claims to be an ecologically-based process supported by solar energy which is minimally dependent upon mechanical equipment and chemicals. In fact, the AEES process utilizes the same mechanical energy sources and chemicals as conventional wastewater treatment technologies designed to achieve the same performance goals. In effect, the AEES process is an extended aeration process followed by aerobic/anoxic filtration. The plants growing in the

system, and utilizing the solar energy, provide largely aesthetic and horticultural benefits.

20. A predecessor concept known as "Solar Aquatics" was also developed by OAI and the lessons learned from this earlier technology were the basis for many of the improvements utilized at the Frederick, MD facility. The "Solar Aquatics" technology is now marketed by others. It is believed that many of the technical and cost limitations of the "Living Machine" discussed in this report would apply to the "Solar Aquatics" process also.

14.2 Recommendations

1. A follow-up study of the Frederick, MD facility is recommended to validate the potential performance expectations described above. It is assumed that the Frederick system will be in true steady state operation by late fall 1995. An independent evaluation of the 1996 performance data generated by OAI would complete this effort.

2. Operational modifications to the Frederick facility should be considered by OAI. The Duckweed Clarifier is now ineffectual but, with some piping changes, it could be used as a clarifier after the Aerated Tanks. This would also require a pump to move the clarifier effluent back to the first Ecological Fluidized Bed.

3. Nitrification in the first two Aerated Tanks at Frederick could be improved by maintaining a higher sludge concentration in these tanks with sludge recycle from the modified clarifier. Nitrification could also be improved by addition of appropriate media in these tanks to provide the substrate for the nitrifier organisms.

4. The Anaerobic Bio-reactor used at Frederick is an excellent primary component in the AEES process and its continued use is recommended in future applications. Perhaps the second compartment could include a deeper, hopper-bottomed pit instead of the present configuration. This would allow more time for digestion and sludge storage, and reduce the frequency of sludge wasting.

5. The 80,000 gpd AEES in South Burlington, VT should be operational In late 1995. This facility incorporates modifications and "lessons learned" from the Frederick facility, and it also must operate in a colder climate. An independent evaluation of the OAI performance data from this facility in late 1996 would establish the capabilities of this modified system.

Section 15

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Appendix A

Quality Assurance Project Plan

This Appendix contains the Quality Assurance Project Plan (QAPjP) for the process evaluation of the Ocean Arks AEES in Frederick, MD. The QAPjP describes the Quality Assurance Plan organization and responsibilities, the objectives of the plan and the sampling and analytical procedures used on the project.

FINAL

QUALITY ASSURANCE PROJECT PLAN

EVALUATION OF ALTERNATIVE WASTEWATER TREATMENT TECHNOLOGIES

CONTRACT NO. 68-C2-0102
WORK ASSIGNMENT NO. 3-18

SUBMITTED BY:

PARSONS ENGINEERING SCIENCE, INC.

REVIEWED AND APPROVED BY:

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PARSONS ES PROJECT MANAGER:	LAUREN FILLMORE	2/27/95 DATE
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ABBREVIATIONS LIST

QAPjP	Quality Assurance Project Plan
EPA	Environmental Protection Agency
OWEC	Office of Wastewater Enforcement and Compliance
O&M	Operation and Maintenance
AEES	Advanced Ecologically Engineered System
OA	Ocean Arks International
QA	Quality Assurance
COD	Chemical oxygen demand
BOD	Biochemical oxygen demand
TSS	Total suspended solids
VSS	Volatile suspended solids
TKN	Total kjeldahl nitrogen
NH_4	Ammonia
NO_3	Nitrate
TP	Total phosphorus
DO	Dissolved oxygen
Parsons ES	Parsons Engineering Science, Inc.
LD	Laboratory Director
QAC	Quality Assurance Director
QAM	Quality Assurance Manager
PM	Project Manager
TD	Technical Director
MDL	Method detection limit
RPD	Relative percent difference
PRR	Percent recovery range
L	Liter
HRT	Hydraulic retention time
WWTP	Wastewater treatment plant
COC	Chain of custody
NPDES	National Pollutant Discharge Elimination System

SECTION 1

PROJECT DESCRIPTION

1.1 GENERAL OVERVIEW

The evaluation of new technologies for wastewater treatment is supported by the United States Environmental Protection Agency (EPA) as required by Section 201 of the Clean Water Act. Technology transfer programs in the Office of Wastewater Enforcement and Compliance (OWEC) are designed to allow new and emerging technology development. OWEC often evaluates new wastewater treatment processes or applications to verify performance, since information provided by the developer of the technology is sometimes incomplete. These evaluations are beneficial in answering design-related questions, identifying specific weaknesses or limitations, providing cost data, and resolving operation and maintenance (O&M) problems. In addition, the results of the evaluation may identify a specific range of conditions under which the process or technology demonstrates maximum or minimum performance efficiency. These technology evaluations are an essential first step in disseminating actual field data on the operation of selected processes or techniques.

The wastewater control technology evaluated in this study is the Advanced Ecologically Engineered System (AEES) developed by Ocean Arks International (OA), a non-profit educational and research institution. The purpose of this study is to gather reliable data and information on the effectiveness of the AEES technology for wastewater treatment.

1.1.1 Description of the Advanced Ecologically Engineered System

In May 1992, the House Subcommittee on Fisheries and Wildlife Conservation hearings featured the potential benefits of using advanced ecological engineering of living systems to clean wastewater. Since this time, federal funding totaling $3.75 million has

been provided by congress for the development and evaluation of OA's AEES demonstration facilities in Maryland, California, Vermont, and Massachusetts.

The Maryland AEES facility, which is located on a one quarter acre lot in Frederick, was constructed in 1993 and is currently operational. This facility incorporates the experience gained from previous OA systems in Massachusetts, Vermont, and Rhode Island, and represents a second generation design of what OA terms a 'Living Machine". The system is designed to clean wastewater to advanced wastewater treatment standards using a natural, solar-powered greenhouse instead of chemicals. The Frederick facility is the focus of the independent testing program to be conducted under this work assignment, since the facilities in California and Vermont are either under construction or in the planning stages.

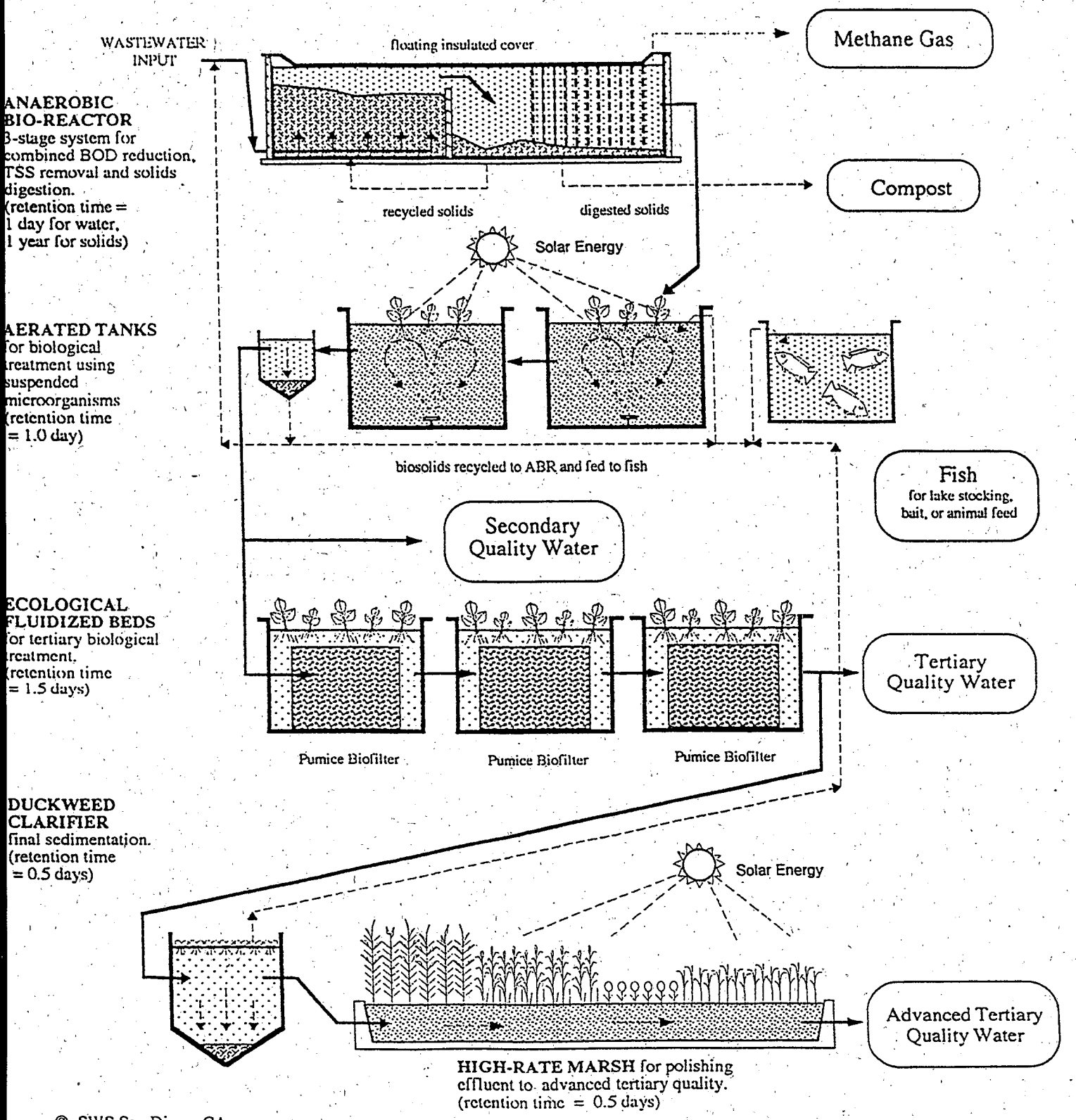
The Frederick facility, which is called Ballanger Creek AEES, takes sewage from the neighboring Ballanger Creek Sewage Treatment Plant. The screening and degritting operations at the treatment plant are not very effective, therefore, AEES often receives influent that contains scum and grit. The AEES system was originally designed for 40,000 gallons per day (gpd) maximum steady state flow, but the recorded flows have been closer to an average of 33,000 gpd. The lower flow rates are due to a higher strength sewage than anticipated and also the design capacity of the anaerobic bio-reactor (approximately 30,000 gpd). During the proposed study period, it is anticipated that the three treatment trains will run at approximate flow rates of 13,300 gpd, 10,000 gpd and 13,300 gpd.

The process begins when raw wastewater is pumped from the treatment plant to the AEES. Once at the AEES, primary treatment of the wastewater occurs in an outdoor anaerobic bio-reactor, as shown in Figure 1-1. Wastewater is retained within this stage of treatment for approximately 24 hours, during which time the organic wastewater constituents are partially broken down by bacteria in the absence of oxygen. Flow from the bio-reactor is then pumped into one of three treatment trains; the AEES has three parallel secondary and tertiary treatment trains.

FIGURE 1-1

PROCESS FLOW DIAGRAM FOR THE BALLENGER CREEK LIVING MACHINE

A demonstration project of an innovative ecological wastewater treatment technology in Frederick, Maryland. The system is designed, and managed by Ocean Arks International. The project is funded U.S. EPA.



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Secondary treatment takes place in two aerated tanks in series, followed by a secondary clarifier. Wastewater is retained in the aerated tanks for approximately 24 hours (12 hours in each tank) before flowing through the secondary clarifier. Floating plants such as duckweed, water hyacinths, and pennywort are contained in the aerated tanks. Flow from the secondary clarifier is then pumped into one of the three tertiary treatment units. Tertiary treatment is achieved in three pumice stone filters located in series, followed by a tertiary clarifier. Wastewater is retained in the pumice stone filters for approximately 36 hours, the buoyant pumice stones in these tanks providing additional surface area for microbial growth. The pumice stone filters also contain plants such as duckweed, oregano, cedar, foxtail, and elephant ears. Wastewater flow from the pumice stone filters is then pumped into one of three high-rate marshes, which contain various plant species; any accumulated sludges are settled out and removed at the tertiary clarifier tanks prior to the marshes. Each marsh has a capacity of 4,000 gallons and a retention time of 10 hours. The gravel media and plant roots in the marshes perform the final treatment of the effluent to meet advanced wastewater treatment standards.

Other demonstration facilities in California, Vermont, and Massachusetts will be evaluated as part of this work assignment. The facility under construction in San Francisco, California, is a skid-mounted demonstration polishing facility designed to treat approximately 30,000 gpd of secondary effluent to meet California Title 22 reuse standards (oxidized, filtered to a very low turbidity standard, and disinfected to 2.2 coliforms per 100 ml). This facility is planned to be operated for a minimum of six months.

The Chittenden County, Vermont facility is currently in the planning and design stage. It is intended to treat approximately 80,000 gpd. The design is based on the same principles used in Frederick and San Francisco but adapted to Vermont climatic conditions and wastewater influent temperatures.

The Harwich, Massachusetts, demonstration project involves the evaluation of a "Lake Restorer" bioremediation system located in Flax Pond in this community. Flax

Pond is polluted due to long-term seepage from adjacent septage pits over the years. Ammonia nitrogen is believed to be the pollutant of major concern. The Lake Restorer device is essentially an airlift unit suspended from a floating raft. The airlift raises pond water through a media and over the vegetated surface of the raft.

1.1.2 Laboratory Selection Criteria

The laboratory or laboratories selected for this study will conform to the following criteria:

- Have an active quality assurance (QA) program that is based on a written QA protocol;
- Have a designated QA staff member with the authority to implement corrective actions; and
- Have demonstrated good analytical performance based on a federal or state performance sample program, or a sample splitting program.

Specific QA components that will be evaluated for the laboratory will include the following:

- Documentation of routine quality control analyses including spikes, duplicates, blanks, unknowns, calibration standards, detection level standards, and performance standards;
- Assignment of sample accession numbers to all samples to ensure proper cross-reference of analytical results;
- Proper sample storage procedures to ensure sample integrity;
- Documentation of routine maintenance of analytical instruments;
- Documentation of routine calibration of analytical instruments;
- Certification or training of laboratory staff in general laboratory procedures and specialized instrumentation; and
- Documentation of the successful use of corrective actions and follow-up evaluations to identify, resolve, and prevent problem conditions.

1.1.3 Statement of Project Goals

The goals of this study are to:

- Evaluate the performance capabilities and cost effectiveness of the AEES technology under demonstration in Maryland;
- Compare the influent, effluent and sludge data gathered by Parsons ES to influent, effluent, and sludge data gathered by OA and analyzed by a certified laboratory to determine the possibility of using OA influent, effluent, and sludge data in the evaluation. The degree of water quality sampling will be kept flexible to consider the use of the OA data analyzed by the certified laboratory;
- Comparison of the capital and operation and maintenance costs of the demonstration facilities to more conventional wastewater treatment approaches for meeting the same water quality objectives;
- Prepare one draft report that includes process descriptions of the Living Machine technologies (i.e., direct observation and literature comparisons), findings on the Ballanger Creek AEES process performance evaluation, and comparisons to conventional wastewater treatment systems (e.g., land treatment, sand filters, BNR);
- Prepare a second draft report that provides an assessment of the status and potential for future application of the Living Machine technology for wastewater treatment; and
- Prepare two final reports based on revisions made to the two draft reports.

1.2 EXPERIMENTAL DESIGN

The Ballanger Creek AEES performance study will consist of the following tasks:

- Flow monitoring;
- Tracer study;
- Performance evaluation;

- Residuals testing; and
- Collection of available, existing data at OA AEES facilities in California, Vermont, and Massachusetts.

A brief description of these tasks is presented in the following paragraphs.

Flow Monitoring: Influent and effluent flows will be monitored and recorded to determine the average daily influent and effluent flow rates through the Ballanger Creek AEES.

Tracer Study: A tracer study will be conducted to determine the detention time within each major system component of the selected treatment train. Lithium chloride will be the tracer compound that is used due to its conservative properties. The detention time for seven components of the system will be determined. Discrete wastewater samples will be collected hourly up to three times the theoretical detention time and will be analyzed for lithium concentration.

Performance Evaluation: A performance evaluation will include water quality testing to determine the treatment achieved in the selected treatment train. Water quality parameters that will be tested for include total and soluble chemical oxygen demand (COD), total and soluble biochemical oxygen demand (BOD), total suspended solids (TSS), volatile suspended solids (VSS), total kjeldahl nitrogen (TKN), ammonia (NH_4), nitrate (NO_3), total phosphorus (TP), pH, dissolved oxygen (DO), temperature, and fecal coliform. Grab samples will be collected for measurement of pH, DO, temperature, and fecal coliform; the remainder of the samples will be 24-hour composite samples.

Residuals Testing: Analytical testing will be conducted on the process' residuals (i.e., sludge and plants) to determine the characteristics of the residuals resulting from the wastewater treatment process in the selected treatment train. Residual samples will be tested for pH, percent solids (sludge only), TKN, TP, fecal coliform, and the Part 503 metals.

Data Collection at Other OA Facilities: All available data from OA systems in California, Vermont; and Massachusetts will be obtained through site visits. Key areas of information to be obtained will include design, operation and maintenance requirements, performance data, and applicability. Design and cost data are the only information available for the Vermont system since this facility is still in the planning and design stage.

1.3 CRITICAL VERSUS NON-CRITICAL MEASUREMENTS

Critical measurements are defined as "measurements that are necessary to achieve the project objectives" (EPA, 1989). Procedures for critical measurements will follow EPA-approved methods as described in Section 3. A list of critical measurements to be performed is provided in Table 1.1. Table 1.1 also lists non-critical measurements, which will be analyzed to better define process operations, document process control data, or provide general background information. The system conditions (i.e., test operating parameters and process controls) for each measurement are noted in Table 1.1. System conditions are defined as parameters that are routinely monitored to ensure proper operating conditions for critical measurements.

1.4 SCHEDULE

The time sequence of the study components is presented in Table 1.2. The study will be conducted over an approximate seven month period. Assuming approval of the site-specific Quality Assurance Project Plan (QAPjP), the field activities will tentatively begin in mid-March, 1995. Prior to beginning field activities, an initial background review of the Ballanger Creek AEES wastewater, flow, and sludge data will be conducted. The facility has been operational for nearly one year and during this time wastewater and sludge samples have been taken to determine the effectiveness of the treatment system. Effluent flow rates from three treatment trains have also been monitored. This historical OA data will be collected and reviewed. Since changes have been made to the three treatment trains to make the system more effective, some of the historical OA data obtained may not be appropriate for comparison to the current treatment system. The

TABLE 1.1

CRITICAL AND NON-CRITICAL MEASUREMENTS

Measurement	Matrix	System Conditions	Responsible Party
Critical Measurement			
Conventional Pollutant Analysis:			
COD, total	Water	Instrument	Parsons ES Atlanta Laboratory
COD, soluble	Water	Calibration	Parsons ES Atlanta Laboratory
BOD, total	Water	"	Parsons ES Atlanta Laboratory
BOD, soluble	Water	"	Parsons ES Atlanta Laboratory
TSS	Water	"	Parsons ES Atlanta Laboratory
VSS	Water	"	Parsons ES Atlanta Laboratory
TKN	Water	"	Parsons ES Atlanta Laboratory
TKN	Sludge/Plant tissue	"	Parsons ES Atlanta Laboratory
NH_4	Water	"	Parsons ES Atlanta Laboratory
NO_3	Water	"	Parsons ES Atlanta Laboratory
TP	Water	"	Parsons ES Atlanta Laboratory
TP	Sludge/Plant tissue	"	Parsons ES Atlanta Laboratory
pH	Water	"	Parsons ES Atlanta Laboratory
Fecal coliforms	Water/Sludge/Plant tissue	"	Parsons ES Atlanta Laboratory
Part 503 Metals	Sludge/Plant tissue	"	Parsons ES Atlanta Laboratory
Tracer Study:			
Lithium	Water	"	Parsons ES Atlanta Laboratory
Flow Monitoring:			
Flow	Water	"	Parsons ES Field Team
Non-Critical Measurements			
Dissolved oxygen (field)	Water	"	Parsons ES Field Team
pH (field)	Water	"	Parsons ES Field Team
Temperature (field)	Water	"	Parsons ES Field Team

TABLE 1.2 PROJECT SCHEDULE

Task Description	Date
Start of Data Collection and Review of OA Data from Frederick facility	February 1, 1995
Submission of Quality Assurance Project Plan and Health and Safety Plan	February 15, 1995
Start of Technical Direction	February 1, 1995
Start of Field Testing	February 27, 1995
Start of Additional Field Testing	9 weeks after start of field testing
Start of Data Collection from OA facilities in MA, VT, and CA	June 1, 1995
Submission of draft "Future Potential of Living Machine Technology" report	August 15, 1995
Submission of draft "Frederick AEES Living Machine System" report	August 15, 1995
Receipt of comments on draft reports	September 1, 1995
Submission of final reports	September 30, 1995

changes that have taken place and the reasons for the alternations will be obtained during the background review.

Field data collection will begin in late February and is anticipated to continue for 9 weeks. The data collection will be extended 4 weeks if OA data analyzed by the certified laboratory does not statistically compare to the gathered Parsons ES data. The extended sampling period will provide additional data for the database and a broader view of the treatment achieved by the system. Following data collection and evaluation, two draft reports will be submitted to the EPA. Based on EPA revisions, revised draft reports will be submitted for EPA's peer review process. Two final reports will be submitted to the EPA following incorporation of peer review comments and EPA approval.

1.5 QUALITY ASSURANCE PROGRAM ORGANIZATION AND RESPONSIBILITIES

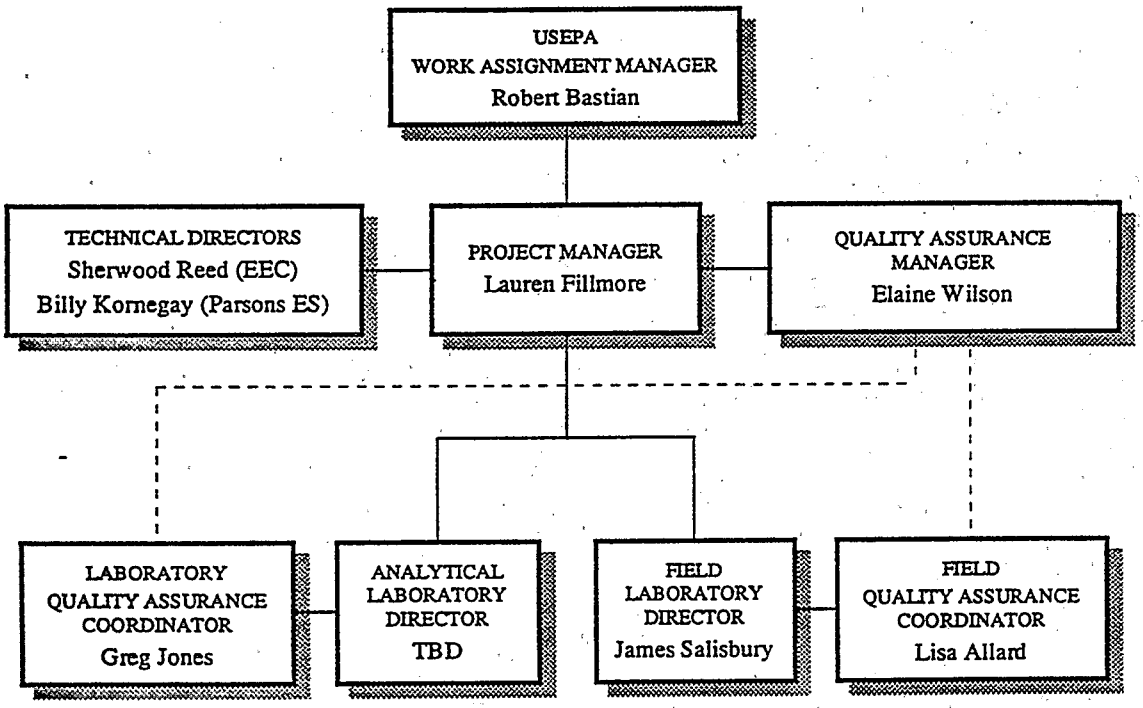
Quality assurance program organization for this study is shown in Figure 1-2 and includes individuals from each party participating in the study. Due to the need for specialized expertise in natural systems for the treatment of wastewater, Parsons Engineering Science, Inc. (Parsons ES) will use the services of Environmental Engineering Consultants (EEC) to complete the assignment. Parsons ES will have overall responsibility for QA. Parsons ES Atlanta Laboratory will have QA responsibility for their portion of the work.

To implement an effective QA program, the QAPjP includes the following assignments:

- Laboratory Director (LD) - The laboratory and field monitoring organizations will each assign a LD who will be responsible for maintaining daily quality control of all sampling and analysis activities;
- Quality Assurance Coordinator (QAC) - The laboratory and field monitoring organizations will each assign a QAC who will be responsible for confirming

FIGURE 1.2

QUALITY ASSURANCE PROGRAM ORGANIZATION



quality control of all laboratory or field activities by conducting monthly internal QA reviews;

- Quality Assurance Manager (QAM) - A QAM will be assigned to the project who will be responsible for overall project QA and for coordinating QA activities of the laboratory and field monitoring organizations;
- Project Manager (PM) - The PM will interact with the QAM to ensure that the QA objectives for the project are achieved; and

Technical Director (TD) - The project TD will ensure that quality assurance is addressed in all technical management aspects of the study.

1.5.1 Responsibilities

As shown in Figure 1-2, the LDs from each organization will provide quality control (QC) data to the organization's QAC. QACs will report to the QAM and the QAM will report to the PM. The QA organization can function independently of the technical management organization. Responsibilities of each of the QA staff are outlined as follows:

Laboratory Director: The LD maintains daily QC of all laboratory/field activities by:

- Ensuring that QC documentation including chain of custody (COC) forms, laboratory notebooks, calculations, analytical data, and QC data is compiled;
- Maintaining QC procedures including calibration and internal standards, duplicate analyses, and spike sample analyses;
- Maintaining acceptable analytical and reporting schedules to ensure that sample analyses or field measurements are performed in a timely manner;
- Preparing monthly reports using LD Form 1 (Section 4), which summarizes laboratory and/or field analytical results, QC analytical results, and any corrective action(s) required and performed.

Quality Assurance Coordinator: The QAC monitors the performance and adequacy of the QC checks for all laboratory and/or field activities by:

- Verifying documentation by reviewing COC forms, laboratory notebooks (or other appropriate data reporting systems), calculations and analytical data, QC data, and the LD Form 1;
- Verifying the performance of QC procedures including calibration and internal standards, duplicate analyses, and spike sample analyses;
- Preparing monthly reports using QAC Form 1 (Section 4), which consists of the QAC's comments on the review of analytical or field QC data including identification of possible QC discrepancies;
- Preparing special reports to notify the QAM and/or PM (within 24 hours) of any discrepancies or required corrective actions;
- Maintaining and updating the organization's QA file, which will include LD Form 1, QAC Form 1, and any special reports to the QAM and/or PM.

Quality Assurance Manager: The QAM maintains and coordinates QA of all laboratory and field activities by:

- Verifying results from LD Form 1;
- Verifying QA activities noted in QAC Form 1;
- Verifying that reports are reviewed by the Technical Directors and that they have signed a project review sign-off sheet, as required by the Project Management Plan (ES, 1992);
- Verifying that the analytical schedule is being met;
- Preparing monthly reports using QAM Form 1 (Section 4), which summarizes analytical results and field data, QC analytical results, QC discrepancies, and corrective actions taken to address QC discrepancies; and
- Maintaining and updating the project QA files, which include LD Form 1, QAC Form 1, QAM Form 1, and any additional QA reports.

Project Manager: The PM ensures that overall QA objectives for the project are met by:

- Reviewing and verifying monthly QAM Form 1 reports; and
- Initiating corrective actions identified by the QAM.

Technical Director: The project TD ensures that QA program requirements are being met and that the technical objectives of the project are achieved by:

- Reviewing and verifying monthly QAM Form 1 reports.

Preparation and submittal of QA report forms is described in detail in Section 4. Table 1.1 delineates each organization's responsibility in performing the critical measurements for this study. In addition, the laboratory will be responsible for providing sample containers, receiving samples, and ensuring the sample handling procedures are followed as described in Section 3.

