Microbial Assessment of the Lanai Auxiliary Reclamation Facility to Produce Wastewater Effluent For Unrestricted, Non-Potable Reuse

Roger S. Fujioka,
Alfredo J. Bonilla
Geeta K. Rijal

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Prepared for:

Dr. Charles Gerba
Collaborative Study Coordinator
Department of Soil, Water & Environmental Science
University of Arizona
Tucson, Arizona 85721

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Principal Investigator: Roger S. Fujioka

Water Resources Research Center
University of Hawaii at Manoa
2540 Dole Street
Honolulu, Hawaii 96822

I. Identification of Collaborative Study and Study Conducted in Hawaii

A tri-state (Arizona, California, Hawaii) collaborative study entitled, "Enteric Pathogen Reduction by Artificial Wetlands" was funded by the Regional Competitive Grants Program, Western Region of National Institutes for Water Resources, United States Geological Survey in September of 1996. Dr. Charles Gerba of the University of Arizona was the overall principal investigator of this collaborative study. He coordinated the three studies in the three different states as well as directed the study conducted in Arizona. Dr. Marylynn Yates was the principal investigator for the study conducted in California while Dr. Roger Fujioka was the principal investigator for the study conducted in Hawaii. The goal of this collaborative study was to evaluate and compare the effectiveness of treating human wastewater for re-use (irrigation) utilizing various processes that included artificial wetlands in three separate states (Arizona, California, Hawaii). The focus of this collaborative study was to determine how different states incorporated artificial wetland systems to effectively treat wastewater for reuse by measuring the effectiveness of the treatment processes to remove/destroy microbial fecal indicators and especially enteric pathogens such as human enteric viruses and protozoa.

In the state of Hawaii, the study site for this collaborative study was the Auxiliary Reclamation Facility (ARF) on the island of Lanai owned by the Lanai Company. This site was selected because it was the only facility in the state of Hawaii which uses artificial wetland process (water hyacinth pond) as part of the effluent treatment scheme to produce a wastewater effluent which had been approved for unrestricted, non-potable reuse. Dr. Roger Fujioka of the Water Resources Research Center, University of Hawaii obtained approval from Lanai Company to use their facility as the study site to be conducted in Hawaii.

II. Rationale and Goal of Study

The island of Lanai is one of the smallest (364 sq km) and least populated (<3,000) of the islands which comprise the state of Hawaii. The relative location of this island in the chain of Hawaiian Islands as well as the central location of the Lanai City Wastewater treatment facility and the Auxiliary Reclamation Facility on the island of Lanai are shown in Figure 2. For many years, the economy and land of Lanai was dedicated to raising pineapple. When that economy collapsed, the economy was switched to up-scale tourism and large sections of that island are now dedicated to tourism and includes golf courses. Initially, groundwater, the only readily available source of potable water, was used to irrigate the golf courses. However, due to the limited quantity of potable groundwater, the County of Maui passed an ordinance that non-potable water be used to irrigate golf courses. For Koele Golf Course, located near Lanai City, the obvious solution was to use wastewater from the Lanai City Wastewater Treatment Plant which was available and at reasonable distance to the golf course. However, State of Hawaii Guidelines require that wastewater must be effectively treated to meet R-1 quality before it can be used to irrigate the golf course. This effluent quality is required to ensure the safety of people working at and using the golf course. This effluent quality is also required to prevent contamination of groundwater.

Historically, R-1 quality wastewater effluent is produced by the addition of coagulation, filtration and disinfection processes to a secondary treated sewage treatment plant. However, the Lanai City Wastewater Treatment Plant uses stabilization ponds and the effluent does not meet conventional secondary treatment characteristics. One option was to completely rebuild the Wastewater Treatment Plant to a secondary treatment facility so traditional treatment processes could be used. This is an expensive option for a small treatment plant. Belt Collins Hawaii recommended an alternative plan of accepting the wastewater effluent from the stabilization ponds and building an Auxiliary Reclamation Facility (ARF) to produce a wastewater effluent which would meet the R-1 quality criteria. The ARF was built near the stabilization ponds and the reclamation treatments included slow passage through a pond completely covered with water hyacinths, followed by chemical flocculation, upflow filtration through a sand column and finally, disinfection by ultraviolet light.