SECTION 2

QUALITY ASSURANCE OBJECTIVES

2.1 QUALITY ASSURANCE OBJECTIVES

The QA objective of this project is to gather sufficiently precise and accurate data to permit the evaluation of the AEES Living Machine in Frederick, Maryland. Chemical analyses of wastewater and residual samples will be conducted using EPA-approved methods. The collected data includes the following:

- Concentrations of lithium in each discrete sample collected for the tracer study;
- Concentrations of COD, BOD, TSS, VSS, TKN, NH_4, NO_3, TP in each wastewater composite sample;
- pH, dissolved oxygen, temperature, and fecal coliform in each wastewater grab sample;
- Concentrations of TKN, TP, fecal coliform, and Part 503 metals in each residual sample; and
- pH and percent solids (sludge only) in each residual sample.

The collected data should be suitable for determining the following:

- Conventional pollutant concentrations, wastewater flow rates, and tracer concentrations in the wastewater;
- Removal of conventional pollutants by the AEES; and
- Detention time of each major system component.

2.2 QUANTITATIVE OBJECTIVES

A summary of the quantitative objectives for this study are shown in Table 2.1. Descriptions of each of the QA objectives are provided in the paragraphs below.

TABLE 2.1
QUANTITATIVE OBJECTIVES

Measurement	Matrix	Method	Units	MDL (2)	Precision (3) (RPD)	Accuracy (3) (%Recovery) (PRR)	Completeness (%)
COD, total	Water	410.4 HACH	mg/l	50	20	±20	90
COD, soluble	Water	410.4 HACH	mg/l	50	20	±20	90
BOD, total	Water	405.1	mg/l	4	20	±25	90
BOD, soluble	Water	405.1	mg/l	4	20	±25	90
TSS	Water	160.2	mg/l	4	30 (4)	-	90
VSS	Water	160.4	mg/l	4	30 (4)	-	90
TKN	Water	351.3	mg/l	0.20	20	±20	90
TKN	Sludge/Plant tissue	351.3 Mod.	mg/l, mg/kg	10/TBD	30/TBD	±30/TBD	90
NH_4	Water	350.3	mg/l	0.10	20	±20	90
NO_3	Water	352.1	mg/l	0.10	20	±25	90
TP	Water	365.2	mg/l	0.01	20	±20	90
TP	Sludge/Plant tissue	365.2	mg/l, mg/kg	1.0/TBD	30	±30/TBD	90
pH	Water	Field Analysis	pH units	-	-	-	90
Temperature	Water/Sludge	Field Analysis	°C	-	-	-	90
Dissolved Oxygen	Water/Sludge	Field Analysis	mg/l	-	-	-	90
Lithium	Water	SM3111B	mg/l	0.020	20	±20	90
Fecal coliforms	Water	SM9221E	mg/l	-	-	-	90
Fecal coliforms	Sludge/Plant tissue	SM9221E Mod.	mg/l, mg/kg	-	-	-	90
Part 503 Metals	Sludge/Plant tissue	(1)	mg/l, mg/kg	Various	30	±30	90
Percent solids	Sludge	3540	%	0.001%			90

(1) Methods 206.2, 213.1, 218.1, 220.1, 239.1, 245.1, 246.2, 249.1, 270.2, 289.1, or 200.7
(2) Estimated MDL's which may vary based upon sample matrix effects.
(3) Based upon laboratory control (LCS)/laboratory control duplicates (LCSD).
(4) Based upon values of > or = 40 mg/l on TSS and VSS. Lower concentrations may result in greater variability.

2.2.1 Precision

Precision objectives for all of the chemical analyses, except those for pH, are presented as relative percent difference (RPD) of duplicate analyses. The precision objectives for pH are listed in pH units and are expressed as limits for duplicate analyses. The duplicate or matrix spike duplicate analyses will be performed on at least 10 percent of the samples collected for analysis. In cases where more than two replicate observations are made, a relative standard deviation will be utilized as an estimator of precision. Equations used to estimate precision are presented in Section 4.

2.2.2 Accuracy

Accuracy objectives are expressed as the percent recovery range (PRR) for spiked samples. Accuracy objectives for TSS, VSS, fecal coliform, DO (field measurement) and pH (field measurement) are not available for this study. Ten percent of the samples collected for chemical analysis will be spiked. Laboratory control samples will be used to determine accuracy for BOD and COD analyses.

2.2.3 Method Detection Limits

Method detection limits are presented in Table 2.1.

2.2.4 Completeness

Completeness objectives for chemical analyses are to obtain 90 percent of all data within allowable limits for precision and accuracy.

2.3 QUALITATIVE OBJECTIVES

2.3.1 Representativeness

The objectives of the sampling program are to collect samples that will be representative of the sample type. For example, 24-hour composite samples of wastewater will be collected from the research site once per week over a period of several

weeks to account for daily variation in pollutant parameters. This data and potentially the existing OA data will be analyzed for possible trends in daily variation. If such trends become apparent, the sampling schedule will be modified accordingly to maintain the QA objectives. The field activities will continue for a minimum of 9 weeks, and will not address seasonal variation.

2.3.2 Comparability

Standard measurement units for all critical measurements are listed in Table 2.1.

2.4 IMPACT OF NOT MEETING QUALITY ASSURANCE OBJECTIVES

The overall impact of not meeting one or more of the QA objectives will be to reduce the validity of the database. Therefore, whenever possible, samples will be reanalyzed if the data are outside the allowable QA objectives.

SECTION 3

SAMPLING AND ANALYTICAL PROCEDURES

3.1 SAMPLING OBJECTIVES

The main objective of the sampling program is to (1) collect representative samples of wastewater from the selected treatment train in the AEES, (2) measure wastewater flows, and (3) define the detention time in major system components. The assumption of representativeness for the conventional pollutant analytical samples will be satisfied by collecting samples using sampling techniques that are appropriate to the particular waste stream. The variability of the constituents in the wastewater will be assessed by collecting sufficient samples over a period of time.

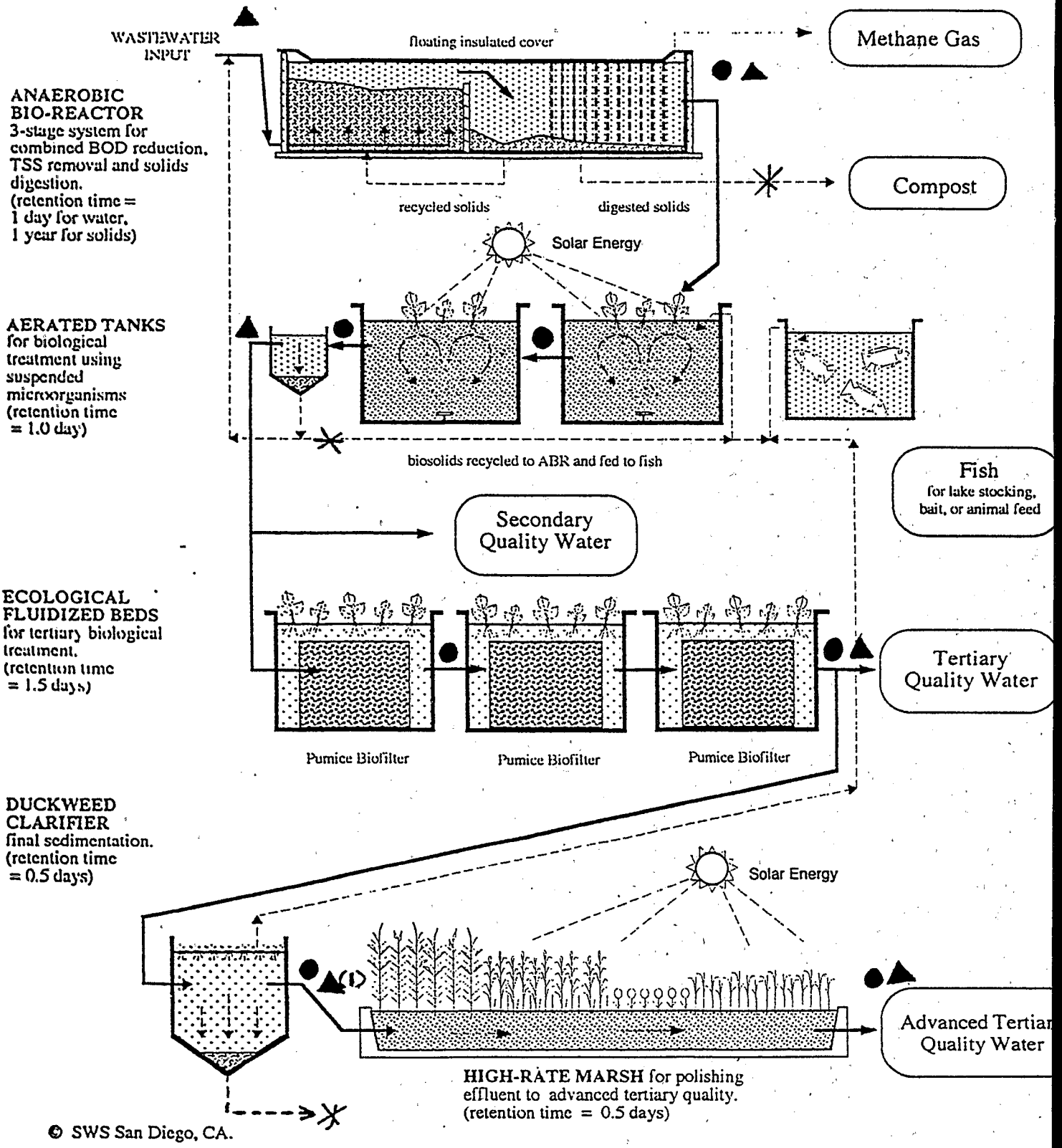
3.2 SAMPLING LOCATIONS

3.2.1 Flow Monitoring

The AEES currently has flow monitoring devices on the three discharge pipes from the marsh unit. These devices have provided OA with accurate effluent flow data. Effluent flow data recorded from the monitoring device will be used to determine the average daily flow through the selected treatment train. Influent flow monitoring devices are not currently installed at the facility. As a result, a flow monitoring device will be installed on the influent pipe to the first aeration tank of the selected treatment train for this evaluation. Data from the influent monitoring device will be used to determine the average daily flow into the selected treatment train. The OA effluent flow meter and the influent flow meter will be calibrated prior to the start of the field studies.

AEES FACILITY IN FREDERICK

A demonstration project of an innovative ecological wastewater treatment technology in Frederick, Maryland. The system is designed, and managed by Ocean Arks International. The project is funded U.S. EPA.



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✳ Sludge Sampling Location
▲ Water Quality Sampling Location
● Tracer Study Sampling Location

(1) may be moved to after first pumice stone filter.

3.2.2 Tracer Study

The tracer study will be performed at several locations throughout the system, as shown in Figure 3-1, to determine the detention time and performance of the major system components. Wastewater samples will be collected at the following seven locations:

- Marsh;
- Final clarifier;
- Three pumice stone filters in series;
- First pumice stone filter;
- Two aerated tanks in series;
- First aerated tank; and
- Anaerobic bio-reactor.

The tracer study will conducted at the end of the process train and work forward to prevent any influence from previous tests.

3.2.3 Performance Evaluation

The performance evaluation will include water quality testing. Wastewater samples will be collected from the following six sampling locations, as shown in Figure 3-1:

- Raw sewage to anaerobic bio-reactor;
- Anaerobic bio-reactor to first aeration tank;
- Clarifier following second aeration tank to first pumice stone filter;
- Third pumice stone filter to final clarifier;
- Final clarifier to marsh; and
- Marsh effluent.

There has been some discussion about the usefulness of the sampling location from the final clarifier to the marsh. OA indicates that there is little difference in the water

quality from the third pumice stone effluent to the final clarifier effluent. There does appear, however, to be a significant difference in water quality from the first pumice stone filter to the second pumice stone filter. If after review of OA data this is indeed the case, then the sampling location will be switched to the area between the first pumice stone filter and the second pumice stone filter.

3.2.4 Residuals Testing

Wastewater sludge samples will be collected from three locations in the treatment process including the anaerobic bio-reactor, the clarifier after the aerated tank, and the final clarifier after the pumice stone filter. Five plant samples will be collected in the treatment process (locations to be determined).

3.3 SAMPLING SCHEDULE

The field activities are anticipated to begin in late February 1995, and will continue for approximately 9 weeks (13 weeks, if necessary). Flow rate measurements and the tracer study will be performed in conjunction with the water quality sampling.

3.4 SAMPLING PROTOCOL

3.4.1 Sampling Equipment

The sampling equipment used in this study will consist of automatic Isco samplers and manual aids such as sampling poles. All sampling equipment that is placed in direct contact with the sample will be made of, or lined with, inert non-toxic plastic materials, Teflon, stainless steel, or glass, and will be equipped with lids made of similar material. The required container type is shown in Table 3.1. All sampling equipment, including automatic samplers will be cleaned and inspected on a routine basis.

Prior to the start of the first sampling round, reusable automatic sampler tubing will be scrubbed with hot water and detergent then rinsed several times with tap water, followed by distilled or deionized water and finally rinsed three times with the wastewater

TABLE 3.1

SAMPLE VOLUMES, CONTAINERS, PRESERVATION TECHNIQUES AND HOLDING TIMES

Analysis	Matrix	Minimum Quantity Required	Container Type	Sample Preservation	Maximum Holding Time (days)
COD, total and soluble	Water	0.25 L	Plastic	2 ml H_2SO_4/l < pH 2	28
BOD, total and soluble	Water	1.0 L	Plastic	4°C	2
TSS	Water	1.0 L	Plastic	4°C	7
VSS	Water	-	Plastic	4°C	7
TKN	Water	1.0 L	Plastic	2 ml H2SO4/ L	28
NH4	Water	-	Plastic	2 ml H2SO4/ L	28
NO3	Water	-	Plastic	2 ml H2SO4/ L	14
TP	Water	-	Plastic	2 ml H2SO4/ L	28
Lithium	Water	0.25 L	Plastic	1 ml HNO_3	6 months
Fecal coliforms	Water	0.12 L	Sterile plastic	4°C	6 hours
Fecal coliforms	Sludge/Plant	0.12 L / 10 g	Sterile plastic	4°C	6 hours
Part 503 metals	Sludge/Plant	1.0 L / 10 g	Plastic	4°C	6 months
TP	Sludge/Plant	1.0 L / 10 g	Plastic	4°C	28
TKN	Sludge/Plant	- / 10 g	Plastic	4°C	28
Percent solids	Sludge	-	Plastic	4°C	28

to be sampled. After the sampling event, the tubing and collection container will be rinsed with tap water. Prior to subsequent sampling events, the tubing and collection container will be flushed three times with the wastewater being tested. A dedicated automatic sampler will be located at each sampling location. Each automatic sampler will be calibrated according to manufacturer specifications. A notebook will be maintained by the person performing the sampling and will note the cleaning, inspection, and calibration of all samplers used in this study. Manual sampling aids such as sampling poles will be designated for sampling only one type of sample (i.e., pumice stone filter effluent). This equipment will be rinsed with the wastewater being sampled and wiped clean prior to each sample collection.

All sampling containers and labels will be supplied by the laboratory. Whenever possible, new sample containers supplied and cleaned by the laboratory will be used and will not require pre-cleaning by the field team. Prior to initial sample collection, sampling containers (Isco automatic sampling containers, grab samplers) will be cleaned according to the following standard EPA procedures:

- Wash with synthetic, biodegradable, non-phosphate detergent;
- Rinse with hot tap water;
- Rinse with 20 percent hydrochloric acid;
- Rinse with tap water;
- Rinse with 20 percent nitric acid;
- Rinse with tap water;
- Rinse with distilled or deionized water; and
- Allow to dry.

All cleaning using the above procedure will be conducted in areas of adequate ventilation and away from areas that could subject the freshly cleaned equipment to airborne contamination. Further, personnel engaged in cleaning will wear appropriate dress including laboratory coats and safety glasses.

3.4.2 Sampling Procedure

Wastewater samples will be collected from six locations once per week for at least nine weeks by Parsons ES personnel and will consist of 24-hour, time-proportioned composite samples collected with portable automatic samplers and grab samples. Samples will be chilled to 4°C during composite sample collection. Composite samples will be used for conventional pollutant characterizations; grab samples will be used for measurement of fecal coliform, pH, temperature, and dissolved oxygen. After collection, the wastewater samples will be stored on ice.

Samples of residual sludge and plant tissue will also be collected by Parsons ES personnel. There will be three sludge grab samples taken on different days from three locations and five plant samples taken from locations within the treatment train. The samples will be stored on ice until shipped to the laboratory. EPA procedures will be followed for all sampling.

The tracer study will be conducted by adding a solution of lithium chloride, in a single batch, to the influent of the major system component being tested. The testing will start from the end of the treatment train and proceed backwards until all components are tested. The lithium chloride solution will be prepared by dissolving seven pounds of dry lithium chloride in each ten gallons of water required. Approximately one gallon of the solution will be needed for every 10,000 gallons per day of actual flow into the treatment train. As a significant amount of heat is released during the dissolution of the lithium chloride, care must be exercised during preparation of the solution.

Sampling of the effluent from the system component being tested will begin after one-quarter of a theoretical hydraulic retention time (HRT) has passed and will continue up to three times the theoretical HRT. Discrete samples will be collected on an hourly basis using an automatic discrete sampler. Samples will be collected in plastic containers.

Influent and effluent flow rates will be measured for one of the treatment trains. The effluent flow meter has been installed by OA staff. The instantaneous effluent flow

rate is currently recorded, however, the software for totalizing the flow is not yet functional. At this time OA staff perform calculations to obtain the totalized effluent flow. Flow data will be obtained in this manner if the software is not available at the time of the sampling. The OA calculations will be reviewed to verify the results of the calculations. An influent flow meter will be installed to the selected treatment train. The flow meters will be calibrated prior to the start of the sampling session. Documentation of the calibration will be retained in the project file.

3.4.3 Sample Transfer

Samples for this study will be analyzed by the Parsons ES laboratory, with the exception of fecal coliform. Fecal coliform will be analyzed by a certified laboratory, different to that already used by OA for coliform analyses. The fecal coliform samples will be hand delivered to this laboratory. Other samples will be delivered via an overnight courier service to the Parsons ES laboratory in compliance with hazardous waste transport regulations. All samples will be delivered in iced containers within 24 hours of sample collection. Samples which are not immediately delivered to the laboratory will be stored at 4°C in a secured refrigerator. Upon receipt of the sample by the laboratory, the sample will be immediately refrigerated or analyzed. The laboratory will receive chain of custody forms and field sheets for each sample.

3.5 SAMPLE HANDLING

3.5.1 Sample Preparation

A sufficient volume of wastewater will be collected to conduct the chemical analyses. The minimum sample volume required for each chemical analysis is presented in Table 3.1. Composite samples will be stored in an iced or refrigerated container during collection. Immediately following collection, the samples will be preserved according to the techniques listed in Table 3.1. The lids of the sample containers should be taped shut and samples will be shipped to the laboratory in iced coolers to maintain a temperature of 4°C or less. A description of the type of container, container preparation, and

preservation techniques for each critical measurement is presented in Table 3.1. The following information will be collected for each sampling event:

- Date and time that each sample is collected;
- Weather conditions;
- Field pH, temperature, and dissolved oxygen for each wastewater and sludge sample; and
- Narrative description of the sample during sample collection (color, plant type, etc.).

3.6 SAMPLE CUSTODY

Sample custody will consist of the following procedures:

- Chain of custody (COC);
- Sample labeling;
- Sample receipt and documentation; and
- Sample storage and security.

3.6.1 Chain of Custody

The COC is a documentation mechanism for tracking a sample from the time of its collection through its delivery to the analytical laboratory (Figure 3-2). The chain begins with the sampling person who will initiate a COC form for each sample. As the samples are passed from individual to individual, the transfers will be noted on these forms. This process will continue until the samples are delivered to the laboratory, where the receipt of each sample listed on the COC form will be verified and the form will be signed as received and entered into the project file.

The COC form will document the material sampled, location sampled, and the number and type of containers collected and shipped to the laboratory. The form must be completed in accordance with the designations stated in this QAPjP to minimize

FIGURE 3-2

PARSONS ENGINEERING SCIENCE, INC.

CHAIN OF CUSTODY RECORD

ES JOB NO.	PROJECT NAME/LOCATION:	PRESERVATIVE REQUIRED	SHIP TO:
			Parsons Engineering Science, Inc. Atlanta Laboratory 2585 Chantilly Dr., N.E. Atlanta, GA 30324 404/325-5923

SAMPLER(S): (Signature)

ANALYSES REQUIRED

DATE	TIME	SAMPLE DESCRIPTION	NUMBER OF CONTAINERS										MATRIX	REMARKS

Relinquished By: (Signature) Date / Time	Received for Laboratory by: (Signature) Date / Time	Remarks: Airbill #:
Relinquished By: (Signature) Date / Time	Received for Laboratory by: (Signature) Date / Time	Remarks: Airbill #:
Relinquished By: (Signature) Date / Time	Received for Laboratory by: (Signature) Date / Time	Remarks:

ambiguity or confusion. To ensure quality control for sample documentation, each laboratory will be required to maintain copies of all COC forms that are initiated.

3.6.2 Sample Labeling

Information on the sample label should be identical to the corresponding information entered on COC forms. This information should be verified before samples are released for transport. The following information, at a minimum, will be required on each sample label:

Client	Date Collected
Project Number	Time Collected
Location	Collected by
Analysis Required	Preservative(s)
Parsons ES Sample Number	Sample Type (i.e., grab)

3.6.3 Field Data Sheet

The appropriate field data sheet (Table 3.2, 3.3, and 3.4) will be completed by the sample collector for each day of sample collection. The field data sheet will document study location, sample type (i.e., grab versus composite), sample code, preservation technique, date and time sampled, and weather conditions during sampling.

3.6.4 Sample Receipt and Documentation

After samples have been collected, labeled, and the appropriate information on the COC forms recorded, the forms and field data sheets will be transported with the samples to the laboratory. Upon receipt of the samples, the laboratory's sample custodian will inspect each sample for integrity and check the samples against the COC

Table 3.2 . Field Data Sheet for the Tracer Study

LITHIUM CHLORIDE TRACER STUDY Tracer Dosage and Sample Collection	
DATA SHEET NUMBER:	PAGE OF
Section of process being investigated:	
Dosage of Lithium Chloride Tracer	
Date and time of dosage:	Dosing performed by:
Location of lithium chloride injection point:	
Dosage of lithium chloride: a) quantity of lithium chloride used: b) volume of water used to make solution:	
Weather conditions at time of dosing:	
Other comments (e.g. problems, notable details, etc.):	
Sampling of Wastewater to Detect Tracer	
Date and time of sampling:	Sampling performed by:
Location of sample point:	
Sampler ID Number (if available):	
Sample Type (e.g. composite, grab, etc.):	
Sample ID Number(s):	
Sample Preservation Method Used (See Table 3.1 in QAPjP):	
Weather conditions at time of sampling:	
Description of Sample and Other comments (e.g. problems, notable details, etc.):	

Table 3.3 Field Data Sheet for Water Quality Study

WATER QUALITY STUDY Sample Collection and Field Analysis		
DATA SHEET NUMBER:	PAGE	OF
Wastewater Sampling		
Date and time of sampling:	Sampling performed by:	
Location of sample point:		
Sampler ID Number (if available):		
Sample Type (e.g. composite, discrete, grab, etc.):		
Sample ID Number(s):		
Sample Preservation Method Used (See Table 3.1 in QAPjP):		
Weather conditions at time of sampling:		
Description of Samples and Other comments (e.g. problems, notable details, etc.):		
Wastewater Grab Sampling and Field Analysis		
Date and time of sampling:	Sampling performed by:	
Location of sample point:		
Sample Type (e.g. composite, discrete, grab, etc.):		
Sample ID Number(s):		
Sample Preservation Method Used (See Table 3.1 in QAPjP):		
Weather conditions at time of sampling:		
pH meter calibrated?	DO meter calibrated?	
Field pH:	Field DO (%):	Sample Temp (°C):
Sample sent to laboratory for fecal coliform analysis?		
Description of Sample and Other comments (e.g. problems, notable details, etc.):		

Table 3.4 Field Data Sheet for the Residuals Study

RESIDUALS STUDY Sample Collection and Field Analysis		
DATA SHEET NUMBER:		PAGE OF
Sludge Sampling and Field Analysis (NB. *sample needed for fecal coliform analysis*)		
Date and time of sampling:	Sampling performed by:	
Location of sample point:		
Sample Type (e.g. composite, discrete, grab, etc.):		
Sample ID Number(s):		
Sample Preservation Method Used (See Table 3.1 in QAPjP):		
Weather conditions at time of sampling:		
pH meter calibrated?	DO meter calibrated?	
Field pH:	Field DO (%):	Sample Temp (°C):
Sample sent to laboratory for fecal coliform analysis?		
Description of Samples and Other comments (e.g. problems, notable details, etc.):		
Plant Sampling (NB. *sample needed for fecal coliform analysis*)		
Date and time of sampling:	Sampling performed by:	
Location of sample point:		
Sample Type (e.g. composite, discrete, grab, etc.):		
Sample ID Number(s):		
Sample Preservation Method Used (See Table 3.1 in QAPjP):		
Weather conditions at time of sampling:		
Sample sent to laboratory for fecal coliform analysis?		
Description of Sample (including plant type) and Other comments (e.g. problems, notable details, etc.):		

form. When the samples received and the COC forms are in agreement, the custodian will sign the COC form, enter the sample information into the laboratory log, and assign a laboratory accession number to each sample. Any discrepancies between the COC form and a sample label will be documented and the sampling organization will be notified. If the discrepancies cannot be corrected, then the sample will be discarded. Corrective actions, as described in Section 4, will be initiated to ensure that the problem does not recur.

3.6.5 Sample Storage and Security

During storage, samples will be maintained in a refrigerator at 4°C ± 2°C, unless otherwise specified. Maximum holding time allowed for each analysis is indicated in Table 3.1. If analyses are not initiated within the maximum allowable holding time, the samples will be discarded and new samples will be collected. Corrective actions, as described in Section 4, will be initiated to ensure that the problem does not recur. Samples will be retained for 30 days after analyses have been completed so that any unforeseen analytical problems may be addressed. At the end of 30 days, the samples will be discarded.

3.7 ANALYTICAL PROCEDURE

The standard methods for conventional pollutant analyses were chosen because they are the type most commonly specified in National Pollutant Discharge Elimination System (NPDES) permits for municipal wastewater treatment plants. Analytical procedures and references to be used in this study are presented in Table 2.1. This table also presents the minimum analytical detection limits. All standard procedures are taken from EPA support documents or EPA approved manuals.

3.8 CALIBRATION

Calibration standards will be performed as required by EPA (EPA, 1983) for the conventional pollutant analyses listed in Table 2.1. Calibration procedures for the critical

SECTION 4

APPROACH TO QA/QC

4.1 CALCULATION OF RESULTS

4.1.1 Data Utilization

Evaluation of OA's AEES will be based on data collected during the monitoring phase of the project. Effluent purity as well as technology effectiveness will be based on the degree to which wastewater constituents are removed from the waste stream as it passes through the individual treatment trains of the Living System. Pollutant removal effectiveness will be calculated using percent removal of selected pollutants from individual components of the system as well as the final product delivered from the system. Percent removal of pollutants from individual components of the system will be calculated using the following equation:

$$\text{Percent Removal} = (P_b - P_a)/P_b * 100$$

Where: P_b = Pollutant initial concentration

P_a = Pollutant concentration after treatment train

The percent removal of pollutants in the final product will be based on the following equation:

$$\text{Percent Removal} = (P_i - P_e)/P_i * 100$$

Where: P_i = Pollutant concentration in influent

P_e = pollutant concentration in effluent

Those pollutants being monitored for overall system removal as well as component reduction from the waste stream include COD, BOD, TSS, VSS, TKN, NH_4, NO_3, and TP.

The evaluation of the OA's AEES will incorporate operation and maintenance costs performed during the study. Collected data will include material or equipment replacement costs, maintenance, and any problems encountered at the project site. Figure 4-1 is an example of the log sheet that will be used to collect O&M information.

4.1.2 Data Validation

The laboratory directors selected for assuring quality of samples collected at the study site will be responsible for reviewing and validating all data generated. Data will be validated by spot checking field notebooks, hand-written notes as well as computer generated data and calculations. All data conforming to QC limits will be acceptable for use in this project. Data found to be acceptable will be compiled and reported to the QAC's and PM along with accompanying QC verification data. Data entered into spreadsheets will be periodically checked against raw data.

Data that does not conform to allowable QC limits will be reanalyzed when possible. Reanalysis of samples may not be possible in some situations, and in such circumstances, the unacceptable data either will not be used or, if used, will be noted in the Project Final Report with an explanation of why those analyses were not repeated.

The integrity of data produced will be verified by QACs and the QAM. The LD will report data which are outside the allowable QC limits to the QAC, who will be responsible to ensure that corrective actions are taken. QA forms and reporting requirements are described in Subsection 4.6. Data found to be unacceptable for precision purposes will be recorded on Figure 4-2.

4.2 INTERNAL QUALITY CONTROL CHECKS

The internal quality control checks for all critical measurements are presented in this section. Samples will be collected in sufficient volume to allow for appropriate internal quality control analysis.

FIGURE 4.1

OPERATION AND MAINTENANCE LOG SHEET

Date	Problem during operation	Maintenance performed	Costs incurred (1)

(1) Records should be kept on both labor and parts for costs incurred.

PAGE OF

FIGURE 4.2 QA REPORT FORM: LD LAB FORM 1 (pg 1 of 2)

REPORT PERIOD_____

SAMPLE CUSTODY

Chain of custody forms attached: Yes ( )No ( )
QC sample preservation techniques maintained: Yes ( )No ( )

RESULTS

Test Initiation Date	Sample Description	Accession Number	Critical Measure-ment	Precision RPD	Accuracy % recovery

System conditions monitored during tests: Yes ( )No ( )

Percent Completeness: _____ of_____ submitted samples were analyzed during this report period.
It is estimated that _____ samples will be analyzed during the report period ending _____.

DOCUMENTATION

Analytical data and QC data entered onto computer: Yes ( )No ( )
Laboratory notebooks and records maintained: Yes ( )No ( )

QA/QC ANALYSES

REPORT PERIOD: _____

FIGURE 4.2. QA REPORT FORM: LD LAB FORM 1 (pg 2 of 2)

	Not Applicable	Analyses Performed		Within QC Limits	
		Yes	No	Yes	No
Calibration Standard	( )	( )	( )	( )	( )
Internal Standards	( )	( )	( )	( )	( )
Split Samples	( )	( )	( )	( )	( )
Spiked Samples	( )	( )	( )	( )	( )
Replicate Analyses	( )	( )	( )	( )	( )
Other _____	( )	( )	( )	( )	( )

COMMENTS:

_____

_____

_____

CORRECTIVE ACTION

REPORT PERIOD: _____

Problem condition(s) identified during report period which required corrective action:	Yes ( )	No ( )
QAC notified of problem condition:	Yes ( )	No ( )
Cause of problem condition identified:	Yes ( )	No ( )

PROBLEM CONDITIONS REQUIRING CORRECTIVE ACTION

_____

_____

_____

ANTICIPATED QA EFFORTS FOR THE NEXT REPORT PERIOD

_____

_____

_____

Approved By:

_____ Date_____

Laboratory Director

4.2.1 Calibration Standards

Calibration standards will be used daily for TKN, NH_4, NO_3, and TP analysis. Internal quality control checks will be employed to ensure that the analytical equipment is functioning properly and the method is being performed correctly by the analyst. Calibration standards will be utilized to establish standard curves which will allow calculation of sample concentrations based upon instrument response.

4.2.2 Spiked Sample Analysis

Spiking samples with a known standard will be used to monitor data accuracy. Ten percent of the samples collected for analysis of TKN, NH_4, NO_3, and TP will be spiked. For proper spike determination, the standard addition of the spiking compound will be at a level approximately mid range in the calibration range. Allowable spiked sample recovery ranges for each analysis are presented in Table 2.1.

4.2.3 System Blanks

System blanks will be analyzed to ensure that system conditions are not biasing the data. These will include filters, laboratory pure water, and reagents.

4.2.4 Duplicate Analysis

Duplicate or matrix spike duplicate analysis will be performed on all critical measurements listed in Table 2.1. At a minimum, ten percent of all samples collected for analysis will be subjected to duplicate analysis.

4.2.5 Additional Internal Quality Control Checks

In addition to the internal quality control checks listed above, analysis of performance samples will be used in this study to ensure and maintain quality control. Performance samples are currently analyzed by the Parsons ES Laboratory two times per year to maintain quality control and such samples are provided by the EPA.

4.3 SYSTEM AUDITS

Technical system audits will be conducted by each QAC to qualitatively evaluate the components of the field and laboratory procedures. These audits will be performed shortly after initiation of the study (one to two weeks) to allow early detection of problems and identify needed corrective actions as soon as possible. During such audits, all components of each field and laboratory procedure will be evaluated and will include the following:

- Sample collection, delivery, storage and chain of custody;
- Field and laboratory analysis techniques including equipment calibration; technician performance and data calculation methods; and
- QC procedures including calculation of data quality indicators.

Following receipt of the data generated during this period, the systems audit will continue with an evaluation of the following components:

- Data reduction, validation and reporting procedures; and
- Quality control reports.

Field and laboratory checklists, as shown in Figure 4-3 and 4-4, will be used during the system audit. Results of the findings of the systems audits will be forwarded to the QAM who will summarize the information in a letter report to the PM. If necessary, corrective action will be initiated using procedures described in Subsection 4.5.

4.4 CALCULATION OF DATA QUALITY INDICATORS

Data quality indicators from this study will include precision, accuracy, completeness and method detection limit. These indicators will be used to determine if the QA objectives for this study are being met.

FIGURE 4-3. QUALITY ASSURANCE FIELD AUDIT CHECKLIST

PARSONS ENGINEERING SCIENCE
Project: AEES Evaluation

Conducted by _____
Date _____

AUDIT QUESTIONS	REFERENCE	CONFORMS YES	CONFORMS NO	COMMENTS
A. Sample Collection		√	√	
1 Sample containers for collecting and transporting samples are new or precleaned glass or plastic.	QAPjP			
2 New or precleaned tubing initially used on samplers.	QAPjP			
3 Automatic samplers routinely cleaned, inspected, and calibrated and documented in a notebook.	QAPjP			
4 Sampling poles rinsed and wiped clean prior to use.	QAPjP			
5 Collection container/sampler is chilled (4° ± 2°C) during collection, handling, and transport to lab.	QAPjP			
6 Sampler is set to obtain a 24-h composite sample.	QAPjP			
7 Grab samples are collected for field measurements of pH, DO, and temperature, and for fecal coliform.	QAPjP			
8 Sample containers for fecal coliform are kept closed until the moment the sample is collected, the stopper or cap is protected from contamination, and replaced immediately after sample collection.				
9 Required sample volumes are collected for each parameter.	QAPjP			
10 Sample label is complete and legible and corresponds to information on COC.	QAPjP			
11 COC form is complete and legible.	QAPjP			
12 Lids of sample containers are taped shut for transport.	QAPjP			
13 Field data sheet is complete and legible.	QAPjP			
B. Field Calibration of Instruments				
1 SOPs for instrument and automatic sampler calibration and use are available.	EPA			

FIGURE 4-3. QUALITY ASSURANCE FIELD AUDIT CHECKLIST

PARSONS ENGINEERING SCIENCE
Project: AEES Evaluation

Conducted by _____
Date _____

AUDIT QUESTIONS	REFERENCE	CONFORMS YES	CONFORMS NO	COMMENTS
2 Field technician has been trained in sampling and field analytical procedures prior to field analysis.	EPA			
3 Verify documentation of flow meter calibration.	QAPjP			
4 pH meter is calibrated daily prior to use using two pH buffer standards which bracket the sample value.	EPA			
5 pH electrodes are rinsed thoroughly between samples and after calibration with deionized or distilled water.	EPA			
6 Calibration is checked periodically using a pH buffer solution and recorded in a logbook.	EPA			
7 pH buffer solutions are discarded after one use.				
8 Stock buffer standards are dated and have not been opened for more than one year.				
9 DO meter is calibrated daily prior to use according to manual.	EPA			
10 DO calibration checks are recorded in a logbook.				
11 DO membrane is checked for tears or wrinkles.	EPA			
12 DO membrane is rinsed and blotted dry prior to calibration.				
13 DO probe is immersed in a water saturated air environment during calibration.				
14 Thermometer is checked for air bubbles, cracks, etc.	EPA			
15 Thermometer is periodically standardized against an NBS or NBS traceable calibrated thermometer.	EPA			
16 A duplicate is conducted on ten percent of samples for each field parameter (DO, pH, temp), or a minimum of one per day.	QAPjP			

QAPjP - Quality Assurance Project Plan
EPA, 1990, NPDES Compliance Monitoring Inspector Training - Sampling

PARSONS ENGINEERING SCIENCE FIGURE 4-4. QUALITY ASSURANCE LABORATORY AUDIT CHECKLIST

Conducted by _____

Date _____

Project: AEES Evaluation

AUDIT QUESTIONS	REFERENCE	CONFORMS YES	CONFORMS NO	COMMENTS
A. Sample Receipt and Handling		√	√	
1 Sample temperature is recorded upon receipt at the lab and sample is checked for adequate preservation.	EPA			
2 Personnel releasing and receiving custody of sample sign the COC form.	EPA			
3 Sample is logged in a bound logbook and given a unique identification number which is written on the bottle.	EPA			
4 Sample custodian notes condition of custody seal, physical condition of sample, and number of samples received.	EPA			
5 Sample procedures and responsibilities are documented.	EPA			
6 Sample is refrigerated until utilized for testing (wastewater samples).	EPA			
B. Facilities and General Equipment				
1 Laboratory has separate designated areas for sample submission, sample storage, extractions, organic analysis, wet chemistry, and waste disposal.				
2 Source of laboratory pure water available, checked daily for ASTM Type II quality, and corrective action taken as necessary.				
3 Exhaust hoods provided, kept clean, and airflow is checked and recorded.				
4 Temperature of cold storage units recorded daily in logbooks, capable of maintaining 4° + 2°C.				
5 Drying oven temperature recorded daily in logbooks, capable of maintaining 103-105°C.				
6 Muffle furnace temperature recorded daily in logbooks, capable of maintaining 550 +/- 50°C.				
7 BOD incubator temperature recorded daily in logbooks, capable of maintaining 20 +/- 1°C.				
C. Documentation/Quality Assurance/Quality Control				
1 SOPs for sample receipt and handling	EPA			

PARSONS ENGINEERING SCIENCE FIGURE 4-4. QUALITY ASSURANCE LABORATORY AUDIT CHECKLIST Conducted by _____

Date _____

Project: AEES Evaluation

AUDIT QUESTIONS	REFERENCE	CONFORMS YES	CONFORMS NO	COMMENTS
2 SOPs for sample preservation/storage	EPA			
3 SOPs for instrument calibration and use	EPA			
4 SOPs for glassware cleaning	EPA			
5 SOPs for chemical parameters	EPA			
6 SOPs for data reduction, validation, and reporting	EPA			
7 SOPs are readily accessible to technicians	EPA			
8 Individual bound logbooks used for instrument calibration, maintenance, and analysis for each chemical parameter				
9 Bound logbooks are legible and pages numbered consecutively				
10 Logbooks maintained in accordance with GLP (e.g., single-line crossouts, dates, initials, etc.)				
11 Control charts are maintained and current for each chemical parameter	EPA			
12 Problem conditions are reported to QA Coordinator (indicate written or verbal reports)				
13 QC records show corrective action implemented to meet QC criteria				
14 Supervisory personnel review data and QC results				
15 Lab routinely produces acceptable results on EPA performance evaluation samples				
D. Chemical Analysis				
For Items 1-4, indicated number of nonconformances to total number for the past 12 months:				
1 Calibration standards within acceptable QC limits	QAPjP			
2 Spiked samples within acceptable QC limits	QAPjP			
3 Replicate analyses within acceptable QC limits	QAPjP			
4 System blanks within acceptable QC limits	QAPjP			
5 Out of range samples are diluted and reanalyzed				

PARSONS ENGINEERING SCIENCE FIGURE 4-4. QUALITY ASSURANCE LABORATORY AUDIT CHECKLIST Conducted by _____

Project: AEES Evaluation Date _____

AUDIT QUESTIONS	REFERENCE	CONFORMS YES	CONFORMS NO	COMMENTS
6 A duplicate or spike is conducted on ten percent of samples for each parameter, or a minimum of one per day.	QAPjP			
E. Data Reduction, Validation, and Reporting				
1 Data reduction is computerized or calculations are performed in permanently bound notebooks				
2 Individual analysts verify completeness and correctness of data				
3 Data is reviewed for compliance with the established QC criteria set forth in the QAPjP	QAPjP			
4 Laboratory project manager reviews and approves release of data to be complete, legible, and accurate				
5 Monthly LD and QAC forms are complete and submitted monthly to Parsons ES	QAPjP			
6 Sample report includes analytical method, QC results (accuracy, precision, and completeness), blank and standard results, COC form, and copies of all raw data				

4.4.1 Precision

Duplicate analysis will be performed to assess method precision. A sufficient volume of sample will be collected to allow for duplicate analyses. At a minimum, ten percent of the samples collected will be subjected to duplicate analysis. Precision will be determined for all parameters listed in Table 2.1. Precision will be the relative percent difference (RPD) between duplicate analysis. RPD will be calculated using the following equation:

$$RPD = \frac{(Rep\ 1 - Rep\ 2)}{(Rep\ 1 + Rep\ 2)/2} \times 100$$

Where : Rep 1, Rep 2 = Observed values for duplicate analysis.

4.4.2 Accuracy

Spiked sample analysis will be performed to assess method accuracy. A sufficient volume of sample will be collected to allow for spiked sample analysis. Ten percent of the samples collected for NH_4, NO_3, TKN, and TP will be assessed for method accuracy. For proper spike determination, the standard addition will be at a level approximately mid-range in the calibration range. Laboratory control samples will be used to determine accuracy for BOD and COD analyses.

Accuracy will be determined by calculating the percent recovery range (PRR) of the sample spike for NO_3, NH_4, TKN, and TP analysis. PRR will be calculated using the following equation:

$$PRR = \frac{Cs - Cu}{Ca} \times 100\ \%$$

Where : Cs = Measured concentration in spiked sample.

Cu = Measured concentration in unspiked sample.

Ca = Actual concentration of spike added.

4.4.3 Completeness

Completeness objectives for this project are listed in Table 2.1. It will be assessed as the percentage of all analyses performed whose results are within the QA objectives for precision and accuracy. Completeness will be calculated using the following equation:

$$\% C = \frac{Mv}{Mt} \times 100\%$$

Where : % C = Percent completeness.

Mv = Number of valid measurements.

Mt = Total number of measurements.

4.4.4 Method Detection Limit

For the critical measurements listed in Table 2.1, method detection limits will be based on values that are established in the referenced standard procedure for each analysis. Referenced MDL's may not be attainable in the presence of matrix interferences.

4.5 CORRECTIVE ACTION

Each corrective action will involve nine steps as specified in the EPA Preparation Aid for Category II Quality Assurance Project Plans (EPA, 1989). These steps are described as follows:

1. Initial Recognition of a Problem Condition.

   Corrective action will be initiated when one or more of the following problem situations or conditions occur:

   - Procedures for sample collection, handling and storage do not adhere to quality control standards described in Section 3.
   - Predetermined limits for data quality indicators are exceeded.
   - Equipment or instrumentation is found to be faulty.
   - Procedures or data are not suitable for their intended use.
   - The schedule for either the analytical data reporting and/or submittal of QA reports/forms is not being met.

- Data reduction, validation and reporting procedures, as described in Subsection 4.1, are not being followed.
- Performance and system audits indicate QC deficiencies.

2. Identification of a Problem Condition.

Upon recognition of a problem condition, the person making the observation will report the problem to the laboratory's QAC. The QAC will then judge whether it is severe enough to warrant immediate notification of the QAM. Problems not warranting immediate notification of the QAM will be reported in the monthly QA report (Subsection 4.6) and corrected under the direction of the QAC. If such problems are not successfully rectified, they will be referred to the QAM for further corrective action.

3. Assignment of Responsibility for Investigating the Problem.

The QAM will notify the PM of all problem conditions reported by the QACs. These conditions will be reviewed by the QAM and the PM to determine the magnitude of the problem, possible corrective action and who will be responsible for investigating the situation. In general, the QAM will direct the QAC of the affected laboratory to conduct the investigation. However, in critical situations, the QAM will work directly with the QAC to evaluate and resolve the problem.

4. Investigation to Determine the Cause of the Problem.

Investigation of a problem will involve a review of the procedures that may be contributing to the unacceptable situation. Each procedure, including system conditions for critical measurements, will be reviewed with respect to deficiencies in QC. This may include a review of sampling procedures, instrument calibration, system conditions and/or and data handling and reporting.

5. Determination of an Appropriate Corrective Action.

Following investigation of the problem, the QAC and/or QAM, in consultation with the PM, will determine appropriate action to correct the situation. The corrective action will indicate steps to take to preclude repetition of the problem.

6. Assignment of Responsibility for Implementing the Corrective Action.

In most cases, the QAM will assign the QAC of the affected organization to implement the corrective action. The QAC will work closely with the LD to ensure that it is properly implemented. Problem resolution may require the issuance of standard operating procedure (SOP) memoranda to assist the process. Where unusual or significant corrective actions must be implemented, the PM, with assistance from the QAM, will be responsible for implementation.

7. Establishment of the Effectiveness of the Corrective Action.

Effectiveness of the corrective action will be assessed by reviewing ensuing results over an appropriate period of time. The QAC and/or QAM will be responsible for evaluation of effectiveness.

8. Verification that the Corrective Action Has Eliminated the Problem.

Based on the review of the ensuing results, the QAC and/or QAM will prepare a report describing the actions taken and their effectiveness. This report will identify any additional actions, if necessary, that will be required. The report will be submitted to the PM.

9. Documentation of the Problem Condition, Corrective Action Taken, Effectiveness of the Corrective Action and QA Activities to Prevent Further Problem Occurrence.

Documentation of minor problem conditions and their resolution will use the standard QA report forms described in Subsection 4.6. This documentation will include:

- Report (LD Form 1) from the LD to the QAC regarding the occurrence of a problem condition.
- Report (QAC Form 1) from the QAC to the QAM describing the problem and corrective actions taken.
- Report (QAM Form 1) from the QAM to the Project Manager discussing the problem condition and its solution.
- Unusual problem conditions will require special documentation. This documentation will consist of one or more of the following reports:
- Telephone memoranda from the QAC to the QAM regarding the problem.

- A special report from the QAC to the QAM regarding the nature of the problem and steps that could be taken to correct the problem.
- A special report, if necessary, from the QAM to the PM describing the problem and possible steps for its solution.
- Telephone memoranda or letters from the QAM assigning responsibility for investigating the problem.
- A report from the QAC to the QAM regarding the effectiveness of the corrective action and any needed additional steps.
- Copies of all documentation prepared as the result of a corrective action will be maintained by the QAM in the QA file.

4.6 QUALITY ASSURANCE REPORTS TO MANAGEMENT

The main goal of the QA program is to ensure precision and accuracy of the analytical data. It will be achieved by ongoing monitoring of the field operations and by proper management and monitoring of laboratory analytical procedures. This QA program has been designed so that QC problems can be identified and corrected quickly. All data generated or collected during this study will be maintained in a manner which provides for a permanent and traceable path for an external review or audit.

4.6.1 QA Forms And Reporting

The roles of the QA staff in preparing and submitting QA reports are described in Section 1. To ensure timely reporting, the following QA report forms will be utilized in this study.

LD Form 1: This form will be completed by the LD for each month of field work or analytical testing and will be submitted to the organization's QAC. When completed, LD Form 1 (Figure 4-2) will include:

- A summary of samples collected/received and ensuing analytical results;
- Completed QC analytical results;
- Problems requiring corrective action(s); and
- A confirmation that previously noted corrective actions have been taken.

It should be noted that LD Form 1 is intended to provide a summary of results. The checklist format will be utilized to minimize the time and effort required by the LD to report the QC results.

A modified LD Field Form 1 is presented in Figure 4-5 for use by the field laboratory director. This form relates to sample collection.

QAC Form 1: This form (Figure 4-6) will be completed monthly by each QAC and will be submitted to the QAM. The QAC monthly report will include:

- A summary of samples collected/received and their status;
- Field and/or laboratory sample analytical results;
- QA results;
- A description of quality control discrepancies; and
- Copies of LD Form 1 which were completed during the reporting period.

It should be noted that the QAC monthly report will include both QC results and sample analysis results. Copies of original QC and analytical data must be included with the monthly QAC report. QAC Form 1 is intended as a checklist for reporting the necessary information. The QAC may have to prepare special reports which identify significant problems that require the immediate attention of the QAM or the PM.

QAM Form 1: This form will be completed monthly by the QAM and will be submitted to the PM. When completed, QAM Form 1 (Figure 4-7) will include:

- A summary of the samples collected and/or analyzed;
- QA results; and
- QC discrepancies and actions taken.

4.6.2 Quality-Related Training

It is anticipated that properly trained and qualified personnel will be assigned to this project. As a result, quality-related training will not be required for this study.

FIGURE 4-5 QA REPORT FORM: LD FIELD FORM 1 (pg 1 of 2)

REPORT PERIOD_____

SAMPLE COLLECTION

Sampling procedure followed correctly:	Yes ( )	No ( )
Equipment maintained in good condition:	Yes ( )	No ( )
Equipment cleaned properly:	Yes ( )	No ( )

REPORT PERIOD_____

SAMPLE CUSTODY

Chain of custody forms attached	Yes ( )	No ( )
QC sample preservation techniques maintained	Yes ( )	No ( )
Samples are correctly labeled	Yes ( )	No ( )
Information on sample labels correspond with COC forms	Yes ( )	No ( )

DOCUMENTATION

Field data sheets completed daily	Yes ( )	No ( )
Rainfall records maintained	Yes ( )	No ( )
Operation and maintenance costs recorded daily	Yes ( )	No ( )

FIGURE 4-5 QA REPORT FORM: LD FIELD FORM 1 (pg 2 of 2)

CORRECTIVE ACTION
REPORT PERIOD_____

Problem condition(s) identified during report period which required corrective action:	Yes ( )	No ( )
QAC notified of problem condition:	Yes ( )	No ( )
Cause of problem condition identified:	Yes ( )	No ( )

PROBLEM CONDITIONS REQUIRING CORRECTIVE ACTION

_____
_____
_____
_____
_____

ANTICIPATED QA EFFORTS FOR THE NEXT REPORT PERIOD

_____
_____
_____
_____
_____
_____

Approved By:

_____Date_____

Laboratory Director

FIGURE 4-6 QA REPORT FORM: QAC FORM 1 (pg 1 of 2)

REPORT PERIOD_____

The following information is included in this report:

	Not Applicable	Yes	No
Conventional pollutant analysis results:	( )	( )	( )
Field measurement results:	( )	( )	( )
Quality assurance results:	( )	( )	( )
Copies of QA Form 1:	( )	( )	( )

QA REPORT

QA PROGRESS TO DATE

_____
_____
_____
_____
_____
_____

Problem condition(s) identified during report period which required corrective action:	Yes ( )	No ( )
Cause of problem conditon identified:	Yes ( )	No ( )
Corrective action initiated:	Yes ( )	No ( )
Corrective action resolved problem condition:	Yes ( )	No ( )
QAPO notified of corrective action:	Yes ( )	No ( )
PM notified of corrective action:	Yes ( )	No ( )

PROBLEM CONDITIONS REQUIRING CORRECTIVE ACTION

_____
_____
_____
_____
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_____

FIGURE 4-6 QA REPORT FORM: QAC FORM 1 (pg 2 of 2)

ANTICIPATED QA EFFORTS FOR THE NEXT REPORT PERIOD

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_____

Approved By:

_____ Date_____

Quality Assurance Coordinator

FIGURE 4-7 QA REPORT FORM: QAM FORM 1 (pg 1 of 2)

REPORT PERIOD_____

The following information is included in this report:

	Not applicable	Yes	No
CONVENTIONAL POLLUTANT ANALSIS RESLULTS	( )	( )	( )
FIELD MEASUREMENT RESULTS	( )	( )	( )
QUALITY ASSURANCE RESLUTS	( )	( )	( )
COPIES OF LD FORM 1	( )	( )	( )
COPIES OF QA FORM 1	( )	( )	( )

QA\QC REPORT

QA PROGRESS TO DATE

_____
_____
_____
_____
_____
_____

Problem condition(s) identified during report period which required corrective action:	Yes ( ) No ( )
Cause of problem conditon identified:	Yes ( ) No ( )
Corrective action initiated by QAC:	Yes ( ) No ( )
Corrective action resolved problem condition:	Yes ( ) No ( )
QAM notified of corrective action:	Yes ( ) No ( )
PM notified of corrective action:	Yes ( ) No ( )

FIGURE 4-7 QA REPORT FORM: QAM FORM 1 (pg 2 of 2)

PROBLEM CONDITIONS REQUIRING CORRECTIVE ACTION

_____
_____
_____
_____
_____
_____

ANTICIPATED QA EFFORTS FOR THE NEXT REPORT PERIOD

_____
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Approved By:

_____ Date_____

Quality Assurance Coordinator

4.6.3 QA Results In The Project Final Report

The Final Report for this project will include a separate section that addresses how the QA program was implemented during the project. This section will include:

- A description of QA activities;
- Results of QC analyses;
- A description of corrective actions that were taken; and
- Copies of relevant QA documentation (e.g., QAM monthly reports).

SECTION 5

REFERENCES

Engineering-Science, Inc. 1992. Project Management Plan for the Evaluation of Municipal Wastewater Technologies and Sludge Management Systems.

U.S. Environmental Protection Agency. 1983. Methods for the Chemical Analysis of Water and Wastes, EPA-600/4-79-020, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio.

U.S. Environmental Protection Agency. 1989. Preparation Aid for HWERL's Category IV Quality Assurance Project Plans, Office of Research and Development, Hazardous Waste and Engineering Laboratory, Cincinnati, Ohio.

U.S. Environmental Protection Agency. 1990. NPDES Compliance Monitoring Inspector Training: Sampling, Office of Water Enforcement and Permits, Washington, DC.

Appendix B

Raw Data: Flow Monitoring

This appendix contains abbreviated raw flow data for Train B of the process, recorded by both the influent (Parsons ES) and effluent (OAI) flowmeters during the process evaluation of the AEES Facility. The actual flow data from the influent flowmeter is in the form of minute-by-minute flow totals and is considered too much data to include here. For simplicity and brevity, only daily flow totals are shown. These are provided in Table B.1

The periods when the plant was shut down (Section 9.5.3) are indicated in the table by grey shading. Influent daily flow totals annotated with *"est"* were not recorded electronically by the flowmeter but were interpolated from flow total data recorded in the field notebook. This had to be done when problems were encountered with the computer which prevented it from recording the flow data.