The goal of this study was to determine whether the Auxiliary Reclamation Facility was capable of consistently producing a wastewater effluent which had successfully reduced the fecal indicator concentrations to ensure that concentrations of sewage borne pathogens were no longer a public health threat to people who handle the effluent and to people who use facilities where the effluent is used for irrigation. The permitted criteria is that the final effluent should have a geometric mean concentration of < 1 CFU/100 ml of fecal coliform. This criteria was based on previous studies which showed a good correlation that when sewage was treated using a series of conventional schemes (sedimentation, oxidation, flocculation, filtration, disinfection) the concentration of total and fecal coliform in the treated effluent was reduced to non-detectable levels such as <2.2 MPN/100 ml and the pathogen level (human enteric viruses) in the effluent was also reduced to a safe level. In this study, we analyzed water samples for fecal coliform bacteria as well as three other fecal indicators (enterococci, *C. perfringens*, FRNA phage) which are better surrogates for the survival for pathogens such as human enteric viruses or protozoans following sewage treatment processes.

III. Sampling Sites and Experimental Design

The wastewater is provided by the Lanai City Wastewater Treatment Plant that averages approximately 0.4 to 0.5 MGD of sewage. Figure 3 is a schematic of this plant and shows that the raw sewage is piped to two initial stabilization ponds where they are kept for 28 and 29 days. The effluent from this first set of ponds is then piped to a second set of stabilization ponds where the effluent is held for 19 and 25 more days. Thus, the stabilization pond treatment of the wastewater averages approximately 50 days. During this period, abiotic (sunlight, pH, chemicals) and biotic (growth of heterotrophic, predatory, and phototrophic microorganisms) reactions in the pond transform, metabolize and reduce the concentrations of sewage-borne components (Figure 4). Significant reactions include the inactivation of fecal microorganisms (fecal coliform, pathogens) and the transformation of sewage components to form microbial cells and their by-products. Thus, the effluent now contains high concentrations of microbial cells, especially algal cells, which result in effluent quality characterized by elevated levels of turbidity, BOD and suspended solid. Samples of raw sewage entering the plant and effluent leaving the stabilization ponds were collected for analysis (Figure 5,6).

The effluents from the stabilization ponds are piped to the Lanai Company Auxiliary Reclamation facility (ARF). Table 6 outlines the design specifications of the ARF while Figure 1 is a schematic drawing of the ARF and shows the location of the following four sampling sites within that facility:

1. Sample Site 1 (S-1). The influent to the ARF, which is the effluent from the two stabilization ponds from the Lanai City Wastewater Treatment Plant (Figure 7).

2. Sample Site 2 (S-2). The first treatment process of ARF is retention for 9 days in the hyacinth-covered ponds. This treatment allows suspended solids such as algal cells to settle out and allows the hyacinths and the microbial communities on their root systems to extract and to metabolize some of the soluble nutrients. Portions of the water hyacinth beds are routinely harvested to keep the bed of hyacinth growing vigorously (Figure 8). Site 2 is located at the end of the hyacinth pond, just before the effluent leaves the hyacinth pond and is piped to the chemical treatment building where alum and polymers (Cat-Floc) are added to flocculate most of the soluble and suspended matter in this effluent.

3. Sample Site 3 (S-3). The chemically flocculated effluent is piped to a tower of sand filter where it is filtered by up-flow filtration through a sand bed and the backwash of the sand filter bed is added back to the influent to enter the water hyacinth ponds. Site 3 is at the top of the sand filter column and the sample represents effluent, which had been flocculated and then, filtered (Figure 9).