Table B.1
AEES Facility Flow Data
Influent and Effluent Flows for Train B

Date	Day	Influent Flow gallons	Effluent Flow gallons
2/28/95	Tuesday	*10,704 est*	8,194
3/1/95	Wednesday	*10,704 est*	6,538
3/2/95	Thursday	*11,928 est*	12,211
3/3/95	Friday	*13,152 est*	8,813
3/4/95	Saturday	*13,152 est*	11,612
3/5/95	Sunday	*13,152 est*	10,095
3/6/95	Monday	*13,152 est*	6,470
3/7/95	Tuesday	12,392	10,113
3/8/95	Wednesday	13,856	12,587
3/9/95	Thursday	13,892	7,140
3/10/95	Friday	13,528	13,802
3/11/95	Saturday	13,977	9,780
3/12/95	Sunday	13,997	12,443
3/13/95	Monday	13,877	11,753
3/14/95	Tuesday	13,770	11,205
3/15/95	Wednesday	13,791	11,807
3/16/95	Thursday	13,808	11,829
3/17/95	Friday	6,483	4,694
3/18/95	Saturday	275	0
3/19/95	Sunday	301	0
3/20/95	Monday	5,221	3,248
3/21/95	Tuesday	13,900	11,201
3/22/95	Wednesday	13,605	12,230
3/23/95	Thursday	13,970	11,753
3/24/95	Friday	13,740	10,896
3/25/95	Saturday	13,741	10,787
3/26/95	Sunday	13,551	10,665
3/27/95	Monday	13,004	10,199
3/28/95	Tuesday	13,451	9,540
3/29/95	Wednesday	13,360	7,580
3/30/95	Thursday	13,507	9,809
3/31/95	Friday	13,630	11,030
4/1/95	Saturday	13,486	9,284
4/2/95	Sunday	13,314	10,398
4/3/95	Monday	13,318	10,500
4/4/95	Tuesday	13,269	10,674
4/5/95	Wednesday	13,183	9,672
4/6/95	Thursday	12,951	7,007
4/7/95	Friday	13,144	6,992
4/8/95	Saturday	13,815	9,348
4/9/95	Sunday	*15,838 est*	4,389

Table B.1 (continued)
AEES Facility Flow Data
Influent and Effluent Flows for Train B

Date	Day	Influent gallons	Effluent gallons
4/10/95	Monday	*15,838 est*	6,051
4/11/95	Tuesday	*15,838 est*	11,642
4/12/95	Wednesday	*14,264 est*	6,660
4/13/95	Thursday	*14,271 est*	10,559
4/14/95	Friday	*13,560 est*	9,920
4/15/95	Saturday	*13,560 est*	9,342
4/16/95	Sunday	*13,560 est*	9,366
4/17/95	Monday	*13,560 est*	8,201
4/18/95	Tuesday	*13,229 est*	7,889
4/19/95	Wednesday	*13,131 est*	8,561
4/20/95	Thursday	*13,695 est*	9,894
4/21/95	Friday	*14,061 est*	10,280
4/22/95	Saturday	*14,061 est*	10,341
4/23/95	Sunday	*14,061 est*	10,017
4/24/95	Monday	*14,061 est*	8,975
4/25/95	Tuesday	*13,147 est*	8,567
4/26/95	Wednesday	*13,300 est*	10,203
4/27/95	Thursday	12,736	9,872
4/28/95	Friday	12,826	6,935
4/29/95	Saturday	10,380	5,367
4/30/95	Sunday	11,804	6,604
5/1/95	Monday	12,025	7,059
5/2/95	Tuesday	13,436	9,026
5/3/95	Wednesday	13,183	6,644
5/4/95	Thursday	14,043	18,842
5/5/95	Friday	13,600	10,656
5/6/95	Saturday	13,534	12,098
5/7/95	Sunday	13,477	11,960
5/8/95	Monday	13,303	12,246
5/9/95	Tuesday	12,999	11,918
5/10/95	Wednesday	14,329	7,604
5/11/95	Thursday	14,318	11,103
5/12/95	Friday	14,240	14,402
5/13/95	Saturday	14,879	16,311
5/14/95	Sunday	15,104	16,647
5/15/95	Monday	13,890	15,783
5/16/95	Tuesday	13,085	15,315
5/17/95	Wednesday	no data	13,512
5/18/95	Thursday	no data	12,984
5/19/95	Friday	no data	12,773
5/20/95	Saturday	no data	13,866

Table B.1 (continued)
AEES Facility Flow Data
Influent and Effluent Flows for Train B

Date	Day	Influent gallons	Effluent gallons
5/21/95	Sunday	no data	14,546
5/22/95	Monday	no data	14,639
5/23/95	Tuesday	no data	12,960
5/24/95	Wednesday	no data	531
5/25/95	Thursday	no data	812
5/26/95	Friday	no data	0
5/27/95	Saturday	no data	0
5/28/95	Sunday	no data	0
5/29/95	Monday	no data	0
5/30/95	Tuesday	no data	96
5/31/95	Wednesday	no data	0
6/1/95	Thursday	no data	4,676
6/2/95	Friday	no data	8,550
6/3/95	Saturday	no data	7,082
6/4/95	Sunday	no data	7,197
6/5/95	Monday	no data	11,012
6/6/95	Tuesday	no data	13,514
6/7/95	Wednesday	no data	13,572
6/8/95	Thursday	no data	14,621
6/9/95	Friday	13,240	16,497
6/10/95	Saturday	13,840	no data
6/11/95	Sunday	14,340	no data
6/12/95	Monday	12,340	no data
6/13/95	Tuesday	12,710	no data
6/14/95	Wednesday	13,180	no data
6/15/95	Thursday	14,050	no data
6/16/95	Friday	10,600	no data
6/17/95	Saturday	1,040	no data
6/18/95	Sunday	7,400	no data
6/19/95	Monday	13,090	no data
6/20/95	Tuesday	13,320	no data
6/21/95	Wednesday	13,910	no data
6/22/95	Thursday	13,870	no data
6/23/95	Friday	13,880	no data

Appendix C

Raw Data: Water Quality and Residuals

This appendix contains the raw wastewater quality and residuals data recorded during the eleven-week process performance study. As well as listing all of the data, the appendix also describes the data manipulation and statistical analyses performed to identify statistical outliers and spurious data points.

All of the raw water quality data for the eleven-week performance evaluation, along with their summary statistics, are shown in Tables C.1 to C.6.

The raw residuals data were not subjected to the statistical analyses that were performed upon the wastewater data. This was owing to the small sample size (3-5 samples) which, it was considered, made distribution testing and lack-of-fit testing meaningless. Summary statistics, however, were generated for the residuals data. All of the raw sludge data, along with their summary statistics, are shown in Tables C.7 and C.8. The raw data for the plant samples are provided in Table 9.5 (Section 9.4).

Data Manipulation

As described in Section 9.2.1, the first step of the data manipulation was to review the field notebook and laboratory reports to remove or modify data points that were known to be invalid for any reason. The data removed or modified were:

1. Samples W2-0308-0955 (Table C.2) and W3-0308-1023 (Table C.3): all of the data for these two samples were disregarded as the samples were contaminated by raw sludge following a process mishap (Section 9.5.3).
2. Sample W5-0301-1210 (Table C.4): the data for this sample could not be used since the location for sample point W5 was moved after Week 1 of the study (see Section 4).
3. Sample W6-0316-1045 (Table C.6): the TSS and VSS data for this sample were uncharacteristically high. These data were determined to be caused by of pieces of algae that had been scraped off the piping following the replacement of the sample tubing in effluent pipe. Therefore, the solids data for this sample were considered to be unrepresentative of the normal effluent and they were discarded. The other parameters for this sample appeared to be unaffected, so they were retained.
4. Samples W2-0412-1150 & W2-0426-0935 (Table C.2), W3-0426-1000 (Table C.3), W5-0426-1040 (Table C.4), and W6-0330-1030 & W6-0413-1050 (Table C.6): analysis of these samples yielded VSS values that slightly exceeded the TSS values. This was determined to be the result of analytical variability when the two values were, in fact, very close (i.e., the total solids comprised mostly volatile solids). In these cases, the value for VSS was assumed to equal the TSS value.

Table C.1

WATER QUALITY DATA
ELEVEN WEEK PERFORMANCE EVALUATION
SAMPLE POINT W1 (Raw Sewage Inlet)

COMPOSITE SAMPLES

Parameter	Units	Statistical Analyses							Water Quality Results										
		n	Mean	Median	High	Low	Standard Deviation	Confidence Interval (at 95% CL)	W1-0302-1005	W1-0309-1010	W1-0316-1005	W1-0330-0935	W1-0406-0935	W1-0413-0940	W1-0420-1015	W1-0427-0940	W1-0504-0915	W1-0511-0945	W1-0518-0920
Total COD	mg/l	11	1,307.0	1,290.0	1,720.0	997.0	243.2	400.0	997	1,090	1,140	1,230	1,290	1,550	1,720	1,500	1,300	1,550	1,010
Soluble COD	mg/l	10	157.5	154.5	180.0	134.0	13.6	22.3	169	180	151	153	~~212~~[a]	170	134	152	165	156	145
Total BOD_5	mg/l	10	468.8	435.0	670.0	320.0	116.4	191.5	320	330	408	400	410	590	460	670	560	540	no data
Soluble BOD_5	mg/l	10	70.1	66.0	96.0	56.0	14.3	23.5	74	89	56	64	96	80	57	56	61	68	no data
TSS	mg/l	10	470.4	492.5	715.0	229.0	136.4	224.3	229	485	393	520	500	360	567	372	715	563	~~1,040~~[a]
VSS	mg/l	10	364.0	361.5	520.0	216.0	96.4	158.5	216	330	301	460	388	335	413	244	520	433	~~765~~[a]
TKN	mg/l	11	55.9	58.4	63.4	44.2	7.1	11.7	44.2	45.7	58.4	63.3	53.7	61.7	52.5	62.4	60.1	50	63.4
Ammonia	mg/l-N	11	25.6	25.1	32.8	19.5	4.2	6.8	26.9	24.8	23.1	29.7	32.8	26.5	19.5	30.1	25.1	20.1	23
Nitrate	mg/l-N	11	0.16	0.13	0.29	0.10	0.07	0.12	0.11	0.1	0.13	0.15	0.12	0.14	0.12	0.12	0.28	0.29	0.24
Total Phosphorus	mg/l-P	10	13.6	13.4	17.7	10.7	2.2	3.6	10.7	11.6	11.6	14.2	13.5	16.3	17.7	~~37.6~~[a]	13.3	12.6	14

GRAB SAMPLES

Parameter	Units	Statistical Analyses							Water Quality Results										
		n	Mean	Median	High	Low	Standard Deviation	Confidence Interval (at 90% CL)	G1-0302-1030	G1-0309-1020	G1-0316-1015	G1-0330-0950	G1-0406-0950	G1-0413-1000	G1-0420-1030	G1-0427-0950	G1-0504-0940	G1-0511-0955	G1-0518-0935
Fecal Coliform	cfu/100ml	11	8,109,091	5,000,000	24,000,000	2,400,000	6,872,184	11,303,732	16,000,000	24,000,000	2,400,000	2,800,000	7,000,000	13,000,000	5,000,000	8,000,000	3,000,000	3,000,000	5,000,000
Field pH		11	7.98	7.97	8.34	7.61	0.27	0.44	8.20	8.27	7.77	7.68	8.02	7.97	7.61	8.30	8.34	7.71	7.94
Field DO	mg/l	11	2.9	2.8	4.7	1.2	1.0	1.6	4.3	3.1	2.3	2.3	2.9	3.4	2.8	1.2	2.2	4.7	2.4
Sample Temp.	°C	11	17.3	17.0	19.0	15.0	1.1	1.9	16.0	15.0	17.0	17.0	18.0	17.0	17.0	19.0	18.0	18.0	18.5

Notes

A "#" denotes a value that was removed following the review of the field notebook and laboratory reports (see also Section 9.2.1).

A "*" denotes a value that was removed statistically, having been identified as an outlier (see also Section 9.2.1).

1. Some VSS values were analyzed to be greater than the corresponding TSS value, so have been assumed to equal it (see also Section 9.2.1).
2. Some TKN values were analyzed to be less than the corresponding NH_3 value, so have been assumed to equal it (see also Section 9.2.1).
3. Some TSS and VSS samples were analyzed one day outside the seven day holding time but were retained (see also Section 7.3.2).
4. Some TSS or NH_3 analyses did not meet objectives for RPD or PRR but were retained (see also Section 7.3.2).

Table C.2

WATER QUALITY DATA

ELEVEN WEEK PERFORMANCE EVALUATION

Sample Point W2 (Anaerobic Bio-reactor effluent)

COMPOSITE SAMPLES

Parameter	Units	Statistical Analyses							Water Quality Results										
		n	Mean	Median	High	Low	Standard Deviation	Confidence Interval (at 95% CL)	W2-0301-1130	W2-0308-0955	W2-0315-1015	W2-0329-1010	W2-0405-1005	W2-0412-1150	W2-0419-1005	W2-0426-0935	W2-0503-1020	W2-0510-0950	W2-0517-1005
Total COD	mg/l	10	444.7	429.0	562.0	360.0	76.1	125.2	430	~~1,520#~~	360	390	531	562	387	546	363	428	450
Soluble COD	mg/l	10	216.2	217.0	237.0	196.0	15.6	25.7	196	~~216#~~	203	198	226	233	208	237	226	205	230
Total BOD_5	mg/l	9	160.0	160.0	220.0	130.0	32.4	53.3	130	~~300#~~	160	170	130	200	160	220	140	130	no data
Soluble BOD_5	mg/l	9	107.7	98.0	150.0	87.0	22.9	37.7	98	~~87#~~	110	96	87	140	110	150	89	89	no data
TSS	mg/l	10	78.0	82.1	117.0	45.5	22.6	37.2	78.7	~~400#~~	45.5 (4)	52.7	117	91.3	50.7	91.3	85.4	74 (3)	93
VSS	mg/l	10	64.0	60.7	91.3	33.5	20.7	34.0	61.3	~~245#~~	33.5	52	55	91.3 (1)	37.3	91.3 (1)	79.2	60 (3)	79
TKN	mg/l	10	43.3	41.5	53.6	35.7	6.7	11.0	35.7	~~53.8#~~	35.8	37.3	53.6	52.1	39.6	47.3	42.0	48.9	41.0
Ammonia	mg/l-N	10	33.8	33.8	43.1	23.1	5.9	9.8	34.2	~~34.4#~~	29.2	23.1	40.4	43.1 (4)	33.3	29.4	31.9	39.0	34.4
Nitrate	mg/l-N	10	0.15	0.12	0.26	0.10	0.06	0.10	0.10	~~0.10#~~	0.10	0.10	0.10	0.16	0.10	0.14	0.24	0.26	0.15
Total Phosphorus	mg/l-P	10	8.17	8.35	10.10	5.67	1.47	2.42	9.08	~~16.30#~~	7.24	8.12	9.90	7.42	6.41	9.16	10.10	5.67	8.58

GRAB SAMPLES

Parameter	Units	Statistical Analyses							Water Quality Results										
		n	Mean	Median	High	Low	Standard Deviation	Confidence Interval (at 90% CL)	G2-0301-1135	G2-0308-1010	G2-0315-1030	G2-0329-1025	G2-0405-1020	G2-0412-1200	G2-0419-1015	G2-0426-0950	G2-0503-1030	G2-0510-1005	G2-0517-1020
Fecal Coliform	cfu/100ml																		
Field pH		11	7.26	7.22	7.48	7.01	0.17	0.27	7.16	7.28	7.22	7.06	7.19	7.37	7.45	7.48	7.48	7.15	7.01
Field DO	mg/l	11	4.9	4.9	7.5	3.3	1.3	2.1	4.9	7.5	4.9	5.0	5.0	4.2	5.6	6.3	3.4	3.5	3.3
Sample Temp.	°C	11	16.5	16.5	18.0	15.0	1.0	1.7	15.0	15.0	16.0	16.0	15.5	17.0	17.0	18.0	17.5	16.5	17.5

Notes

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A "*" denotes a value that was removed statistically, having been identified as an outlier (see also Section 9.2.1).

1. Some VSS values were analyzed to be greater than the corresponding TSS value, so have been assumed to equal it (see also Section 9.2.1).
2. Some TKN values were analyzed to be less than the corresponding NH_3 value, so have been assumed to equal it (see also Section 9.2.1).
3. Some TSS and VSS samples were analyzed one day outside the seven day holding time but were retained (see also Section 7.3.2).
4. Some TSS or NH_3 analyses did not meet objectives for RPD or PRR but were retained (see also Section 7.3.2).

Table C.3

WATER QUALITY DATA

ELEVEN WEEK PERFORMANCE EVALUATION

Sample Point W3 (Aerated Tank effluent)

COMPOSITE SAMPLES

Parameter	Units	Statistical Analyses							Water Quality Results										
		n	Mean	Median	High	Low	Standard Deviation	Confidence Interval (at 95% CL)	W3-0301-1150	W3-0308-1023	W3-0315-1045	W3-0329-1035	W3-0405-1030	W3-0412-1215	W3-0419-1030	W3-0426-1000	W3-0503-1045	W3-0510-1020	W3-0517-1040
Total COD	mg/l	10	399.4	414.5	524.0	242.0	81.4	134.0	401	~~839~~#	323	330	524	405	242	457	464	424	424
Soluble COD	mg/l	9	63.8	63.0	71.9	54.1	7.0	11.5	57.5	~~112~~#	63	55.2	54.1	71.1	71.1	~~195~~*	71.9	63	67.4
Total BOD_5	mg/l	8	105.6	110.0	117.0	88.0	9.1	15.0	110	~~150~~#	110	100	100	110	~~71~~*	117	110	88	no data
Soluble BOD_5	mg/l	9	9.7	10.0	15.0	6.3	3.1	5.0	10	~~25~~#	6.7	6.3	7.9	15	13	11	11	6.7	no data
TSS	mg/l	10	148.0	152.0	218.0	91.3	36.2	59.6	166	~~358~~#	168 (4)	152	161	152	91.3	107	150	115 (3)	218
VSS	mg/l	10	122.0	121.0	182.0	74.0	30.8	50.7	124	~~269~~#	102	146	124	148	74	107 (1)	118	95 (3)	182
TKN	mg/l	10	46.0	46.8	53.6	35.7	6.0	9.9	35.7	~~47.6~~#	45.6	49.2	53.6	51	36.5	51	47.3	43.4	46.2
Ammonia	mg/l-N	10	28.0	28.1	36.6	20.4	4.6	7.5	26.9	~~28.1~~#	23.8	20.4	31.5	36.6 (4)	26	25	29.5	30.8	29.3
Nitrate	mg/l-N	9	0.38	0.28	0.85	0.17	0.22	0.36	0.35	~~0.1~~#	0.27	0.85	~~1.68~~*	0.38	0.62	0.20	0.28	0.26	0.17
Total Phosphorus	mg/l-P	9	8.54	8.24	10.80	6.90	1.19	1.98	9.45	~~14~~#	7.89	7.61	9.57	7.98	6.9	8.24	10.8	8.38	~~4.69~~*

GRAB SAMPLES

Parameter	Units	Statistical Analyses							Water Quality Results										
		n	Mean	Median	High	Low	Standard Deviation	Confidence Interval (at 90% CL)	G3-0301-1200	G3-0308-1035	G3-0315-1115	G3-0329-1055	G3-0405-1040	G3-0412-1230	G3-0419-1040	G3-0426-1010	G3-0503-1055	G3-0510-1030	G3-0517-1055
Fecal Coliform	cfu/100ml																		
Field pH		11	7.61	7.57	7.94	7.48	0.12	0.20	7.48	7.94	7.62	7.53	7.56	7.61	7.72	7.57	7.58	7.57	7.56
Field DO	mg/l	11	4.9	5.3	6.7	3.2	1.1	1.8	6.1	3.8	6.7	5.5	5.5	3.2	5.3	5.4	3.9	4.7	3.8
Sample Temp.	°C	11	17.1	17.0	18.5	15.0	1.0	1.6	15.0	16.0	17.0	17.0	17.0	18.0	18.0	18.0	17.0	17.0	18.5

Notes

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A "*" denotes a value that was removed statistically, having been identified as an outlier (see also Section 9.2.1).

1. Some VSS values were analyzed to be greater than the corresponding TSS value, so have been assumed to equal it (see also Section 9.2.1).
2. Some TKN values were analyzed to be less than the corresponding NH_3 value, so have been assumed to equal it (see also Section 9.2.1).
3. Some TSS and VSS samples were analyzed one day outside the seven day holding time but were retained (see also Section 7.3.2).
4. Some TSS or NH_3 analyses did not meet objectives for RPD or PRR but were retained (see also Section 7.3.2).

Table C.4

WATER QUALITY DATA

ELEVEN WEEK PERFORMANCE EVALUATION

Sample Point W5 (1st Ecological Fluidized Bed effluent)

COMPOSITE SAMPLES

Parameter	Units	Statistical Analyses							Water Quality Results										
		n	Mean	Median	High	Low	Standard Deviation	Confidence Interval (at 95% CL)	W5-0301-1210	W5-0308-1045	W5-0315-1120	W5-0329-1105	W5-0405-1050	W5-0412-1250	W5-0419-1100	W5-0426-1040	W5-0503-1110	W5-0510-1050	W5-0517-1110
Total COD	mg/l	9	149.8	154.0	201.0	114.0	27.6	45.4	~~89.3#~~	201	150	123	161	167	114	154	159	119	~~270*~~
Soluble COD	mg/l	10	50.7	49.8	74.1	36.3	11.5	19.0	~~87#~~	74.1	43	39.3	36.3	52.2	41.5	58.5	58.5	47.4	56.3
Total BOD_5	mg/l	8	49.4	52.5	60.0	35.0	10.0	16.5	~~40#~~	49	57	44	60	58	~~7.2*~~	56	35	36	no data
Soluble BOD_5	mg/l	9	6.4	6.7	10.0	4.0	2.2	3.6	~~4.7#~~	6.9	7.6	5	4.6	10	4	9	6.7	4	no data
TSS	mg/l	9	42.6	40.0	62.5	33.6	9.2	15.1	~~4.0#~~	41.1	38.5 (4)	37.1	51.5	62.5	40	35	44	33.6 (3)	~~422*~~
VSS	mg/l	9	33.6	33.5	62.5	23.0	11.6	19.1	~~8.0#~~	28	23	34.1	33.5	62.5	28	35 (1)	33.5	25.2 (3)	~~404*~~
TKN	mg/l	10	29.9	28.2	40.9	21.7	6.1	10.0	~~15.2#~~	28.1 (2)	26.8	24.4	31.3	40.9	27.5	30.6	28.2	21.7 (2)	39.4
Ammonia	mg/l-N	10	22.9	22.6	29.9	15.9	4.1	6.7	~~20.3#~~	28.1	19.5	15.9	23.6	29.9 (4)	22.9	20.3	22.2	21.7	25
Nitrate	mg/l-N	9	2.12	1.59	4.71	0.22	1.41	2.32	~~7.81#~~	0.22	1.35	2.57	4.71	0.96	3.78	1.50	2.44	~~7.44*~~	1.59
Total Phosphorus	mg/l-P	10	8.0	8.0	10.4	6.2	1.2	2.0	~~7.31#~~	6.9	6.16	8.87	7.61	10.4	7.64	7.32	8.87	8.29	8.38

GRAB SAMPLES

Parameter	Units	Statistical Analyses*							Water Quality Results										
		n	Mean	Median	High	Low	Standard Deviation	Confidence Interval (at 90% CL)	G5-0301-1220	G5-0308-1055	G5-0315-1125	G5-0329-1125	G5-0405-1100	G5-0412-1310	G5-0419-1115	G5-0426-1055	G5-0503-1120	G5-0510-1105	G5-0517-1125
Fecal Coliform	cfu/100ml																		
Field pH		10	7.47	7.45	7.57	7.36	0.07	0.12	6.72	7.54	7.43	7.51	7.36	7.57	7.54	7.51	7.37	7.42	7.45
Field DO	mg/l	10	5.5	5.3	8.2	3.7	1.3	2.1	2.5	8.2	5.0	4.5	6.0	4.4	6.2	6.1	3.7	5.4	5.3
Sample Temp.	°C	10	17.7	18.0	19.0	16.0	0.9	1.4	16.5	16.0	17.5	17.0	18.0	18.0	19.0	18.0	18.0	17.0	18.5

Notes

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1. Some VSS values were analyzed to be greater than the corresponding TSS value, so have been assumed to equal it (see also Section 9.2.1).
2. Some TKN values were analyzed to be less than the corresponding NH_3 value, so have been assumed to equal it (see also Section 9.2.1).
3. Some TSS and VSS samples were analyzed one day outside the seven day holding time but were retained (see also Section 7.3.2).
4. Some TSS or NH_3 analyses did not meet objectives for RPD or PRR but were retained (see also Section 7.3.2).

Table C.5

WATER QUALITY DATA

ELEVEN WEEK PERFORMANCE EVALUATION

Sample Point W4 (3rd Ecological Fluidized Bed effluent)

COMPOSITE SAMPLES

Parameter	Units	Statistical Analyses							Water Quality Results										
		n	Mean	Median	High	Low	Standard Deviation	Confidence Interval (at 95% CL)	W4-0302-1050	W4-0309-1040	W4-0316-1030	W4-0330-1000	W4-0406-1010	W4-0413-1015	W4-0420-1050	W4-0427-1000	W4-0504-0955	W4-0511-1010	W4-0518-0950
Total COD	mg/l	10	73.4	60.8	141.0	25.6	39.1	64.3	31.9	52.9	25.6	119	~~256~~*	96.4	56.3	141	103	42.9	65.2
Soluble COD	mg/l	10	43.2	42.3	74.1	14.2	19.0	31.3	31.9	39.3	14.2	32.4	23.3	60.8	45.2	~~139~~*	74.1	45.2	65.2
Total BOD_5	mg/l	9	18.4	14.0	39.0	4.0	11.6	19.1	7.2	14	10	22	4	30	26	~~73~~*	39	13	no data
Soluble BOD_5	mg/l	9	11.3	4.1	37.0	4.0	11.2	18.5	4	4.1	4	4	4	18	17	~~59~~*	37	9.2	no data
TSS	mg/l	10	9.9	9.6	25.7	2.0	6.3	10.4	4.4	6.4	9.6	~~98.3~~*	2	25.7	10.8	9.6	10.2	9	11.4
VSS	mg/l	10	6.3	5.0	21.4	2.0	5.5	9.1	2.2	5	4	~~43.3~~*	2	21.4	6.5	6	4.8	6	5
TKN	mg/l	11	10.0	9.8	17.9	3.1	4.8	7.9	17.3 (2)	17.9 (2)	6.07	7.05	3.12	13.9	6.19	11.5	6.99	9.82	10.7
Ammonia	mg/l-N	11	7.5	4.4	17.9	0.3	6.6	10.9	17.3	17.9	4.44	1.08	0.32	12.3	3.76	4.89	2.14	4.04	14.2
Nitrate	mg/l-N	11	10.49	9.01	24.10	1.32	6.89	11.33	9.01	3.92	13.00	20.80	1.32	10.40	24.10	8.59	8.57	11.40	4.24
Total Phosphorus	mg/l-P	10	7.0	7.1	7.9	6.0	0.8	1.3	7.03	6.17	6.02	7.66	6.21	7.89	~~94.5~~*	7.09	6.23	7.82	7.78

GRAB SAMPLES

Parameter	Units	Statistical Analyses							Water Quality Results										
		n	Mean	Median	High	Low	Standard Deviation	Confidence Interval (at 90% CL)	G4-0302-1100	G4-0309-1050	G4-0316-1035	G4-0330-1015	G4-0406-1025	G4-0413-1030	G4-0420-1100	G4-0427-1010	G4-0504-1005	G4-0511-1020	G4-0518-1005
Fecal Coliform	cfu/100ml																		
Field pH		11	7.15	7.12	7.34	6.87	0.14	0.24	6.87	7.21	7.05	7.05	7.34	7.25	7.12	7.30	7.09	7.09	7.31
Field DO	mg/l	11	3.5	2.9	4.9	2.7	0.9	1.5	2.9	2.8	4.7	4.9	4.9	3.9	2.8	2.7	2.9	2.8	2.9
Sample Temp.	°C	11	18.2	18.0	19.5	16.0	1.2	2.0	16.0	16.0	18.0	18.0	19.0	18.0	19.5	19.0	18.0	19.0	19.5

Notes

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1. Some VSS values were analyzed to be greater than the corresponding TSS value, so have been assumed to equal it (see also Section 9.2.1).
2. Some TKN values were analyzed to be less than the corresponding NH_3 value, so have been assumed to equal it (see also Section 9.2.1).
3. Some TSS and VSS samples were analyzed one day outside the seven day holding time but were retained (see also Section 7.3.2).
4. Some TSS or NH_3 analyses did not meet objectives for RPD or PRR but were retained (see also Section 7.3.2).

Table C.6

WATER QUALITY DATA

ELEVEN WEEK PERFORMANCE EVALUATION

Sample Point W6 (High-rate Marsh effluent)

COMPOSITE SAMPLES

Parameter	Units	Statistical Analyses							Water Quality Results										
		n	Mean	Median	High	Low	Standard Deviation	Confidence Interval (at 95% CL)	W6-0302-1110	W6-0309-1100	W6-0316-1045	W6-0330-1030	W6-0406-1045	W6-0413-1050	W6-0420-1115	W6-0427-1115	W6-0504-1020	W6-0511-1035	W6-0518-1035
Total COD	mg/l	11	53.2	58.4	128.0	10.0	33.0	54.3	25.3	30.2	10	32.4	71.1	58.4	128	71.9	69.7	27.4	60.8
Soluble COD	mg/l	10	38.3	30.8	78.6	10.0	23.1	38.0	27.5	25.6	10	21.1	39.3	34	~~128~~*	69.7	78.6	18.4	58.5
Total BOD_5	mg/l	9	12.5	5.5	42.0	4.0	13.2	21.7	4	5.5	4	4	20	6.7	~~68~~*	22	42	4	no data
Soluble BOD_5	mg/l	9	10.2	4.2	41.0	4.0	12.8	21.1	4.1	4.3	4	4	5.3	4.2	~~69~~*	21	41	4	no data
TSS	mg/l	9	3.5	2.0	8.2	2.0	2.4	3.9	2	2	~~70.4~~#	2	~~10.8~~*	2	3.25	2	8.2	2.8	6.8
VSS	mg/l	9	2.2	2.0	2.8	2.0	0.4	0.6	2	2	~~70~~#	2 (1)	~~10.4~~*	2 (1)	2	2	2	2.8	2.8
TKN	mg/l	11	8.4	5.0	23.5	1.5	7.0	11.5	17.3 (2)	14.1 (2)	3.97	1.47	4.86	8.55	4.67	6.83	2.2	5	23.5
Ammonia	mg/l-N	11	5.5	2.6	17.3	0.1	6.3	10.3	17.3	14.1	2.82	0.1	1.73	5.51	2.6	1	0.36	1.71	13.1
Nitrate	mg/l-N	10	5.40	5.71	17.30	0.39	5.20	8.56	6.49	6.89	7.63	17.30	7.77	1.73	0.39	4.92	0.42	~~60.7~~*	0.45
Total Phosphorus	mg/l-P	11	6.8	6.9	7.9	5.3	0.8	1.3	6.07	6.9	6.3	5.28	6.44	7.64	7.4	6.77	7.05	7.52	7.87

GRAB SAMPLES

Parameter	Units	Statistical Analyses							Water Quality Results										
		n	Mean	Median	High	Low	Standard Deviation	Confidence Interval (at 90% CL)	G6-0302-1125	G6-0309-1105	G6-0316-1100	G6-0329-1045	G6-0406-1055	G6-0413-1115	G6-0420-1125	G6-0427-1120	G6-0504-1030	G6-0511-1040	G6-0518-1050
Fecal Coliform	cfu/100ml	10	170	85	800	4	236	388	240	30,000*	80	90	110	800	30	30	80	4	240
Field pH		11	7.30	7.28	7.67	7.05	0.18	0.29	7.05	7.20	7.20	7.18	7.52	7.67	7.28	7.42	7.28	7.17	7.33
Field DO	mg/l	11	2.8	2.7	3.3	2.4	0.2	0.4	2.7	2.8	3.0	2.8	2.7	2.6	2.7	2.4	2.8	2.6	3.3
Sample Temp.	°C	11	18.5	19.0	20.0	15.5	1.6	2.6	15.5	16.0	19.0	18.0	20.0	18.0	20.0	20.0	18.0	19.2	20.0

Notes

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1. Some VSS values were analyzed to be greater than the corresponding TSS value, so have been assumed to equal it (see also Section 9.2.1).
2. Some TKN values were analyzed to be less than the corresponding NH_3 value, so have been assumed to equal it (see also Section 9.2.1).
3. Some TSS and VSS samples were analyzed one day outside the seven day holding time but were retained (see also Section 7.3.2).
4. Some TSS or NH_3 analyses did not meet objectives for RPD or PRR but were retained (see also Section 7.3.2).

Table C.7

SLUDGE DATA SUMMARY

ELEVEN WEEK PERFORMANCE EVALUATION

SAMPLE POINT S1 (Anaerobic Bio-reactor)

LABORATORY ANALYSES

Parameter	Units	Statistical Analyses							Sample Numbers			
		n	Mean	Median	High	Low	Standard Deviation	Confidence Interval (at 90% CL)	S1-0330-1235	S1-0413-1145	S1-0427-1200	S1-0510-1140
Total Phosphorus	mg/l-P	3	384	537	561	53	286	471		53.4	537	561
TKN	mg/l-N	3	1,160	1,190	1,200	1,090	61	100		1,090	1,200	1,190
Solids	%	3	2.99%	2.98%	3.20%	2.78%	0.21%	0.35%		2.98%	3.20%	2.78%
Arsenic	mg/l	3	0.192	0.198	0.234	0.144	0.045	0.075		0.234	0.198	0.144
Cadmium	mg/l	3	0.121	0.124	0.140	0.099	0.021	0.034		0.099	0.140	0.124
Chromium	mg/l	3	1.126	1.220	1.330	0.829	0.263	0.433		1.220	1.330	0.829
Copper	mg/l	3	28.5	31.0	32.2	22.2	5.5	9.0		22.2	32.2	31.0
Lead	mg/l	3	1.53	1.45	1.78	1.36	0.22	0.36		1.36	1.78	1.45
Mercury	mg/l	3	0.0257	0.0236	0.0526	0.0009	0.0259	0.0426		0.0236	0.0526	0.0009
Molybdenum	mg/l	3	0.90	0.79	1.20	0.72	0.26	0.43		0.72	1.20	0.79
Nickel	mg/l	3	1.15	1.15	1.17	1.12	0.03	0.04		1.12	1.17	1.15
Selenium	mg/l	3	0.1	0.1	0.1	0.1	0.0	n/a		0.1	0.1	0.1
Zinc	mg/l	3	31.1	30.6	33.7	29.1	2.3	3.9		29.1	33.7	30.6
Fecal Coliform	cfu/g	2	7,700,000	7,700,000	10,000,000	5,400,000	3,252,691	5,350,199	10,000,000	5,400,000		

FIELD ANALYSES

Parameter	Units	Statistical Analyses							Sample Numbers			
		n	Mean	Median	High	Low	Standard Deviation	Confidence Interval (at 90% CL)	S1-0330-1235	S1-0413-1145	S1-0427-1200	S1-0510-1140
Field pH		4	6.20	6.18	6.42	6.01	0.21	0.34	6.03	6.42	6.33	6.01
Field DO	mg/l	4	0.3	0.2	0.6	0.1	0.2	0.4	0.2	0.2	0.1	0.6
Sample Temp.	°C	4	17.9	17.7	21.0	15.0	2.8	4.6	15.0	16.0	21.0	19.4

Table C.8

SLUDGE DATA SUMMARY

ELEVEN WEEK PERFORMANCE EVALUATION

SAMPLE POINT S2 (Clarifier After 2nd Aeration Tank)

LABORATORY ANALYSES

Parameter	Units	Statistical Analyses							Sample Numbers			
		n	Mean	Median	High	Low	Standard Deviation	Confidence Interval (at 90% CL)	S2-0330-1215	S2-0413-1200	S2-0427-1145	S2-0510-1155
Total Phosphorus	mg/l-P	3	228	302	339	42	162	266		42.1	302	339
TKN	mg/l-N	3	1,156	840	1,840	788	593	975		788	840	1,840
Solids	%	3	1.55%	1.34%	1.99%	1.31%	0.38%	0.63%		1.34%	1.31%	1.99%
Arsenic	mg/l	3	0.10	0.10	0.10	0.09	0.01	0.01		0.09	0.10	0.10
Cadmium	mg/l	3	0.040	0.043	0.051	0.027	0.012	0.020		0.027	0.043	0.051
Chromium	mg/l	3	0.353	0.280	0.530	0.250	0.154	0.253		0.280	0.250	0.530
Copper	mg/l	3	8.95	6.69	13.50	6.65	3.94	6.49		6.65	6.69	13.5
Lead	mg/l	3	0.431	0.378	0.580	0.335	0.131	0.215		0.335	0.378	0.58
Mercury	mg/l	3	0.0135	0.0200	0.0200	0.0004	0.0113	0.0186		0.0200	0.0200	0.0004
Molybdenum	mg/l	3	0.30	0.32	0.38	0.20	0.09	0.15		0.20	0.32	0.38
Nickel	mg/l	3	0.350	0.277	0.505	0.269	0.134	0.220		0.269	0.277	0.505
Selenium	mg/l	3	0.1	0.1	0.1	0.1	0.0	n/a		0.1	0.1	0.1
Zinc	mg/l	3	32.0	14.9	74.5	6.7	37.0	60.9		74.5	6.7	14.9
Fecal Coliform	cfu/g	2	1,350,000	1,350,000	1,400,000	1,300,000	70,711	116,309	1,400,000	1,300,000		

FIELD ANALYSES

Parameter	Units	Statistical Analyses							Sample Numbers			
		n	Mean	Median	High	Low	Standard Deviation	Confidence Interval (at 90% CL)	S2-0330-1215	S2-0413-1200	S2-0427-1145	S2-0510-1155
Field pH		3	6.76	6.74	6.98	6.58	0.17	0.29	6.58	6.81	6.98	6.67
Field DO	mg/l	3	0.3	0.2	0.7	0.1	0.3	0.5	0.7	0.1	0.1	0.2
Sample Temp.	°C	3	18.5	18.3	20.5	17.0	1.5	2.4	17.0	18.0	20.5	18.6

5. Samples W5-0308-1045 & W5-0510-105 (Table C.4), W4-0302-1050 & W4-0309-1040 (Table C.5), and W6-0302-1110 & W6-0309-1100 (Table C.6): these samples gave values for ammonia that exceeded the samples' TKN values. This was determined to be a consequence of the analytical method for TKN when the TKN comprises mainly ammonia (the sample must be refluxed for a period of time which can drive some of the volatile ammonia from the sample). When this was first observed, the analytical method was modified slightly to account for this. However, where this occurred, the TKN value was assumed to equal the ammonia value.

Statistical Analysis

After the initial review described above, the data were analyzed statistically. The analyses performed on the data were as follows:

- Kolgomorov-Smirnov (K-S) distribution testing to determine whether the data was in a normal or lognormal distribution. These analyses were performed as many statistical tests (e.g. T-tests) assume a normal distribution. Consequently, if the data is lognormal, it is necessary to "transform" it before further tests are performed.
- K-S lack-of-fit testing to identify any statistically outlying data that should be discarded. These outliers were removed in order that they would not influence the process evaluation, by influencing the mean data either upwards or downwards. It was intended that, by removing outliers, the data would better reflect the normal operating conditions of the process rather than being influenced by a "spike" result.

The K-S distribution tests were performed on the water quality data using the program Statgraphics Plus, Version 7.0 (distributed by Manugistics).

The K-S lack-of-fit tests were carried out using the following equation:

$$T_{N1} = \frac{x_{(n)} - \bar{x}}{s}$$

Where T_{N1} is the factor generated by the discordancy test;

$x_{(n)}$ is value being tested for discordancy;

$\bar{x}$ is the mean of the data set; and

s is standard deviation of the data set.

This lack-of-fit test assumes a normal distribution and identifies a single outlier only. This was considered suitable for the sample sizes in this study (in most cases, the n was between 9 and 11). In each case, the value furthest from the mean was tested by comparing the factor generated with a critical value, for a 5% significance level, found in statistical tables (see Table C.9). If the generated factor was greater than the critical value, then the point tested was determined to be an outlier and was removed from the data set.

In the main, the K-S distribution testing of the data was inconclusive as to its nature. This is not surprising owing to the relatively low number of values in the data sets. Because of this situation, an assumption had to be made concerning the distribution of the data.

Typically, most environmental data occurs in a lognormal distribution which is a reasonable assumption considering that much environmental data comprises data gathered about the mean value with some spike values - these spikes skew the data into a lognormal distribution pattern. If this assumption was made, the data would have to be "transformed" (by taking the natural log of each data value) before further statistical tests were carried out.

Table C.9 Critical Values for a Single Outlier in a Normal Sample

	Significance Level	
n	5%	1%
3	1.15	1.15
4	1.46	1.49
5	1.67	1.75
6	1.82	1.94
7	1.94	2.10
8	2.03	2.22
9	2.11	2.32
10	2.18	2.41
12	2.29	2.55
14	2.37	2.66
15	2.41	2.71
16	2.44	2.75
18	2.50	2.82
20	2.56	2.88
30	2.74	3.10
40	2.87	3.24

This table is abridged from Grubbs and Beck (1972).

However, in this situation, it was considered that a spike value might influence the data adversely (by increasing or decreasing the mean), with respect to the evaluation of the system's "normal" operating conditions. This is because one spike, in a sample population of 9-11 values could have a large influence on the mean. Therefore, for this process evaluation, the assumption was made that the data was in a normal distribution pattern and, consequently, the data was not transformed before further statistical testing.

The lack-of-fit testing identified a total of 26 outliers throughout the data sets. Additional K-S distribution tests were subsequently performed on the modified data.

The results of both the K-S distribution tests and the lack-of-fit tests are provided in Tables C.10 through C.20.

Table C.10 Distribution Test Results for Total Chemical Oxygen Demand

		K-S Distribution Test Factor [1]		
	Sample	Whole Data Set		Outlier Removed [4]
Laboratory	Location	Normal [2]	Lognormal [3]	Normal
Parsons ES	W1	0.966	0.943	n/a
Parsons ES	W2	0.914	0.928	n/a
Parsons ES	W3	0.781	0.588	n/a
Parsons ES	W4	0.816	0.998	0.890
Parsons ES	W5	0.486	0.767	0.957
Parsons ES	W6	0.799	0.741	n/a

(1) These factors are basicall probabilities that the data is arranged in either a normal or a lognormal

(2) This column shows the factors for the K-S test of the hypothesis that the distribution is "normal".

(3) This column shows the factors for the K-S test of the hypothesis that the distribution is "lognormal".

(4) This column shows the factors for the K-S test of the hypothesis that the distribution is "normal", once a single outlier has been removed from the data set. "n/a" in this column indicates that there were no outliers removed from this data set.

Table C.11 Distribution Test Results for Soluble Chemical Oxygen Demand

		K-S Distribution Test Factor		
	Sample	Whole Data Set		Outlier Removed
Laboratory	Location	Normal	Lognormal	Normal
Parsons ES	W1	0.881	0.958	0.986
Parsons ES	W2	0.642	0.618	n/a
Parsons ES	W3	0.357	0.569	0.921
Parsons ES	W4	0.720	0.997	n/a
Parsons ES	W5	0.979	0.989	n/a
Parsons ES	W6	0.676	0.9998	0.894

Table C.12 Distribution Test Results for Total Biochemical Oxygen Demand

Laboratory	Sample Location	K-S Distribution Test Factor Whole Data Set Normal	Whole Data Set Lognormal	Outlier Removed Normal
Parsons ES	W1	0.849	0.947	n/a
Parsons ES	W2	0.940	0.955	n/a
Parsons ES	W3	0.517	0.533	0.427
Parsons ES	W4	0.886	0.9998	0.858
Parsons ES	W5	0.892	0.309	0.720
Parsons ES	W6	0.371	0.554	0.262

Table C.13 Distribution Test Results for Soluble Biochemical Oxygen Demand

Laboratory	Sample Location	K-S Distribution Test Factor Whole Data Set Normal	Whole Data Set Lognormal	Outlier Removed Normal
Parsons ES	W1	0.947	0.983	n/a
Parsons ES	W2	0.692	0.849	n/a
Parsons ES	W3	0.953	0.917	n/a
Parsons ES	W4	0.521	0.534	0.419
Parsons ES	W5	0.912	0.969	n/a
Parsons ES	W6	0.108	0.158	0.075

Table C.14 Distribution Test Results for Total Suspended Solids

Laboratory	Sample Location	K-S Distribution Test Factor Whole Data Set Normal	Whole Data Set Lognormal	Outlier Removed Normal
Parsons ES	W1	0.575	0.920	0.987
Parsons ES	W2	0.941	0.879	n/a
Parsons ES	W3	0.710	0.485	n/a
Parsons ES	W4	0.047	0.357	0.304
Parsons ES	W5	0.340	0.519	0.722
Parsons ES	W6	0.233	0.492	0.347

Table C.15 Distribution Test Results for Volatile Suspended Solids

Laboratory	Sample Location	K-S Distribution Test Factor Whole Data Set Normal	Whole Data Set Lognormal	Outlier Removed Normal
Parsons ES	W1	0.924	0.9996	0.999
Parsons ES	W2	0.945	0.923	n/a
Parsons ES	W3	0.922	0.996	n/a
Parsons ES	W4	0.042	0.305	0.103
Parsons ES	W5	0.097	0.228	0.242
Parsons ES	W6	0.149	0.295	0.109

Table C.16 Distribution Test Results for Total Kjeldhal Nitrogen

Laboratory	Sample Location	K-S Distribution Test Factor Whole Data Set Normal	Whole Data Set Lognormal	Outlier Removed Normal
Parsons ES	W1	0.865	0.797	n/a
Parsons ES	W2	0.906	0.972	n/a
Parsons ES	W3	0.914	0.811	n/a
Parsons ES	W4	0.826	0.986	n/a
Parsons ES	W5	0.772	0.894	n/a
Parsons ES	W6	0.590	0.978	n/a

Table C.17 Distribution Test Results for Ammonia

Laboratory	Sample Location	K-S Distribution Test Factor Whole Data Set Normal	Whole Data Set Lognormal	Outlier Removed Normal
Parsons ES	W1	0.999	0.999	n/a
Parsons ES	W2	0.961	0.993	n/a
Parsons ES	W3	0.999	0.991	n/a
Parsons ES	W4	0.315	0.891	n/a
Parsons ES	W5	0.994	0.9995	n/a
Parsons ES	W6	0.271	0.975	n/a

Table C.18 Distribution Test Results for Nitrate

Laboratory	Sample Location	K-S Distribution Test Factor Whole Data Set Normal	Whole Data Set Lognormal	Outlier Removed Normal
Parsons ES	W1	0.262	0.540	n/a
Parsons ES	W2	0.448	0.358	n/a
Parsons ES	W3	0.309	0.773	0.529
Parsons ES	W4	0.886	0.504	n/a
Parsons ES	W5	0.739	0.944	0.853
Parsons ES	W6	0.074	0.762	0.696

Table C.19 Distribution Test Results for Total Phosphorus

Laboratory	Sample Location	K-S Distribution Test Factor Whole Data Set Normal	Whole Data Set Lognormal	Outlier Removed Normal
Parsons ES	W1	0.247	0.405	0.895
Parsons ES	W2	0.995	0.990	n/a
Parsons ES	W3	0.505	0.135	0.783
Parsons ES	W4	0.011	0.038	0.627
Parsons ES	W5	0.985	0.994	n/a
Parsons ES	W6	0.993	0.994	n/a

Table C.20 Distribution Test Results for Fecal Coliform

Laboratory	Sample Location	K-S Distribution Test Factor Whole Data Set Normal	Whole Data Set Lognormal	Outlier Removed Normal
Parsons ES	W1	0.586	0.858	n/a
Parsons ES	W6	0.008	0.663	0.325

A simple description of the study data is provided in Table C.21.

Table C.21. Simple Statistical Description for Water Quality Data

Sample Location	Water Quality Parameter	Statistics: Mean	Statistics: Standard Deviation	Analysis
W1	COD (total)	1,307.0	243.2	
	COD (soluble)	157.5	13.6	One outlier (212) was removed from these data statistically.
	BOD_5 (total)	468.8	116.4	
	BOD_5 (soluble)	70.1	14.3	
	TSS	470.4	136.4	Two values (229 & 715) increased the standard deviation of the data. One outlier (1,040) was removed from these data statistically.
	VSS	364.0	96.4	One value (520) increased the standard deviation of the data. One outlier (765) was removed from these data statistically.
	TKN	55.9	7.1	
	Ammonia	25.6	4.2	
	Nitrate	0.16	0.07	Three values (0.24, 0.28 & 0.29) increased the standard deviation of the data.
	Total Phosphorus	13.6	2.2	One outlier (37.6) was removed from these data statistically.
	Fecal Coliform	8,109,091	6,872,184	The range of values (2,400,000 to 24,000,000) was responsible for the high standard deviation.
	Field pH	7.98	0.27	
	Field DO	2.9	1.0	The range of values (1.2 to 4.7) was responsible for the high standard deviation.
W2	COD (total)	444.7	76.1	
	COD (soluble)	216.2	15.6	
	BOD_5 (total)	160.0	32.4	
	BOD_5 (soluble)	107.7	22.9	
	TSS	78.0	22.5	One value (117) increased the standard deviation of the data.
	VSS	64.0	20.7	The range of values (33.5 to 91.3) was responsible for the high standard deviation.
	TKN	43.3	6.7	
	Ammonia	33.8	5.9	
	Nitrate	0.15	0.06	Two values (0.24 & 0.26) increased the standard deviation of the data.
	Total Phosphorus	8.17	1.47	
	Field pH	7.26	0.17	
	Field DO	4.9	1.3	

Table C.21 Simple Statistical Description for Water Quality Data (continued)

Sample Location	Water Quality Parameter	Statistics: Mean	Statistics: Standard Deviation	Analysis
W3	COD (total)	399.4	81.4	
	COD (soluble)	63.8	7.0	One outlier (105) was removed from these data statistically.
	BOD_5 (total)	105.6	9.1	One outlier (71) was removed from these data statistically.
	BOD_5 (soluble)	9.7	3.1	The range of values (6.3 to 15) was responsible for the high standard deviation.
	TSS	148.0	36.2	
	VSS	122.0	30.8	One value (182) increased the standard deviation of the data.
	TKN	46.0	6.0	
	Ammonia	28.0	4.6	
	Nitrate	0.38	0.22	Two values (0.62 & 0.85) increased the standard deviation of the data. One outlier (1.58) was removed from these data statistically.
	Total Phosphorus	8.54	1.19	One outlier (1.69) was removed from these data statistically.
	Field pH	7.61	0.12	
	Field DO	4.9	1.1	
W5	COD (total)	149.8	27.6	One outlier (279) was removed from these data statistically.
	COD (soluble)	50.7	11.5	
	BOD_5 (total)	49.4	10.0	One outlier (7.2) was removed from these data statistically.
	BOD_5 (soluble)	6.4	2.2	The range of values (4.0 to 10.0) was responsible for the high standard deviation.
	TSS	42.6	9.2	One outlier (122) was removed from these data statistically.
	VSS	33.6	11.6	One value (62.5) increased the standard deviation of the data. One outlier (101) was removed from these data statistically.
	TKN	29.9	6.1	
	Ammonia	22.9	4.1	
	Nitrate	2.12	1.41	The range of values (0.22 to 4.71) was responsible for the high standard deviation. One outlier (7.44) was removed from these data statistically.
	Total Phosphorus	8.0	1.2	
	Field pH	7.47	0.07	
	Field DO	5.5	1.3	

Table C.21 Simple Statistical Description for Water Quality Data (continued)

Sample Location	Water Quality Parameter	Statistics: Mean	Statistics: Standard Deviation	Analysis
W4	COD (total)	73.4	39.1	The range of values (25.6 to 141) was responsible for the high standard deviation. One outlier (256) was removed from these data statistically.
	COD (soluble)	43.2	19.0	The range of values (14.2 to 74.1) was responsible for the high standard deviation. One outlier (130) was removed from these data statistically.
	BOD_5 (total)	18.4	11.6	The range of values (4.0 to 39.0) was responsible for the high standard deviation. One outlier (73) was removed from these data statistically.
	BOD_5 (soluble)	11.3	11.2	The range of values (4.0 to 37.0) was responsible for the high standard deviation. One outlier (59) was removed from these data statistically.
	TSS	9.9	6.3	One value (25.7) increased the standard deviation of the data. One outlier (98.3) was removed from these data statistically.
	VSS	6.3	5.5	One value (21.4) increased the standard deviation of the data. One outlier (43.3) was removed from these data statistically.
	TKN	10.0	4.8	The range of values (3.1 to 17.9) was responsible for the high standard deviation.
	Ammonia	7.5	6.6	The range of values (0.32 to 17.9) was responsible for the high standard deviation.
	Nitrate	10.49	6.89	The range of values (1.32 to 24.1) was responsible for the high standard deviation.
	Total Phosphorus	7.0	0.8	One outlier (34.5) was removed from these data statistically.
	Field pH	7.15	0.14	
	Field DO	3.5	0.9	
W6	COD (total)	53.2	33.0	The range of values (10.0 to 128) was responsible for the high standard deviation.
	COD (soluble)	38.3	23.1	The range of values (10.0 to 78.6) was responsible for the high standard deviation. One outlier (128) was removed from these data statistically.
	BOD_5 (total)	12.5	13.2	The range of values (4.0 to 42.0) was responsible for the high standard deviation. One outlier (88) was removed from these data statistically.
	BOD_5 (soluble)	10.2	12.8	The range of values (4.0 to 41.0) was responsible for the high standard deviation. One outlier (80) was removed from these data statistically.

Table C.21 Simple Statistical Description for Water Quality Data (continued)

Sample Location	Water Quality Parameter	Statistics: Mean	Statistics: Standard Deviation	Analysis
W6 (contd.)	TSS	3.5	2.4	The range of values (2.0 to 8.2) was responsible for the high standard deviation. One outlier (19.8) was removed from these data statistically.
	VSS	2.2	0.4	One outlier (10.4) was removed from these data statistically.
	TKN	8.4	7.0	The range of values (1.5 to 23.5) was responsible for the high standard deviation.
	Ammonia	5.5	6.3	The range of values (0.1 to 17.3) was responsible for the high standard deviation.
	Nitrate	5.40	5.20	The range of values (0.39 to 17.3) was responsible for the high standard deviation. One outlier (69.7) was removed from these data statistically.
	Total Phosphorus	6.8	0.8	
	Fecal Coliform	170	236	The range of values (4 to 800) was responsible for the high standard deviation. One outlier (30,000) was removed from these data statistically.
	Field pH			
	Field DO			

Appendix D

Raw Data: Tracer Study

This appendix contains the raw data recorded during the tracer study performed at the AEES, to determine hydraulic detention times of the various process equipment. The data are in the form of sampling times and the corresponding lithium chloride concentrations, and are provided in Tables D.1 through D.7. The graphs of the tracer study data are presented in Figures D-1 through D-7.

The detection limit for the lithium analyses was 0.02 mg/l lithium. Where the concentration of lithium was determined to be < 0.02 mg/l, a concentration of 0.02 mg/l is quoted for the purposes of plotting the graphs and calculating HDTs.

Table D.1
Tracer Study Data Summary
Sample Point T1 (High-rate Marsh)

Sample	Time	Lithium Chloride Concentration (mg/l)
Starting Point (9:00)	9:00	*0.020*
T1-0404-1000	10:00	0.020
T1-0404-1100	11:00	0.020
T1-0404-1200	12:00	0.020
T1-0404-1300	13:00	0.020
T1-0404-1400	14:00	0.052
T1-0404-1500	15:00	0.381
T1-0404-1600	16:00	0.766
T1-0404-1700	17:00	0.971
T1-0404-1800	18:00	0.920
T1-0404-1900	19:00	0.820
T1-0404-2000	20:00	0.663
T1-0404-2100	21:00	0.501
T1-0404-2200	22:00	0.348
T1-0404-2300	23:00	0.236
T1-0404-2400	0:00	0.165
T1-0405-0100	1:00	0.117
T1-0405-0200	2:00	0.097
T1-0405-0300	3:00	0.075
T1-0405-0400	4:00	0.061
T1-0405-0500	5:00	0.049
T1-0405-0600	6:00	0.040
T1-0405-0700	7:00	0.036
T1-0405-0800	8:00	0.035
T1-0405-0900	9:00	0.032
T1-0405-1000	10:00	0.029
T1-0405-1100	11:00	0.028
T1-0405-1200	12:00	0.023

Table D.2
Tracer Study Data Summary
Sample Point T2 (Duckweed Clarifier)

Sample	Time	Lithium Chloride Concentration (mg/l)
Starting Point (9:50)	9:50	*0.020*
T2-0412-1050	10:50	0.020
T2-0412-1150	11:50	0.042
T2-0412-1250	12:50	0.024
T2-0412-1350	13:50	0.079
T2-0412-1450	14:50	0.182
T2-0412-1550	15:50	0.395
T2-0412-1650	16:50	0.464
T2-0412-1750	17:50	0.437
T2-0412-1850	18:50	0.415
T2-0412-1950	19:50	0.408
T2-0412-2050	20:50	0.382
T2-0412-2150	21:50	0.344
T2-0412-2250	22:50	0.313
T2-0412-2350	23:50	0.264
T2-0412-0050	0:50	0.230
T2-0413-0150	1:50	0.186
T2-0413-0250	2:50	0.164
T2-0413-0350	3:50	0.146
T2-0413-0450	4:50	0.121
T2-0413-0550	5:50	0.108
T2-0413-0650	6:50	0.095
T2-0413-0750	7:50	0.088
T2-0413-0850	8:50	0.075

Table D.3a
Tracer Study Data Summary
Sample Point T3 (Ecological Fluidized Beds)
Second Attempt

Sample	Time	Lithium Chloride Concentration (mg/l)
Starting Point (10:00)	10:00	*0.020*
T3-0620-1100	11:00	0.023
T3-0620-1200	12:00	0.076
T3-0620-1300	13:00	0.134
T3-0620-1400	14:00	0.183
T3-0620-1500	15:00	0.221
T3-0620-1600	16:00	0.262
T3-0620-1700	17:00	0.277
T3-0620-1800	18:00	0.288
T3-0620-1900	19:00	0.297
T3-0620-2000	20:00	0.304
T3-0620-2100	21:00	0.298
T3-0620-2200	22:00	0.297
T3-0620-2300	23:00	0.293
T3-0620-2400	0:00	0.287
T3-0621-0100	1:00	0.275
T3-0621-0200	2:00	0.271
T3-0621-0300	3:00	0.264
T3-0621-0400	4:00	0.260
T3-0621-0500	5:00	0.249
T3-0621-0600	6:00	0.241
T3-0621-0700	7:00	0.234
T3-0621-0800	8:00	0.224
T3-0621-0900	9:00	0.218
T3-0621-1000	10:00	0.209
T3-0621-1100	11:00	0.202
T3-0621-1200	12:00	0.195
T3-0621-1300	13:00	0.190
T3-0621-1400	14:00	0.183
T3-0621-1500	15:00	0.178

Table D.3a (continued)
Tracer Study Data Summary
Sample Point T3 (Ecological Fluidized Beds)
Second Attempt

Sample	Time	Lithium Chloride Concentration (mg/l)
T3-0621-1600	16:00	0.170
T3-0621-1700	17:00	0.166
T3-0621-1800	18:00	0.160
T3-0621-1900	19:00	0.154
T3-0621-2000	20:00	0.150
T3-0621-2100	21:00	0.145
T3-0621-2200	22:00	0.141
T3-0621-2300	23:00	0.136
T3-0621-2400	0:00	0.131
T3-0622-0100	1:00	0.126
T3-0622-0200	2:00	0.122
T3-0622-0300	3:00	0.117
T3-0622-0400	4:00	0.114
T3-0622-0500	5:00	0.108
T3-0622-0600	6:00	0.106
T3-0622-0700	7:00	0.101
T3-0622-0800	8:00	0.098
T3-0622-0900	9:00	0.095
T3-0622-1000	10:00	0.092
T3-0622-1100	11:00	0.088
T3-0622-1200	12:00	0.086
T3-0622-1300	13:00	0.084
T3-0622-1400	14:00	0.081
T3-0622-1500	15:00	0.077
T3-0622-1600	16:00	0.076
T3-0622-1700	17:00	0.073
T3-0622-1800	18:00	0.069
T3-0622-1900	19:00	0.067
T3-0622-2000	20:00	0.068
T3-0622-2100	21:00	0.065

Table D.3b
Tracer Study Data Summary
Sample Point T3 (Ecological Fluidized Beds)
First Attempt

Sample	Time	Lithium Chloride Concentration (mg/l)
Starting Point (10:00)	10:00	*0.020*
T3-0417-1100	11:00	0.020
T3-0417-1200	12:00	0.020
T3-0417-1300	13:00	0.040
T3-0417-1400	14:00	0.060
T3-0417-1500	15:00	0.087
T3-0417-1600	16:00	0.123
T3-0417-1700	17:00	0.162
T3-0417-1800	18:00	0.200
T3-0417-1900	19:00	0.216
T3-0417-2000	20:00	0.229
T3-0417-2100	21:00	0.233
T3-0417-2200	22:00	0.249
T3-0417-2300	23:00	0.203
T3-0417-2400	0:00	0.193
T3-0418-0100	1:00	0.197
T3-0418-0200	2:00	0.200
T3-0418-0300	3:00	0.202
T3-0418-0400	4:00	0.211
T3-0418-0500	5:00	0.220
T3-0418-0600	6:00	0.214
T3-0418-0700	7:00	0.207
T3-0418-0800	8:00	0.202
T3-0418-0900	9:00	0.193
T3-0418-1000	10:00	0.185
T3-0418-1100	11:00	0.200
T3-0418-1200	12:00	0.197
T3-0418-1300	13:00	0.185
T3-0418-1400	14:00	0.181
T3-0418-1500	15:00	0.173

Table D.3b (continued)
Tracer Study Data Summary
Sample Point T3 (Ecological Fluidized Beds)
First Attempt

Sample	Time	Lithium Chloride Concentration (mg/l)
T3-0418-1600	16:00	0.165
T3-0418-1700	17:00	0.158
T3-0418-1800	18:00	0.149
T3-0418-1900	19:00	0.143
T3-0418-2000	20:00	0.137
T3-0418-2100	21:00	0.132
T3-0418-2200	22:00	0.126
T3-0418-2300	23:00	0.122
T3-0418-2400	0:00	0.118
T3-0419-0100	1:00	0.113
T3-0419-0200	2:00	0.109
T3-0419-0300	3:00	0.103
T3-0419-0400	4:00	0.099
T3-0419-0500	5:00	0.095
T3-0419-0600	6:00	0.092
T3-0419-0700	7:00	0.090
T3-0419-0800	8:00	0.084
T3-0419-0900	9:00	0.084
T3-0419-1000	10:00	0.077
T3-0419-1100	11:00	*0.081*
T3-0419-1200	12:00	0.084
T3-0419-1300	13:00	0.085
T3-0419-1400	14:00	0.081
T3-0419-1500	15:00	0.078
T3-0419-1600	16:00	0.074
T3-0419-1700	17:00	0.074
T3-0419-1800	18:00	0.065
T3-0419-1900	19:00	0.063
T3-0419-2000	20:00	0.063
T3-0419-2100	21:00	0.063

Table D.4
Tracer Study Data Summary
Sample Point T4 (1st Ecological Fluidized Bed)

Sample	Time	Lithium Chloride Concentration (mg/l)
Starting Point (10:00)	10:00	*0.020*
T4-0424-1100	11:00	0.574
T4-0424-1200	12:00	0.450
T4-0424-1300	13:00	0.359
T4-0424-1400	14:00	0.289
T4-0424-1500	15:00	0.243
T4-0424-1600	16:00	0.207
T4-0424-2400	17:00	0.176
T4-0424-2500	18:00	0.154
T4-0424-1900	19:00	0.133
T4-0424-2000	20:00	0.118
T4-0424-2100	21:00	0.106
T4-0424-2200	22:00	0.092
T4-0424-2300	23:00	0.090
T4-0424-2400	0:00	0.081
T4-0425-0100	1:00	0.076
T4-0425-0200	2:00	0.068
T4-0425-0300	3:00	0.066
T4-0425-0400	4:00	0.058
T4-0425-0500	5:00	0.053
T4-0425-0600	6:00	0.047

Table D.5
Tracer Study Data Summary
Sample Point T5 (Aerated Tanks)

Sample	Time	Lithium Chloride Concentration (mg/l)
Starting Point (10:00)	10:00	*0.020*
T5-0425-1100	11:00	0.135
T5-0425-1200	12:00	0.238
T5-0425-1300	13:00	0.313
T5-0425-1400	14:00	0.370
T5-0425-1500	15:00	0.406
T5-0425-1600	16:00	0.434
T5-0425-2500	17:00	0.447
T5-0425-2600	18:00	0.456
T5-0425-2700	19:00	0.458
T5-0425-2000	20:00	0.446
T5-0425-2100	21:00	0.435
T5-0425-2200	22:00	0.427
T5-0425-2300	23:00	0.421
T5-0425-2400	0:00	0.400
T5-0426-0100	1:00	0.392
T5-0426-0200	2:00	0.372
T5-0426-0300	3:00	0.360
T5-0426-0400	4:00	0.338
T5-0426-0500	5:00	0.327
T5-0426-0600	6:00	0.315
T5-0426-0700	7:00	0.300
T5-0426-0800	8:00	0.279
T5-0426-0900	9:00	0.268
T5-0426-1000	10:00	0.268
T5-0426-1100	11:00	0.262
T5-0426-1200	12:00	0.253
T5-0426-1300	13:00	0.239
T5-0426-1400	14:00	0.233
T5-0426-1500	15:00	0.226
T5-0426-1600	16:00	0.215
T5-0426-2500	17:00	0.178
T5-0426-2600	18:00	0.163
T5-0426-2700	19:00	0.150

Table D.5 (continued)
Tracer Study Data Summary
Sample Point T5 (Aerated Tanks)

Sample	Time	Lithium Chloride Concentration (mg/l)
T5-0426-2000	20:00	0.140
T5-0426-2100	21:00	0.135
T5-0426-2200	22:00	0.130
T5-0426-2300	23:00	0.122
T5-0426-2400	0:00	0.116
T5-0427-0100	1:00	0.137
T5-0427-0200	2:00	0.123
T5-0427-0300	3:00	0.119
T5-0427-0400	4:00	0.117
T5-0427-0500	5:00	0.114
T5-0427-0600	6:00	0.111
T5-0427-0700	7:00	0.103
T5-0427-0800	8:00	0.100
T5-0427-0900	9:00	0.095
T5-0427-1000	10:00	0.092
T5-0427-1100	11:00	0.081
T5-0427-1200	12:00	0.077
T5-0427-1300	13:00	0.075
T5-0427-1400	14:00	0.073
T5-0427-1500	15:00	0.070
T5-0427-1600	16:00	0.067

Table D.6
Tracer Study Data Summary
Sample Point T6 (1st Aerated Tank)

Sample	Time	Lithium Chloride Concentration (mg/l)
Starting Point (9:30)	9:30	*0.020*
T6-0502-1030	10:30	0.504
T6-0502-1130	11:30	0.445
T6-0502-1230	12:30	0.390
T6-0502-1330	13:30	0.344
T6-0502-1430	14:30	0.304
T6-0502-1530	15:30	0.278
T6-0502-1630	16:30	0.252
T6-0502-1730	17:30	0.233
T6-0502-1830	18:30	0.212
T6-0502-1930	19:30	0.198
T6-0502-2030	20:30	0.186
T6-0502-2130	21:30	0.171
T6-0502-2230	22:30	0.161
T6-0502-2330	23:30	0.151
T6-0502-0030	0:30	0.142
T6-0503-0130	1:30	0.137
T6-0503-0230	2:30	0.132
T6-0503-0330	3:30	0.129
T6-0503-0430	4:30	0.125
T6-0503-0530	5:30	0.119
T6-0503-0630	6:30	0.116
T6-0503-0730	7:30	0.112
T6-0503-0830	8:30	0.107
T6-0503-0930	9:30	0.102
T6-0503-1030	10:30	0.094
T6-0503-1130	11:30	0.089
T6-0503-1230	12:30	0.084

Table D.7
Tracer Study Data Summary
Sample Point T7 (Anaerobic Bio-reactor)

Sample	Time	Lithium Chloride Concentration (mg/l)
Starting Point (10:30)	10:30	*0.020*
T7-0509-1130	11:30	0.025
T7-0509-1230	12:30	0.040
T7-0509-1330	13:30	0.076
T7-0509-1430	14:30	0.188
T7-0509-1530	15:30	0.344
T7-0509-1630	16:30	0.503
T7-0509-1730	17:30	0.575
T7-0509-1830	18:30	0.636
T7-0509-1930	19:30	0.682
T7-0509-2030	20:30	0.670
T7-0509-2130	21:30	0.680
T7-0509-2230	22:30	0.674
T7-0509-2330	23:30	0.667
T7-0510-0030	0:30	0.654
T7-0510-0130	1:30	0.621
T7-0510-0230	2:30	0.585
T7-0510-0330	3:30	0.539
T7-0510-0430	4:30	0.506
T7-0510-0530	5:30	0.476
T7-0510-0630	6:30	0.461
T7-0510-0730	7:30	0.452
T7-0510-0830	8:30	0.427
T7-0510-0930	9:30	0.395
T7-0510-1030	10:30	0.330
T7-0510-1130	11:30	0.279
T7-0510-1230	12:30	0.257
T7-0510-1330	13:30	0.237
T7-0510-1430	14:30	0.225
T7-0510-1530	15:30	0.196

Table D.7 (continued)
Tracer Study Data Summary
Sample Point T7 (Anaerobic Bio-reactor)

Sample	Time	Lithium Chloride Concentration (mg/l)
T7-0510-1630	16:30	0.177
T7-0510-1730	17:30	0.159
T7-0510-1830	18:30	0.140
T7-0510-1930	19:30	0.128
T7-0510-2030	20:30	0.130
T7-0510-2130	21:30	0.125
T7-0510-2230	22:30	0.108
T7-0510-2330	23:30	0.103
T7-0511-0030	0:30	0.094
T7-0511-0130	1:30	0.087
T7-0511-0230	2:30	0.088
T7-0511-0330	3:30	0.082
T7-0511-0430	4:30	0.074
T7-0511-0530	5:30	0.068
T7-0511-0630	6:30	0.063
T7-0511-0730	7:30	0.061
T7-0511-0830	8:30	0.059
T7-0511-0930	9:30	0.058
T7-0511-1030	10:30	0.052
T7-0511-1130	11:30	0.048
T7-0511-1230	12:30	0.042
T7-0511-1330	13:30	0.040
T7-0511-1430	14:30	0.039
T7-0511-1530	15:30	0.038
T7-0511-1630	16:30	0.037
T7-0511-1730	17:30	0.038
T7-0511-1830	18:30	0.040
T7-0511-1930	19:30	0.034

Figure D-1

Tracer Study to Determine HDTs

Location: *Across High-rate Marsh (T1)*

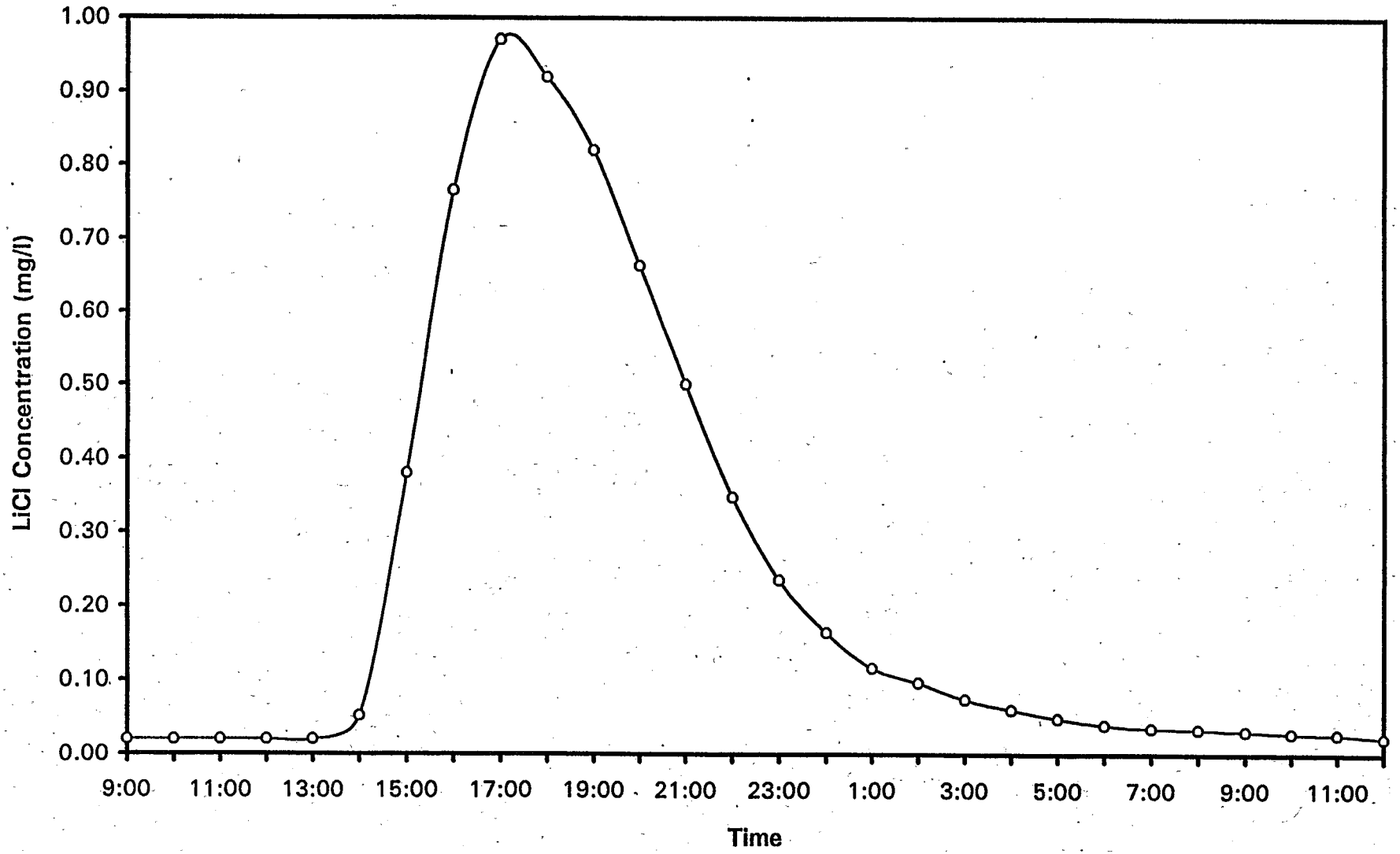


Figure D-2

Tracer Study to Determine HDTs

Location: *Across Duckweed Clarifier (T2)*

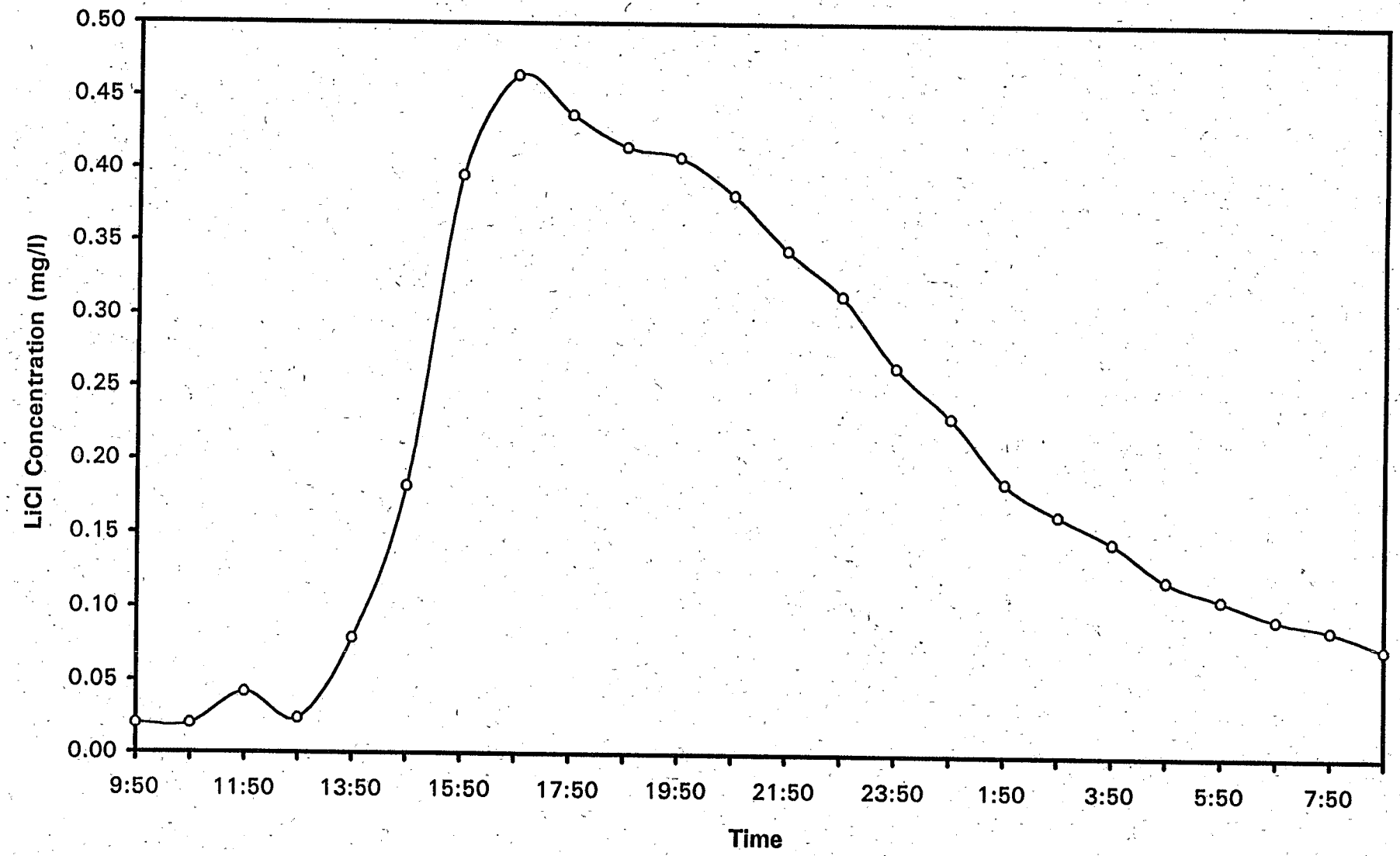


Figure D-3

Tracer Study to Determine HDTs

Location: *Across 3 Ecological Fluidized Beds (T3)*

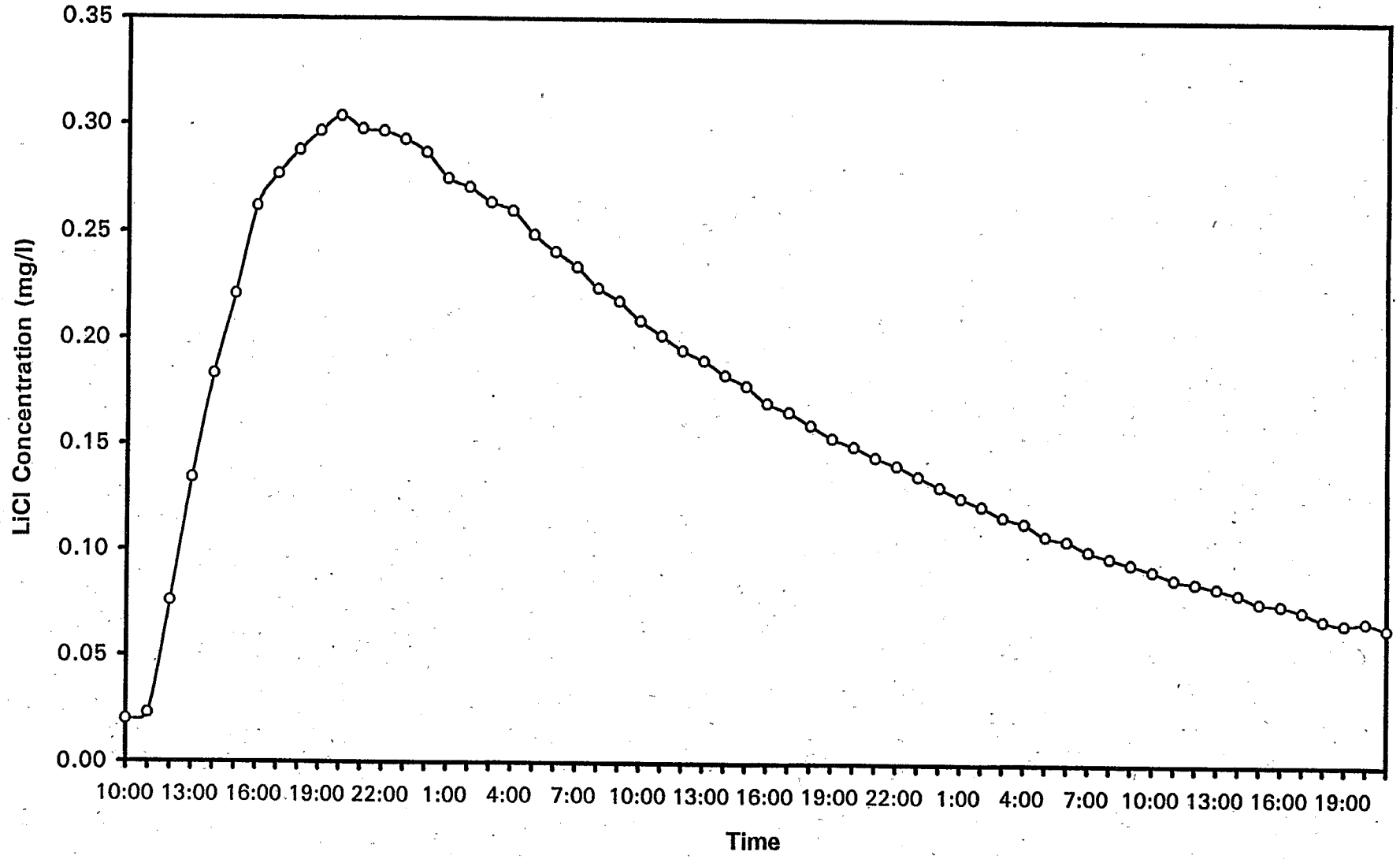


Figure D-4

Tracer Study to Determine HDTs

Location: *Across 1 Ecological Fluidized Bed (T4)*

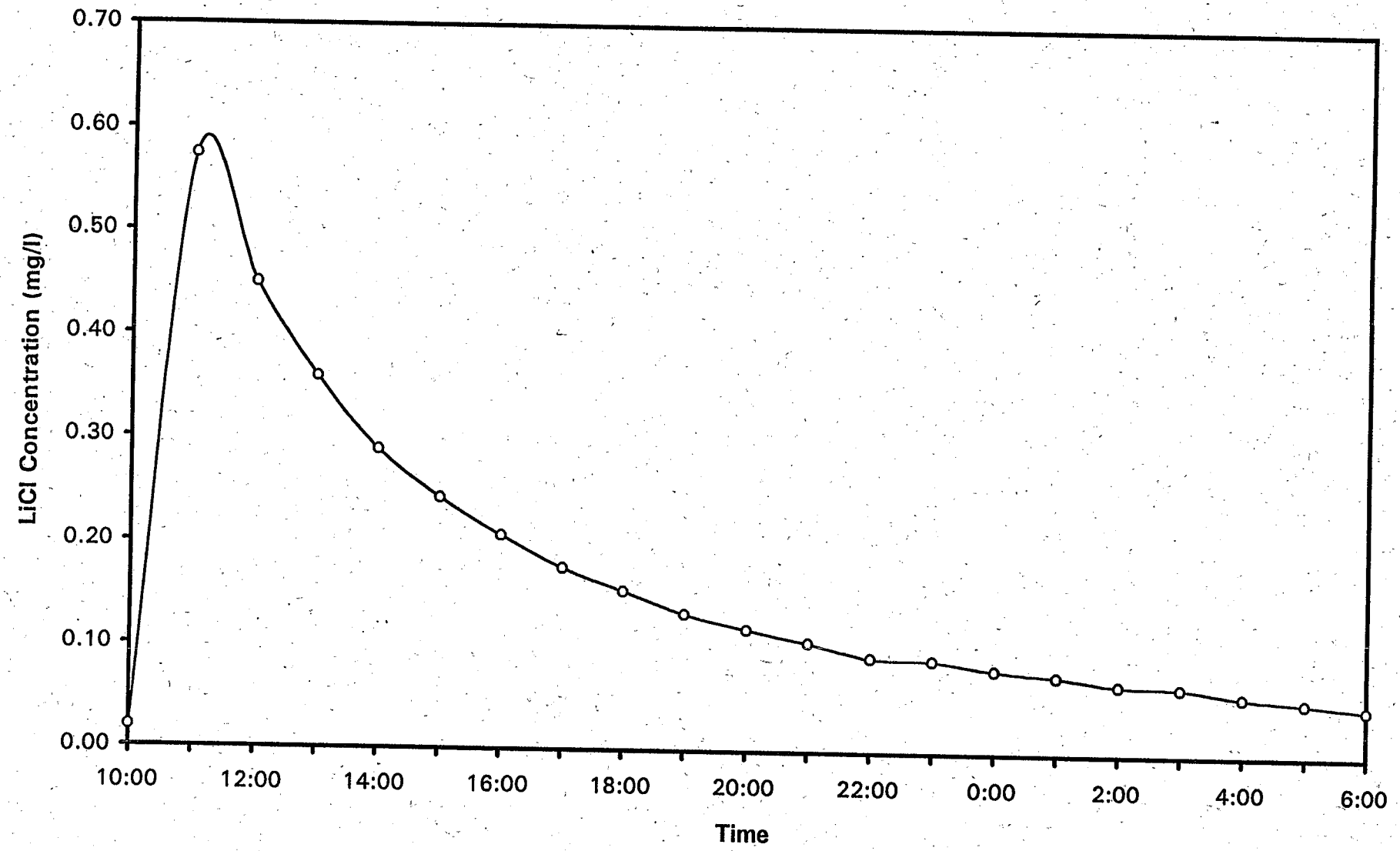


Figure D-5

Tracer Study to Determine HDTs

Location: *Across 2 Aerated Tanks (T5)*

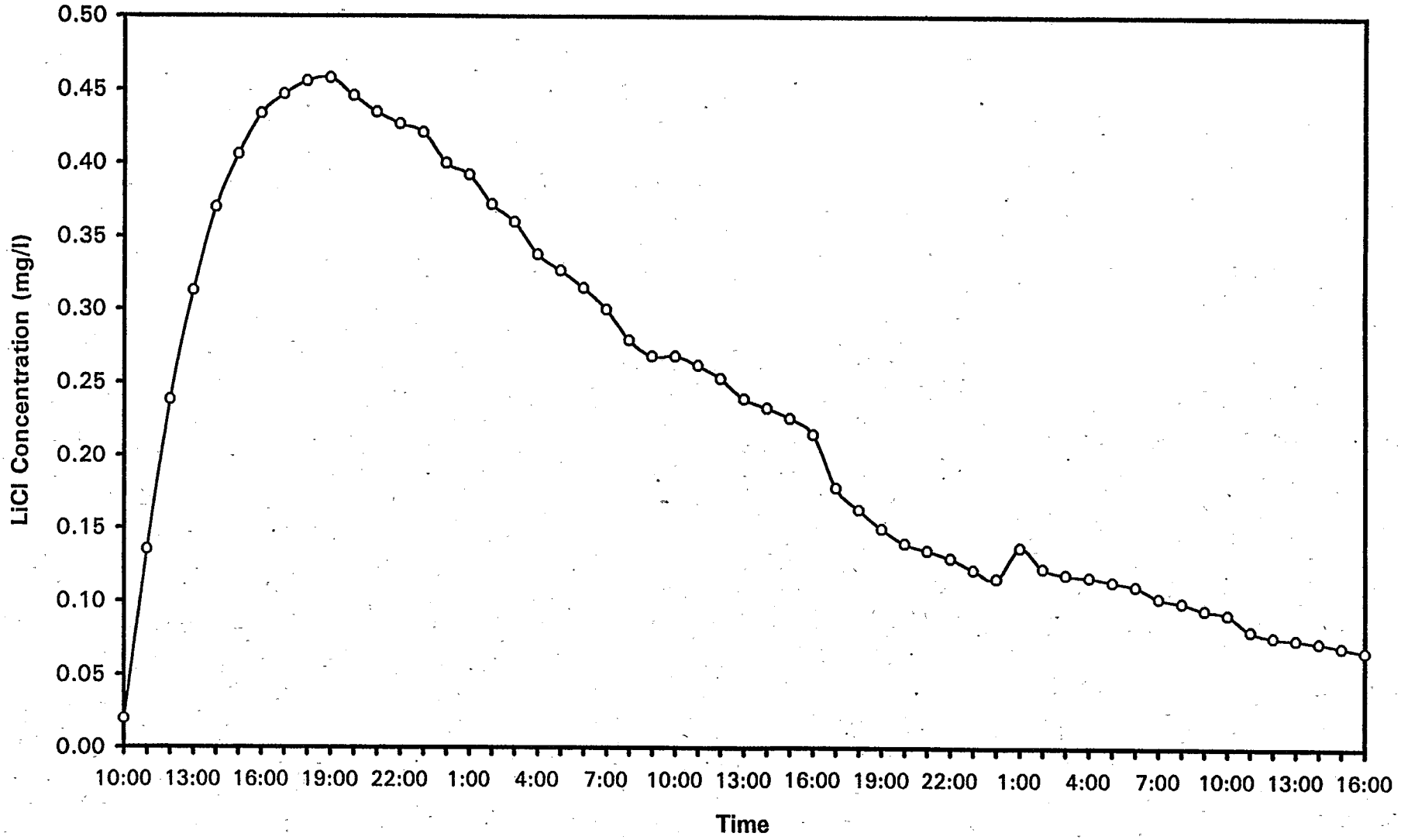


Figure D-6

Tracer Study to Determine HDTs

Location: *Across 1 Aerated Tank (T6)*

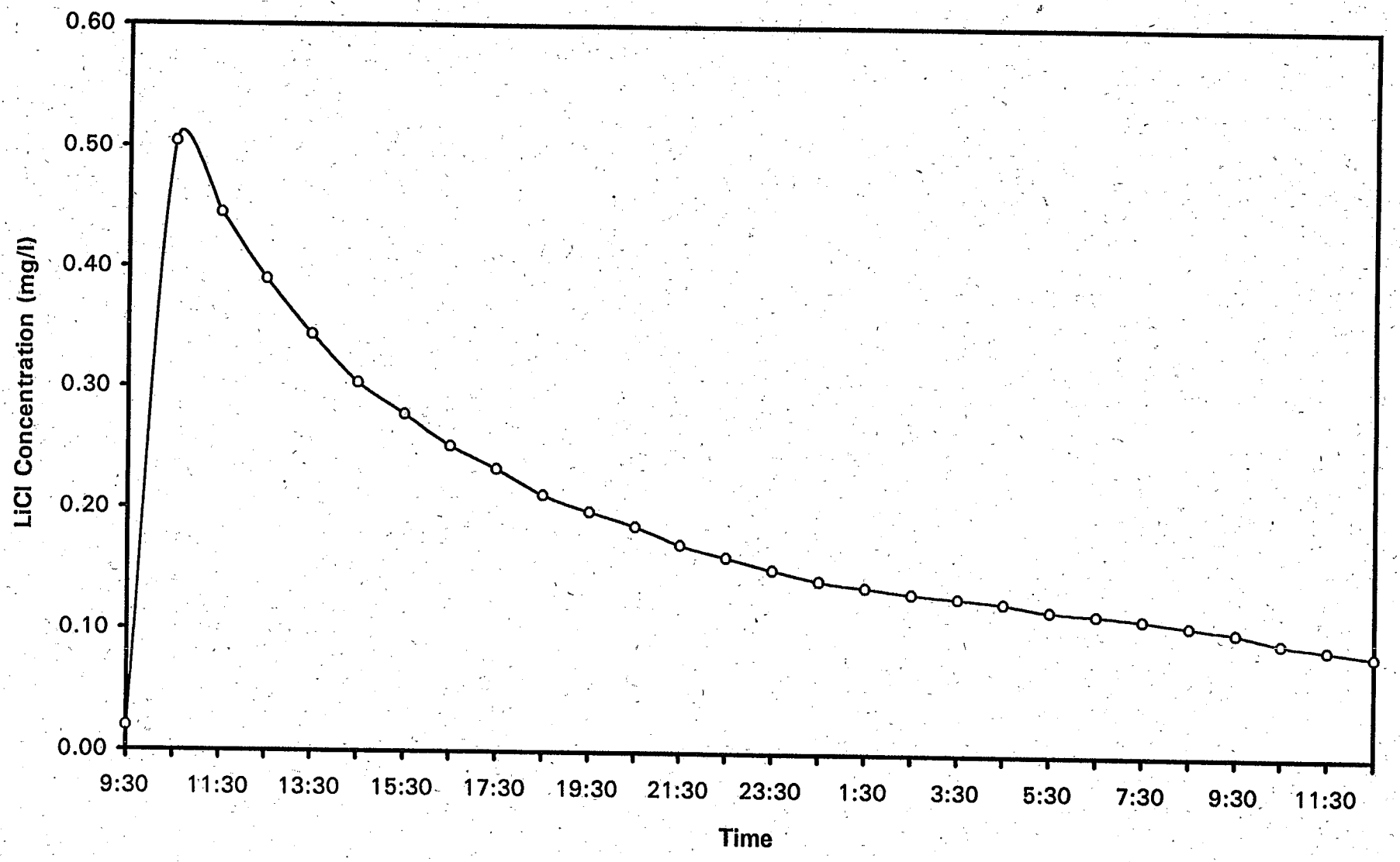
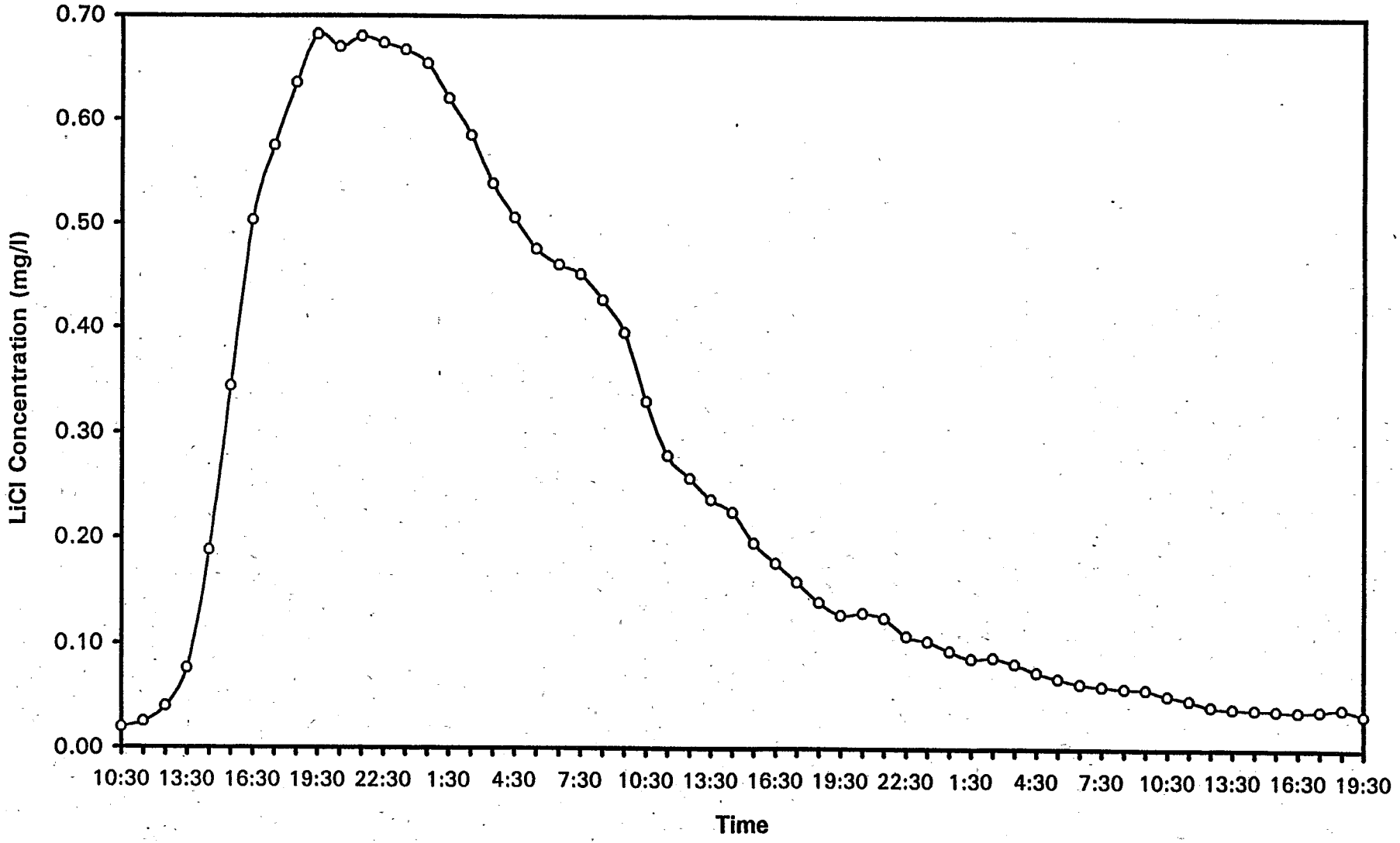


Figure D-7

Tracer Study to Determine HDTs

Location: *Across Anaerobic Bio-reactor (T7)*



Appendix E

Raw Data: Water Quality (System Without Plants)

This appendix contains the raw data from the three-week study that investigated the performance of the Advanced Ecologically Engineered System once the plants had been removed from the Aerated Tanks.

These water quality data were not subjected to the same statistical analyses that were performed upon the wastewater data from the eleven-week process evaluation. This was owing to the small sample size (3 samples per location) which, it was considered, made distribution testing and lack-of-fit testing meaningless. Summary statistics, however, were generated for this data.

All of the raw water quality data for this three-week evaluation, along with their summary statistics, are shown in Tables E.1 to E.6.

Table E.1

WATER QUALITY DATA

TREATMENT FACILITY WITH NO PLANTS

SAMPLE POINT W1 (Raw Sewage Inlet)

COMPOSITE SAMPLES

Parameter	Units	Statistical Analyses							Water Quality Results		
		n	Mean	Median	High	Low	Standard Deviation	Confidence Interval (at 90% CL) (Note 1)	W1-0608-0945	W1-0615-1010	W1-0622-0935
Total COD	mg/l	3	1,203.3	1,230.0	1,250.0	1,130.0	64.3	105.7	1,230	1,250	1,130
Soluble COD	mg/l	3	191.7	192.0	208.0	175.0	16.5	27.1	208	192	175
Total BOD_5	mg/l	3	316.7	320.0	330.0	300.0	15.3	25.1	330	320	300
Soluble BOD_5	mg/l	3	94.0	97.0	110.0	75.0	17.7	29.1	97	110	75
TSS	mg/l	3	597.0	563.0	705.0	523.0	95.6	157.3	523	563	705
VSS	mg/l	3	443.3	403.0	530.0	397.0	75.1	123.6	397	403	530
TKN	mg/l	3	51.0	51.8	53.2	47.9	2.7	4.5	51.8	53.2	47.9
Ammonia	mg/l-N	3	25.9	26.6	27.0	24.0	1.6	2.7	26.6	27	24
Nitrate	mg/l-N	3	0.12	0.1	0.14	0.10	0.02	0.03	0.14	0.11	0.1
Total Phosphorus	mg/l-P	3	13.8	14.4	15.3	11.7	1.9	3.1	15.3	11.7	14.4

GRAB SAMPLES

Parameter	Units	Statistical Analyses							Water Quality Results		
		n	Mean	Median	High	Low	Standard Deviation	Confidence Interval (at 90% CL) (Note 1)	G1-0608-0955	G1-0615-1030	G1-0622-0950
Fecal Coliform	cfu/100ml	3	19,333,333	17,000,000	30,000,000	11,000,000	9,712,535	15,975,692	11,000,000	30,000,000	17,000,000
Field pH		3	7.82	7.82	7.94	7.70	0.12	0.20	7.70	7.82	7.94
Field DO	mg/l	3	2.3	2.3	2.7	1.9	0.4	0.7	2.3	2.7	1.9
Sample Temp.	°C	3	21.0	21.0	21.0	21.0	0.0	n/a	21.0	21.0	21.0

Notes

1. Confidence intervals were not calculated for those cases where all three values were identical.

Table E.2

WATER QUALITY DATA

TREATMENT FACILITY WITH NO PLANTS

Sample Point W2 (Anaerobic Bio-reactor effluent)

COMPOSITE SAMPLES

Parameter	Units	Statistical Analyses							Water Quality Results		
		n	Mean	Median	High	Low	Standard Deviation	Confidence Interval (at 90% CL) (Note 1)	W2-0607-1035	W2-0614-0955	W2-0621-0930
Total COD	mg/l	3	470.3	464.0	499.0	448.0	26.1	42.9	499	448	464
Soluble COD	mg/l	3	190.0	192.0	197.0	181.0	8.2	13.5	197	181	192
Total BOD_5	mg/l	3	156.7	150.0	180.0	140.0	20.8	34.2	150	180	140
Soluble BOD_5	mg/l	3	89.0	90.0	94.0	83.0	5.6	9.2	94	90	83
TSS	mg/l	3	105.7	108.0	130.0	79.0	25.6	42.1	108	130	79
VSS	mg/l	3	69.7	73.8	76.4	59.0	9.4	15.4	73.8	76.4	59
TKN	mg/l	3	37.4	37.7	38.2	36.4	0.9	1.5	38.2	37.7	36.4
Ammonia	mg/l-N	3	30.3	30.4	32.3	28.1	2.1	3.5	32.3	30.4	28.1
Nitrate	mg/l-N	3	0.1	0.1	0.1	0.1	0.0	n/a	0.10	0.10	0.10
Total Phosphorus	mg/l-P	3	10.1	10.0	14.6	5.8	4.4	7.3	14.60	9.96	5.77

GRAB SAMPLES

Parameter	Units	Statistical Analyses							Water Quality Results		
		n	Mean	Median	High	Low	Standard Deviation	Confidence Interval (at 90% CL) (Note 1)	G2-0607-1045	G2-0614-1015	G2-0621-0935
Fecal Coliform	cfu/100ml										
Field pH		3	7.13	7.10	7.24	7.04	0.10	0.17	7.04	7.24	7.10
Field DO	mg/l	3	3.1	2.4	4.7	2.3	1.4	2.2	2.4	4.7	2.3
Sample Temp.	°C	3	21.3	22.0	22.0	20.0	1.2	1.9	22.0	20.0	22.0

Notes

1. Confidence intervals were not calculated for those cases where all three values were identical.

Table E.3

WATER QUALITY DATA

TREATMENT FACILITY WITH NO PLANTS

Sample Point W3 (Aerated Tank effluent)

COMPOSITE SAMPLES

Parameter	Units	Statistical Analyses*							Water Quality Results		
		n	Mean	Median	High	Low	Standard Deviation	Confidence Interval (at 90% CL) (Note 1)	W3-0607-1110	W3-0614-1030	W3-0621-0950
Total COD	mg/l	3	438.3	421.0	504.0	390.0	58.9	97.0	390	421	504
Soluble COD	mg/l	3	62.2	63.0	67.4	56.3	5.6	9.2	67.4	63	56.3
Total BOD_5	mg/l	3	98.0	93.0	110.0	91.0	10.4	17.2	91	110	93
Soluble BOD_5	mg/l	3	9.2	8.3	12.0	7.3	2.5	4.1	12	8.3	7.3
TSS	mg/l	3	142.0	141.0	157.0	128.0	14.5	23.9	128	141	157
VSS	mg/l	3	103.4	101.0	124.0	85.3	19.5	32.0	85.3	101	124
TKN	mg/l	3	38.7	36.2	46.0	33.9	6.4	10.6	33.9	36.2	46
Ammonia	mg/l-N	3	25.5	25.5	26.0	24.9	0.6	0.9	25.5	24.9	26
Nitrate	mg/l-N	3	0.2	0.1	0.3	0.1	0.1	0.1	0.25	0.12	0.12
Total Phosphorus	mg/l-P	3	7.6	7.2	8.5	7.0	0.8	1.4	6.96	8.51	7.21

GRAB SAMPLES

Parameter	Units	Statistical Analyses							Water Quality Results		
		n	Mean	Median	High	Low	Standard Deviation	Confidence Interval (at 90% CL) (Note 1)	G3-0607-1125	G3-0614-1040	G3-0621-1000
Fecal Coliform	cfu/100ml										
Field pH		3	7.66	7.66	7.70	7.63	0.04	0.06	7.70	7.63	7.66
Field DO	mg/l	3	6.3	6.3	7.1	5.4	0.9	1.4	7.1	6.3	5.4
Sample Temp.	°C	3	21.8	21.0	24.0	20.5	1.9	3.1	20.5	21.0	24.0

Notes

1. Confidence intervals were not calculated for those cases where all three values were identical.

Table E.4

WATER QUALITY DATA

TREATMENT FACILITY WITH NO PLANTS

Sample Point W5 (1st Ecological Fluidized Bed effluent)

COMPOSITE SAMPLES

Parameter	Units	Statistical Analyses							Water Quality Results		
		n	Mean	Median	High	Low	Standard Deviation	Confidence Interval (at 90% CL) (Note 1)	W5-0607-1145	W5-0614-1055	W5-0621-1010
Total COD	mg/l	3	149.7	163.0	170.0	116.0	29.4	48.3	116	170	163
Soluble COD	mg/l	3	57.8	51.8	78.6	42.9	18.6	30.6	78.6	51.8	42.9
Total BOD_5	mg/l	3	37.7	40.0	46.0	27.0	9.7	16.0	27	46	40
Soluble BOD_5	mg/l	3	7.1	7.0	8.5	5.8	1.4	2.2	8.5	7	5.8
TSS	mg/l	3	37.1	44.0	48.5	18.8	16.0	26.3	18.8	48.5	44
VSS	mg/l	3	27.4	34.4	35.0	12.8	12.6	20.8	12.8	35	34.4
TKN	mg/l	3	27.9	27.7	29.3	26.6	1.4	2.2	26.6	29.3	27.7
Ammonia	mg/l-N	3	27.3	26.6	29.3	26.0	1.8	2.9	26.6	29.3	26.0
Nitrate	mg/l-N	3	0.78	0.6	1.53	0.23	0.67	1.11	0.58	0.23	1.53
Total Phosphorus	mg/l-P	3	6.8	6.7	7.3	6.3	0.5	0.8	6.32	7.28	6.73

GRAB SAMPLES

Parameter	Units	Statistical Analyses							Water Quality Results		
		n	Mean	Median	High	Low	Standard Deviation	Confidence Interval (at 90% CL) (Note 1)	G5-0607-1155	G5-0614-1105	G5-0621-1015
Fecal Coliform	cfu/100ml										
Field pH		3	7.51	7.51	7.52	7.51	0.01	0.01	7.52	7.51	7.51
Field DO	mg/l	3	5.0	5.7	5.8	3.5	1.3	2.1	5.8	5.7	3.5
Sample Temp.	°C	3	21.9	21.0	24.0	20.7	1.8	3.0	21.0	20.7	24.0

Notes

1. Confidence intervals were not calculated for those cases where all three values were identical.

Table E.5

WATER QUALITY DATA

TREATMENT FACILITY WITH NO PLANTS

Sample Point W4 (3rd Ecological Fluidized Bed effluent)

COMPOSITE SAMPLES

Parameter	Units	Statistical Analyses							Water Quality Results		
		n	Mean	Median	High	Low	Standard Deviation	Confidence Interval (at 90% CL) (Note 1)	W4-0608-1015	W4-0615-1045	W4-0622-1010
Total COD	mg/l	3	53.2	50.6	71.1	38.0	16.7	27.5	50.6	71.1	38.0
Soluble COD	mg/l	3	39.6	39.3	43.8	35.7	4.1	6.7	43.8	39.3	35.7
Total BOD_5	mg/l	3	15.6	15.0	22.0	9.7	6.2	10.1	15	9.7	22
Soluble BOD_5	mg/l	3	9.8	9.8	15.0	4.7	5.2	8.5	9.8	4.7	15
TSS	mg/l	3	6.6	7.2	8.2	4.4	2.0	3.2	7.2	8.2	4.4
VSS	mg/l	3	4.6	3.8	6.4	3.6	1.6	2.6	3.8	6.4	3.6
TKN	mg/l	3	19.3	19.9	22.5	15.4	3.6	5.9	19.9	22.5	15.4
Ammonia	mg/l-N	3	16.4	17.3	18.9	12.9	3.1	5.1	17.3	18.9	12.9
Nitrate	mg/l-N	3	2.95	2.9	4.01	1.95	1.03	1.70	1.95	2.90	4.01
Total Phosphorus	mg/l-P	3	7.6	7.4	8.3	7.1	0.6	1.0	7.42	7.1	8.28

GRAB SAMPLES

Parameter	Units	Statistical Analyses							Water Quality Results		
		n	Mean	Median	High	Low	Standard Deviation	Confidence Interval (at 90% CL) (Note 1)	G4-0608-1035	G4-0615-1105	G4-0622-1025
Fecal Coliform	cfu/100ml										
Field pH		3	7.40	7.38	7.49	7.32	0.09	0.14	7.32	7.49	7.38
Field DO	mg/l	3	3.8	4.2	4.5	2.7	1.0	1.6	4.2	4.5	2.7
Sample Temp.	°C	3	22.5	22.0	23.5	22.0	0.9	1.4	22.0	22.0	23.5

Notes

1. Confidence intervals were not calculated for those cases where all three values were identical.

Table E.6

WATER QUALITY DATA

TREATMENT FACILITY WITH NO PLANTS

Sample Point W6 (High-rate Marsh effluent)

COMPOSITE SAMPLES

Parameter	Units	Statistical Analyses							Water Quality Results		
		n	Mean	Median	High	Low	Standard Deviation	Confidence Interval (at 90% CL) (Note 1)	W6-0608-1045,	W6-0615-1115	W6-0622-1050
Total COD	mg/l	3	26.6	27.9	30.2	21.8	4.3	7.1	27.9	30.2	21.8
Soluble COD	mg/l	3	25.8	25.6	32.4	19.5	6.5	10.6	25.6	32.4	19.5
Total BOD_5	mg/l	3	4.8	4.9	5.6	4.0	0.8	1.3	5.6	4	4.9
Soluble BOD_5	mg/l	3	4.0	4.0	4.0	4.0	0.0	n/a	4	4	4
TSS	mg/l	3	2.9	3.0	3.2	2.6	0.3	0.5	3.2	2.6	3
VSS	mg/l	3	2.0	2.0	2.0	2.0	0.0	n/a	2	2	2
TKN	mg/l	3	15.6	16.3	19.2	11.2	4.1	6.7	16.3	19.2	11.2
Ammonia	mg/l-N	3	14.3	14.2	18.0	10.6	3.7	6.1	14.2	18	10.6
Nitrate	mg/l-N	3	0.70	0.7	0.90	0.52	0.19	0.31	0.68	0.90	0.52
Total Phosphorus	mg/l-P	3	7.3	7.5	7.6	6.9	0.4	0.6	7.46	6.9	7.64

GRAB SAMPLES

Parameter	Units	Statistical Analyses							Water Quality Results		
		n	Mean	Median	High	Low	Standard Deviation	Confidence Interval (at 90% CL) (Note 1)	G6-0608-1105	G6-0615-1135	G6-0622-1100
Fecal Coliform	cfu/100ml	3	637	900	900	110	456	750	110	900	900
Field pH		3	7.32	7.35	7.37	7.25	0.06	0.11	7.25	7.37	7.35
Field DO	mg/l	3	2.9	2.6	3.8	2.2	0.8	1.4	3.8	2.6	2.2
Sample Temp.	°C	3	22.7	23.0	23.0	22.0	0.6	0.9	23.0	22.0	23.0

Notes

1. Confidence intervals were not calculated for those cases where all three values were identical.

Appendix F

Cost Estimates for Conventional Treatment Systems

Introduction

This task involved obtaining or developing capital and O&M cost data for conventional treatment systems for comparison against the Advanced Ecologically Engineered System that is presently being pilot-tested in Frederick, MD. All of the conventional treatment systems that were costed are packaged treatment systems; the only costs that were estimated were for concrete tankage, electrical supply and connection, and instrumentation. Specifically, the costs for yard piping, buildings, site preparation, land, and equipment redundancy are not included in these cost estimates. These cost estimates were developed to be comparable with cost data provided by OAI for similarly sized AEES.

Influent Wastewater Characteristics and Effluent Discharge Criteria

For the purpose of this report, the influent wastewater characteristics (strength) and effluent criteria for the conventional treatment systems are the same as for the AEES. These values are provided in Tables F.1 and F.2 below.

Table F.1 Influent Waste Characteristics

Parameter	Unit	Concentration in Influent
Total COD	mg/l	1,043
Soluble COD	mg/l	174.5
Total BOD_5	mg/l	325
Soluble BOD_5	mg/l	81.5
TSS	mg/l	357
VSS	mg/l	273
TKN	mg/l	45
Ammonia	mg/l-N	25.9
Nitrate	mg/l-N	0.1
Total Phosphorus	mg/l-P	11.2

Table F.2 Effluent Criteria used for Conventional Treatment Cost Evaluation

Parameter	Unit	Effluent Critieria
Total BOD_5	mg/l	< 10
TSS	mg/l	< 10
Ammonia	mg/l-N	< 1
Nitrate	mg/l-N	< 5
Total Phosphorus	mg/l-P	< 6

The flowrates included in this evaluation are 40,000 gpd (the same flowrate as the AEES in Frederick, Maryland), 80,000 gpd, and 1 mgd.

Biological nitrogen removal has been included in the selection of the conventional treatment systems for comparison. Nitrification, the oxidation of ammonia to nitrate, and denitrification, the reduction of nitrate to nitrogen gas, can be accomplished biologically without the addition of an external carbon source by two of the conventional systems evaluated - the oxidation ditch and the sequencing batch reactor. The packaged extended aeration plants require an external carbon source (methanol) for denitrification. The carrousel oxidation ditch requires alum for phosphorous removal.

Conventional treatment systems

The costs of the following treatment technologies were evaluated in this estimate:

- For the 40,000 gpd conventional system, we have costed out a small conventional (extended aeration) packaged wastewater treatment plant.
- For the 80,000 gpd system, we have costed out sequencing batch reactor with prefabricated tankage and with concrete tankage option.
- For the 1 mgd system, we have costed out a packaged BNR wastewater treatment plant and a carrousel oxidation ditch.

Ultraviolet disinfection was included for microbial inactivation prior to discharge. This cost was based on a manufacturer's quotation for the complete UV disinfection lamps with a steel channel and the appropriate instrumentation.

Method of Cost Estimating

The cost of the equipment and size of the tankage has been provided by the manufacturer of the technology based on historical information assembled as a result of supplying these systems to clients in the requested size range. In the cases where the manufacturer recommends that the tankage be constructed of reinforced concrete, the

quantity of concrete has been estimated and priced. If not included in the manufacturer's quote, materials and labor pricing for installing the equipment was estimated as a percentage (25%) of the equipment cost. The cost for instrumentation was included in the manufacturer's quotation; the equipment recommended by the manufacturer allows for automatic operation of the system. Mobilization, bonds and insurance, and miscellaneous direct cost are assumed to be a percentage of the direct cost of construction. Overhead and profit is assumed at 15%, and a contingency of 15% was included to cover other items that could not accurately estimated.

The AEES is primarily a treatment process for the liquid stream and not the solids stream; therefore, this evaluation focuses on the treatment cost of the liquid stream. However, capital and O&M costs for sludge handling and disposal are estimated, where applicable. The method of disposal assumed for the smaller facilities (40,000 and 80,000 gpd) is via a septic hauler to an off-site treatment facility, eliminating any capital costs. This method of sludge disposal is typical for treatment facilities of this size. The larger 1 mgd facilities are costed for a sludge handling facility, which includes a polymer system, belt filter presses, and lime stabilization equipment. A sludge digestion tank is included in the package plant and the corresponding capital costs. Sludge digestion is not required for the sludge produced by the oxidation ditch since primary sludge is not produced by this system. The cost is based on information received from the Downingtown WWTP, PA.

The cost estimate for O&M is based on information from the manufacturer on power requirements, number of operators required, and the additional cost of chemicals, if required. A unit O&M cost for sludge processing, stabilization, and disposal at the 1 mgd facilities is based on historical data from *ALCOSAN Diversified Resuiduals Management Program,* 1994 and *Sludge Management Alternatives Evaluation Report*, 1994. This value, $500.00 per dry ton, includes belt filter press dewatering, lime stabilization, and contract land application. Costs for sludge handling and disposal at the 40,000 gpd and 80,000 gpd facilities is estimated based on quotes for septic haulers to remove and dispose the residuals from a proposed 15,000 gpd SBR facility in the Village of Aldie, VA.

In developing a conceptual estimate of this type, the focus is on the tankage and the equipment. Other ancillary items, such as exterior lighting and paving, while required for construction, have not been included. It is assumed that the costs of these ancillary items have not been included in the cost estimate provided by OAI.

Cost Estimates for 40,000 gpd Conventional Treatment System

Extended Aeration System

The estimated capital cost for a packaged treatment system that is rated for 40,000 gpd is $405,000. This cost is for a complete steel packaged extended aeration system constructed on an at-grade concrete pad. A denitrifying filter and UV disinfection are included at the end of the process for denitrification and final polishing as well as disinfection. The packaged treatment system is 12 feet wide by 12 feet high by 80 feet long and the filter is 8 feet wide by 12 feet high by 16 feet long.

The estimated cost for annual operation and maintenance, which includes sludge processing and disposal, is approximately $65,900. Based on a twenty year plant life and assuming an annual inflation rate of 7%, the present value for operation and maintenance is

$697,000. The total present value, $1,102,000, is the sum of the capital cost and the present value of operation and maintenance.

Cost Estimates for 80,000 gpd Conventional Treatment System

Sequencing Batch Reactor - Package Treatment System

For this flow regime, two sequencing batch reactor systems were costed out; one with concrete tankage and one with prefabricated tanks. These costs are the average cost of these two SBR Systems. The estimated capital cost for an SBR that is rated for 80,000 gpd is $659,800. This cost is complete for two 24' x 24' tanks with mixing equipment, a filter with automatic backwash, and UV disinfection.

The average annual cost for operation and maintenance of the two SBR systems is estimated at $78,000 per year. Assuming a 7% interest rate and a life cycle of 20 years bring the present worth of operation and maintenance to $827,600. The total present value for capital cost and O&M is estimated at $1,486,900.

Cost Estimates for 1 mgd Conventional Treatment Systems

Packaged BNR Treatment Plant

The estimated capital cost for a 1 mgd packaged BNR treatment plant $3,324,700. This cost is complete for a circular packaged system, complete with a denitrification filter, UV disinfection, and a sludge handling facility. This cost is based on a steel structure that is field-supported on a concrete pad.

The annual cost for operation and maintenance is estimated at $371,400 per year. Assuming a 7% inflation rate and a life cycle of 20 years bring the present worth of operation and maintenance to approximately $3,934,900. The total present value for capital cost and O&M estimated at $7,259,600.

Carrousel Oxidation Ditch

The estimated capital cost for a carrousel oxidation ditch is $3,307,700 and includes a concrete carrousel "racetrack" style tank complete with mixers and a return sludge pumping station, aeration equipment, two final clarifiers, polishing filter, and UV disinfection and a sludge handling facility.

The annual cost for O&M of the carrousel system is $320,900 and the present worth cost at 7% interest over 20 years is $3,399,700. The total present worth cost of this system is $6,707,400.

EPA AEES Evaluation					
Task 3D: Conventional Treatment Systems Estimate					
Treatment System Evaluated and Avg Daily Flow:		Package Plant @ 40,000 gpd			
Mean's Ref. No.	Item	Qty.	Unit	Unit Price	Total Price
Division 1 - General					
Division 2 - Sitework					
Division 3 - Concrete					
1.1-140-6300	Footer excavation and construction	184	lf	$ 50.00	$ 9,200.00
1.1-500-0170	Base slab construction	36	cy	$ 250.00	$ 8,888.89
Division 7 - Thermal and Moisture Protection					
Division 8 - Doors and Windows					
Division 9 - Finishes					
Division 10 - Specialties (none)					
Division 11 - Equipment					
	Package Plant (12' w x 12' h x 80' l)	1	ls	$ 238,750.00	$ 238,750.00
	inc. filtration equipment				
	UV disinfection	1	ls	$ 9,450.00	$ 9,450.00
Division 12 - Furnishings (none)					
Division 13 - Special Construction					
Division 14 - Conveying Systems (none)					
Division 15 - Mechanical					
Division 16 - Electrical					
	Subtotal				$ 266,288.89
	Bonds, Insurance @		3%		$ 7,988.67
	Mobilization @		4%		$ 10,651.56
	Miscellaneous Direct Costs @		10%		$ 26,628.89
	Total				$ 311,558.00
	Contractor's OH & P @		15%		$ 46,733.70
	Contingency @		15%		$ 46,733.70
	Total Estimate				$ 405,025.40

EPA ALTERNATIVES EVALUATION					
OPERATIONS AND MAINTENANCE ESTIMATE					
SYSTEM: PACKAGE PLANT					
FLOWRATE: 40,000 GPD					
PREPARED BY:	BFS				
CHECKED BY:	KJK				
ENERGY CONSUMPTION					
			UNIT	TOTAL	
ITEM		KW-HRS/DAY	PRICE	PRICE	
EST. ENERGY CONSUMPTION		358	$ 0.07	$ 25.07	
EST. ENERGY CONSUMPTION - UV		4.1	$ 0.07	$ 0.30	
CHEMICAL CONSUMPTION					
		LBS/DAY	U.P.	TOTAL	
METHANOL		35	$ 0.23	$ 7.95	
MANPOWER REQUIREMENTS					
			UNIT	TOTAL	
	QTY	UNIT/DAY	PRICE	PRICE	
OPERATOR @ $25/HR INC. FRINGE	4	HRS/DAY	$ 25.00	$ 100.00	
SLUDGE PROCESSING AND DISPOSAL					
			UNIT	TOTAL	
	QTY	UNIT/DAY	PRICE	PRICE	
SLUDGE PROCESSING & DISPOSAL (1)	40000	GALLONS	0.0009	$ 36.00	
TOTAL DAILY OPERATING COST				$ 169.32	
YEARLY OPERATING COST				$ 61,801.06	
ANNUAL MAINTENANCE ESTIMATED					
AT 1% OF CONSTRUCTION COST				$ 4,050.25	
ANNUAL OPERATING AND MAINTENANCE COST				$ 65,851.32	
PRESENT VALUE BASED ON 20 YEARS AT 7%			10.594	$ 697,628.87	
Note: (1) Sludge collected by septage hauler and disposed by the hauler at a cost of $95/hr. The cost to remove sludge from a 15,000 gpd SBR plant is $5,000 per year. Cost per gallon treated at this rate is $0.0009/gal. treated					

EPA AEES Evaluation					
Task 3D: Conventional Treatment Systems Estimate					
Treatment System Evaluated and Avg Daily Flow:		SBR @ 80,000 gpd			
Mean's Ref. No.	Item	Qty.	Unit	Unit Price	Total Price
Division 1 - General					
Division 2 - Sitework					
Division 3 - Concrete					
1.1-140-6300	Footer construction	250	lf	$ 50.00	$ 12,500.00
1.1-500-0170	Base slab construction	140	cy	$ 250.00	$ 35,000.00
	Tank wall construction	250	cy	$ 350.00	$ 87,500.00
Division 4 - Masonry					
Division 5 - Miscellaneous Metals					
Division 6 - Woods and Plastics					
Division 7 - Thermal and Moisture Protection					
Division 8 - Doors and Windows					
Division 9 - Finishes					
Division 10 - Specialties					
Division 11 - Equipment					
	SBR Equipment and installation	1	ls	$ 230,742.40	$ 230,742.40
	Filtration equipment	1	ls	$ 40,000.00	$ 40,000.00
	UV disinfection	1	ls	$ 11,060.00	$ 11,060.00
Division 12 - Furnishings (none)					
Division 13 - Special Construction					
Division 14 - Conveying Systems					
Division 15 - Mechanical					
Division 16 - Electrical					
	Subtotal				$ 416,802.40
	Bonds, Insurance @		3%		$ 12,504.07
	Mobilization @		4%		$ 16,672.10
	Miscellaneous Direct Costs @		10%		$ 41,680.24
	Total				$ 487,658.81
	Contractor's OH & P @		15%		$ 73,148.82
	Contingency @		15%		$ 73,148.82
	Total Estimate				$ 633,956.45

EPA ALTERNATIVES EVALUATION				
OPERATIONS AND MAINTENANCE ESTIMATE				
SYSTEM: SEQUENCING BATCH REACTOR				
FLOWRATE: 80,000 GPD				
PREPARED BY:	BFS			
CHECKED BY:	KJK			
ENERGY CONSUMPTION				
			UNIT	TOTAL
ITEM		KW-HRS/DAY	PRICE	PRICE
EST. OPERATING BRAKE HP - SBR		334	$ 0.07	$ 23.38
EST. ENERGY CONSUMPTION - UV		8.16	$ 0.07	$ 0.60
CHEMICAL CONSUMPTION - NONE				
MANPOWER REQUIREMENTS				
			UNIT	TOTAL
	QTY	UNIT/DAY	PRICE	PRICE
OPERATOR @ $25/HR INC. FRINGE	4	HRS	$ 25.00	$ 100.00
SLUDGE PROCESSING AND DISPOSAL				
			UNIT	TOTAL
	QTY	UNIT/DAY	PRICE	PRICE
SLUDGE PROCESSING & DISPOSAL (1)	80000	GALLONS	0.0009	$ 72.00
TOTAL DAILY OPERATING COST				$ 195.98
YEARLY OPERATING COST				$ 71,531.12
ANNUAL MAINTENANCE ESTIMATED				
AT 1% OF CONSTRUCTION COST				$ 6,339.56
ANNUAL OPERATING AND MAINTENANCE COST				$ 77,870.69
PRESENT VALUE BASED ON 20 YEARS AT 7%			10.594	$ 824,962.07
Note: (1) Sludge collected by septage hauler and disposed by the hauler at a cost of $95/hr. The cost to remove sludge from a 15,000 gpd SBR plant is $5,000 per year. Cost per gallon treated at this rate is $0.0009/gal. treated				

EPA AEES Evaluation					
Task 3D: Conventional Treatment Systems Estimate					
Treatment System Evaluated and Avg Daily Flow:		Package Plant @ 80,000 gpd			
Mean's Ref. No	Item	Qty.	Unit	Unit Price	Total Price
Division 1 - General					
Division 2 - Sitework					
Division 3 - Concrete					
1.1-140-6300	Footer construction	244	lf	$ 50.00	$ 12,200.00
1.1-500-0170	Base slab construction	36	cy	$ 250.00	$ 8,888.89
Division 7 - Thermal and Moisture Protection					
Division 8 - Doors and Windows					
Division 9 - Finishes					
Division 10 - Specialties (none)					
Division 11 - Equipment					
	Package Plant (12' w x 12' h x 80' l)	1	ls	$ 418,000.00	$ 418,000.00
	inc. filtration equipment				
	UV disinfection	1	ls	$ 11,060.00	$ 11,060.00
Division 12 - Furnishings (none)					
Division 13 - Special Construction					
Division 14 - Conveying Systems (none)					
Division 15 - Mechanical					
Division 16 - Electrical					
	Subtotal				$ 450,148.89
	Bonds, Insurance @		3%		$ 13,504.47
	Mobilization @		4%		$ 18,005.96
	Miscellaneous Direct Costs @		10%		$ 45,014.89
	Total				$ 526,674.20
	Contractor's OH & P @		15%		$ 79,001.13
	Contingency @		15%		$ 79,001.13
	Total Estimate				$ 684,676.46

EPA ALTERNATIVES EVALUATION					
OPERATIONS AND MAINTENANCE ESTIMATE					
SYSTEM: SEQUENCING BATCH REACTOR					
FLOWRATE: 80,000 GPD					
PREPARED BY:	BFS				
CHECKED BY:	KJK				
ENERGY CONSUMPTION					
			UNIT	TOTAL	
ITEM		KW-HRS/DA	PRICE	PRICE	
EST. OPERATING BRAKE HP - SBR		334	$ 0.07	$ 23.38	
EST. ENERGY CONSUMPTION - UV		8.16	$ 0.07	$ 0.60	
CHEMICAL CONSUMPTION - NONE					
MANPOWER REQUIREMENTS					
			UNIT	TOTAL	
	QTY	UNIT/DAY	PRICE	PRICE	
OPERATOR @ $25/HR INC. FRINGE	4	HRS	$ 25.00	$ 100.00	
SLUDGE PROCESSING AND DISPOSAL					
			UNIT	TOTAL	
	QTY	UNIT/DAY	PRICE	PRICE	
SLUDGE PROCESSING & DISPOSAL	80000	GALLONS	0.0009	$ 72.00	
TOTAL DAILY OPERATING COST				$ 195.98	
YEARLY OPERATING COST				$ 71,531.12	
TENANCE ESTIMATED AT 1% OF CONSTRUCTION COST				$ 6,846.76	
ANNUAL OPERATING AND MAINTENANCE COST				$ 78,377.89	
PRESENT VALUE BASED ON 20 YEARS AT 7%			10.594	$ 830,335.34	
Note: (1) Sludge collected by septage hauler and disposed by the hauler at a cost of $95/hr. The cost to remove sludge from a 15,000 gpd SBR plant is $5,000 per year. Cost per gallon treated at this rate is $0.0009/gal. treated					

EPA AEES Evaluation					
Task 3D: Conventional Treatment Systems Estimate					
Treatment System Evaluated and Avg Daily Flow:		Package Plant @ 1 mgd			
Mean's Ref. No	Item	Qty.	Unit	Unit Price	Total Price
Division 1 - General					
Division 2 - Sitework					
Division 3 - Concrete					
1.1-140-6300	Footer construction (121' dia. tank)	379.9	lf	$ 50.00	$ 18,997.00
	Footer construction (12' x 105' filter)	234	lf	$ 51.00	$ 11,934.00
1.1-500-0170	Base slab construction (tank)	425.7	cy	$ 250.00	$ 106,418.38
	Base slab construction (filter)	46.67	cy	$ 251.00	$ 11,713.33
Division 7 - Thermal and Moisture Protection					
Division 8 - Doors and Windows					
Division 9 - Finishes					
Division 10 - Specialties (none)					
Division 11 - Equipment					
	Package Plant (12' w x 12' h x120' l)	1	ls	$ 1,165,000.00	$ 1,165,000.00
	inc. filtration equipment				
	UV disinfection	1	ls	$ 44,800.00	$ 44,800.00
Division 12 - Furnishings (none)					
Division 13 - Special Construction					
Division 14 - Conveying Systems (none)					
Division 15 - Mechanical					
Division 16 - Electrical					
	Subtotal				$ 1,358,862.71
	Bonds, Insurance @		3%		$ 40,765.88
	Mobilization @		4%		$ 54,354.51
	Miscellaneous Direct Costs @		10%		$ 135,886.27
	Total				$ 1,589,869.37
	Contractor's OH & P @		15%		$ 238,480.41
	Contingency @		15%		$ 238,480.41
	Subtotal				$ 2,066,830.19
	Solids Handling Facility (1)				880,539
	Contractor's OH & P @		15%		132,081
	Contingency @		15%		132,081

	Subtotal				1,144,700
	Total				$ 3,211,531
	NOTE: (1) Capital costs were scaled using the six-tenths rule.				
	Log-log plot of capacity versus equipment cost for a given type of equipment				
	should be a straight line with a slope of 0.6. Solids handling capital cost were				
	scaled from a 7 mgd (5.5 DTPD) design capacity plant - Downingtown WWTP.				
	Aerobic digester cost was included in the original cost estimate. This cost estimate				
	represents additional solids handling equipment downstream of the digester -				
	polymer system, belt filter presses, and lime stabilization equipment.				

EPA ALTERNATIVES EVALUATION					
OPERATIONS AND MAINTENANCE ESTIMATE					
SYSTEM: PACKAGE PLANT					
FLOWRATE: 1 MGD					
PREPARED BY:	BFS				
CHECKED BY:	KJK				
ENERGY CONSUMPTION					
			UNIT	TOTAL	
ITEM		KW-HRS/DAY	PRICE	PRICE	
EST. DAILY POWER REQUIREMENTS		3939	$ 0.07	$ 275.72	
EST. DAILY POWER REQUIREMENTS- UV		81.6	$ 0.07	$ 5.71	
CHEMICAL CONSUMPTION - NONE					
		LBS/DAY	U.P.	TOTAL	
METHANOL		130	$ 0.23	$ 29.55	
MANPOWER REQUIREMENTS					
			UNIT	TOTAL	
	QTY	UNIT/DAY	PRICE	PRICE	
OPERATOR @ $25/HR INC. FRINGE	1	EA	$200.00	$ 200.00	
SLUDGE PROCESSING AND DISPOSAL					
			UNIT	TOTAL	
	QTY	UNIT/DAY	PRICE	PRICE	
SLUDGE PROCESSING & DISPOSAL	0.9	DTPD	$500.00	$ 450.00	
TOTAL DAILY OPERATING COST				$ 960.98	
YEARLY OPERATING COST				$ 350,757.35	
ANNUAL MAINTENANCE ESTIMATED					
AT 1% OF CONSTRUCTION COST				$ 20,668.30	
ANNUAL OPERATING AND MAINTENANCE COST				$ 371,425.66	
PRESENT VALUE BASED ON 20 YEARS AT 7%			10.594	$ 3,934,883.41	

EPA AEES Evaluation					
Task 3D: Conventional Treatment Systems Estimate					
Treatment System Evaluated and Avg Daily Flow:		Carrousel Oxidation Ditch @ 1 mgd			
				Unit	Total
Mean's Ref. No.	Item	Qty.	Unit	Price	Price
Division 1 - General					
Division 2 - Sitework					
	Pump station wet well	1	mh	$ 4,000.00	$ 4,000.00
	Pump station drywell	1	mh	$ 4,000.00	$ 4,000.00
Division 3 - Concrete					
1.1-140-6300	Footer construction (caroussel)	634	lf	$ 50.00	$ 31,700.00
1.1-500-0170	Base slab construction (caroussel)	1044	cy	$ 250.00	$ 261,000.00
	Tank wall construction (caroussel)	599	cy	$ 350.00	$ 209,650.00
	Footer construction (clarifiers)	283	lf	$ 50.00	$ 14,130.00
	Base slab construction (clarifiers)	94	cy	$ 250.00	$ 23,500.00
	Tank wall construction (clarifiers)	124	cy	$ 350.00	$ 43,400.00
Division 4 - Masonry (none)					
Division 5 - Miscellaneous Metals					
Division 6 - Woods and Plastics					
	FRP tanks for alum addition	2	ea	$ 9,000.00	$ 18,000.00
Division 7 - Thermal and Moisture Protection					
Division 8 - Doors and Windows					
Division 9 - Finishes					
Division 10 - Specialties					
Division 11 - Equipment					
	Aeration Equipment	1	ls	$ 206,250.00	$ 206,250.00
	RAS Pump Station	1	ls	$ 50,000.00	$ 50,000.00
	Filtration equipment	1	ls	$ 312,000.00	$ 312,000.00
	UV disinfection	1	ls	$ 50,000.00	$ 50,000.00
	Clarifier Mechanisms	2	ea	$ 60,000.00	$ 120,000.00
Division 12 - Furnishings (none)					
Division 13 - Special Construction					
Division 14 - Conveying Systems (none)					
Division 15 - Mechanical					
Division 16 - Electrical					

CARROUSEL (1 mgd)

	Subtotal				$ 1,347,630.00
	Bonds, Insurance @		3%		$ 40,428.90
	Mobilization @		4%		$ 53,905.20
	Miscellaneous Direct Costs @		10%		$ 134,763.00
	Total				$ 1,576,727.10
	Contractor's OH & P @		15%		$ 236,509.07
	Contingency @		15%		$ 236,509.07
	Subtotal				$ 2,049,745.23
	Solids Handling Facility (1)				$ 880,538.75
	Contractor's OH & P @		15%		$ 132,081
	Contingency @		15%		$ 132,081
	Subtotal				$ 1,144,700
	Total Estimate				$ 3,194,446
	NOTE: (1) Capital costs were scaled using the six-tenths rule.				
	Log-log plot of capacity versus equipment cost for a given type of equipment				
	should be a straight line with a slope of 0.6. Solids handling capital cost were				
	scaled from a 7 mgd (5.5 DTPD) design capacity plant - Downingtown WWTP.				
	The digester is not required for the Carrousel oxidation ditch. This cost estimate				
	represents solids handling equipment (polymer system, belt filter presses,				
	and lime stabilization equipment).				

EPA ALTERNATIVES EVALUATION					
OPERATIONS AND MAINTENANCE ESTIMATE					
SYSTEM: CARROUSEL OXIDATION DITCH					
FLOWRATE: 1 MGD					
PREPARED BY:	BFS				
CHECKED BY:	KJK				
ENERGY CONSUMPTION					
			UNIT	TOTAL	
ITEM		KW-HRS/DAY	PRICE	PRICE	
EST. DAILY POWER REQUIREMENTS		1850.0	$ 0.07	$ 129.50	
EST. DAILY POWER REQUIREMENTS- UV		81.6	$ 0.07	$ 5.71	
CHEMICAL CONSUMPTION - NONE		GAL/DAY	U.P.	TOTAL	
MANPOWER REQUIREMENTS					
			UNIT	TOTAL	
	QTY	UNIT/DAY	PRICE	PRICE	
OPERATOR @ $25/HR INC. FRINGE	8	hrs	$ 25.00	$ 200.00	
SLUDGE PROCESSING AND DISPOSAL					
			UNIT	TOTAL	
	QTY	UNIT/DAY	PRICE	PRICE	
SLUDGE PROCESSING & DISPOSAL	1.08	DTPD	$ 500.00	$ 537.50	
TOTAL DAILY OPERATING COST				$ 872.71	
YEARLY OPERATING COST				$ 318,539.88	
ANNUAL MAINTENANCE ESTIMATED					
AT 1% OF CONSTRUCTION COST				$ 2,365.09	
ANNUAL OPERATING AND MAINTENANCE COST				$ 320,904.97	
PRESENT VALUE BASED ON 20 YEARS AT 7%			10.594	$ 3,399,667.26	

Appendix G

Cost Estimates for the AEES

The AEES cost estimates presented in Tables G.1 and G.2 were provided in August 1995 by Living Technologies, Inc., Burlington, VT. They include significant revisions of original estimates that were provided in May 1995. As noted in Section 13 of this report some modifications to the estimates below were made by the senior author of this report to reflect the actual costs for power and gas, the actual sludge production, and the actual horticultural revenue at the AEES facility in Frederick, MD. Additional minor changes were made to ensure compatibility between the AEES and Parsons ES estimates for labor rates, power rates, maintenance needs, etc.

Notes by the Senior Author of this Report

Table G.1 estimates sludge production at 40,000 gpd at about 2 dry ton per year. Based on the actual data from the Frederick system, the sludge production would be 12 dry ton per year. This then requires an increase in size and costs for the reed beds. These increases were then extrapolated for the 80,000 gpd and 1 mgd flows for the cost tables in Section 13 of this report.

Table G.1 estimates horticultural revenue at 40,000 gpd at $17,472. The May 1995 cost estimate produced by Living Technologies assumed a horticultural revenue of $5,411. The actual horticultural revenue at the Frederick, MD facility during the 1995 market season was about $2,400 with 75 percent of that for the plants grown on the High-rate Marsh. The sale of potted plants grown on the other tanks returned about $600. The cost estimates for the systems in this appendix do not include a marsh component so the only horticultural revenue is from the potted plants. An estimate of 4 times the actual potted plant revenue was used for the 40,000 gpd AEES costs tabulated in Section 13. This value was then extrapolated to the higher flow rates.

Table G.2 gives gas costs at 40,000 gpd at $1,800 per year. Based on the records at Frederick, MD the gas costs are $3,231 per year. This value was then extrapolated to the 80,000 gpd and 1 mgd rates in Section 13 of the report.

Table G.2 also gives electricity costs at $5,000 for 40,000 gpd. Based on records at Frederick, MD the electricity costs were about $9,000 per year. This value was then extrapolated to the higher flow rates in the cost tables in Section 13.

The cost of reed beds increases because of the higher sludge production which then increases the capital costs of the system, and also the maintenance costs which are taken as a percentage of the capital costs. Parsons ES used 1% in their estimates whereas Tables G.1 and G.2 used 2.5%. For continuity, a value of 1% was used for all of the cost tables in Section 13.

Table G.1 Total Estimated System Costs for the AEES

Item	Units	40,000 gpd	80,000 gpd	1,000,000 gpd
Greenhouse Area	ft^2	2,184	3,000	31,584
Number of operators		0.6	0.8	3.6
Costs w/ greenhouse				
Construction	$	$402,475	$560,457	$4,043,026
Annual O&M	$	$47,697	$66,689	$373,471
Costs w/o greenhouse				
Construction	$	$348,414	$485,289	$3,554,987
Annual O&M	$	$44,545	$62,410	$339,270
Total Cost w/ greenhouse & reed bed				
Horticultural revenue	$	$17,472	$24,000	$221,088
Plant residuals	kg/yr	430	861	10,785
Sludge residuals	kg/yr	4,148	8,295	103,693
Reed bed area	ft^2	1,383	2,765	34,564
Reed bed cost	$	$13,826	$24,886	$207,386
Construction	$	$416,301	$585,343	$4,250,412
Annual O&M	$	$49,128	$68,690	$384,675
Total Present Worth	$	**$562,063**	**$1,313,045**	**$8,325,659**
Total Annual Cost	$	**$88,427**	**$123,946**	**$785,913**

Table G.2 O&M Cost Estimates for the AEES

Item	40,000 gpd		80,000 gpd		1 mgd	
	w/ ghouse	w/o ghouse	w/ ghouse	w/o ghouse	w/ ghouse	w/o ghouse
Labor						
Operator	$15,000	$15,000	$20,000	$20,000	$45,000	$45,000
Assistant	$5,200	$5,200	$7,800	$7,800	$67,600	$67,600
Materials & Supplies						
Bioaugment	$2,000	$2,000	$2,500	$2,500	$18,000	$18,000
Horticulture	$1,500	$1,500	$1,950	$1,950	$8,000	$8,000
Other Costs	$800	$800	$1,000	$1,000	$5,500	$5,500
Contingencies	$645	$645	$818	$818	$4,725	$4,725
Maintenance						
2.5% Capital	$10,062	$8,710	$14,011	$12,132	$101,076	$88,875
Utilities						
Telephone	$1000	$1,000	$1,000	$1,000	$4,000	$4,000
Gas	$1,800	$0	$2,400	$0	$22,000	$0
Electricity	$5,000	$5,000	$9,000	$9,000	$73,000	$73,000
Trash & Water	$650	$650	$650	$650	$2,050	$2,050
Total	**$47,697**	**$44,545**	**$66,689**	**$62,410**	**$373,471**	**$339,270**