4. Sample 4 (S-4). The filtered effluent is then piped to flow through four banks of UV light to be disinfected. Site 4 represents the final effluent after it had passed through the four banks of UV light (Figure 10) and just before the effluent is piped to the reservoir tank for storage or is piped directly to the Koele Golf Course for irrigation (Figure 11). The quality of this final effluent must meet R-1 water quality criteria.

Since a major criterion of R-1 quality water is that the concentration of fecal coliform in the wastewater must be reduced to a geometric mean of <1 CFU/100 ml. We monitored all water samples for fecal coliform to track the effectiveness of each of the individual process to reduce the level of fecal coliform. However, we also analyzed all water samples for three additional microbial indicators (enterococci, *C. perfringens*, and FRNA phage) as well as total heterotrophic bacteria for two reasons. First, because sufficient data had been accumulated to show that fecal coliform are much more sensitive to inactivation by environmental conditions and to disinfectants than many pathogens. Second, because the process used to treat wastewater by the ARF system was experimental and had not been shown to effectively reduce the levels of pathogens such as human enteric viruses. To address these concerns, enterococci bacteria were monitored because their stability is slightly better than that of fecal coliform. FRNA phages were monitored because this group of virus has the same structure and stability as human enteric viruses. *C. perfringens* was monitored because this species of bacteria forms spores which are known to be more resistant than pathogenic enteric viruses. The rationale for this experimental design is that if the treatment process can successfully remove and disinfect fecal indicators

which are more resistant than human pathogens, then the process must have reliably removed and disinfected the pathogens.

One recognized limitation in the experimental design was the fact that all of the other alternative fecal indicators are present in lower concentrations in the sewage than fecal coliform. In this regard, the concentrations of enterococci in sewage are 10 fold lower than fecal coliform and concentrations of FRNA phage and *C. perfringens* are approximately 100 fold lower. As a result, when their concentrations are reduced to very low levels by the various treatment processes, the efficiency by which the final UV process is disinfecting the effluent can not be accurately measured. To address this concern, we also monitored for total heterotrophic bacteria because this group of bacteria is present in sewage at concentrations about 100 fold higher than fecal coliform.

IV. Hawaii Research Team and the Cooperative Agencies

The research study conducted in Hawaii was a cooperative effort between the University of Hawaii team and three agencies responsible for producing the sewage effluent for re-use. Dr. Roger Fujioka who was the Principal Investigator for the research study conducted in Hawaii led the University of Hawaii team. He directed the study and was responsible for writing all the project reports including this final report. Mr. Fred Bonilla, a graduate student in the Department of Microbiology and Dr. Geeta Rijal, a post-doctoral fellow with Water Resources Research Center worked together to obtain the samples, to analyze the water samples, to summarize the data and to prepare preliminary reports.

The UH team acknowledges that without the excellent cooperation it received from the three cooperative agencies, this project could not have been completed. The UH team thanks the following people for their invaluable assistance:

1. Lanai Company, Owner of ARF and Koele Golf Course:
   Vince Bagoyo Jr., Will Garvin, Russell Dooge

2. Aqua Engineers, Inc.: Contractors operating the ARF:
   Hugh Strom, Bruce Mitsunaga, Erwin Ozoa, Glenn Titcomb

3. Lanai City Wastewater Treatment Plant: Owners of the Plant which provided the treated wastewater to ARF:
   Eassie Miller, John Oka

V. Project Schedule, Meetings and Reporting of Data

A. Project Approval. USGS informed Dr. Charles Gerba of University of Arizona that the tri-state (Arizona, California, Hawaii) collaborative water re-use proposal was approved for funding to begin in September of 1996. Dr. Gerba initiated subcontracts from the University of Arizona to University of Hawaii and University of California at Riverside.

B. Initial Meeting on Lanai. On November 12, 1996, Roger Fujioka and Fred Bonilla traveled to Lanai to meet with Mr. Vince Bagoyo Jr. and Mr. Will Garvin of the Lanai Company to discuss the details of the project, to reach agreements on how the project was to be carried out and to visit the Lanai Company's Auxiliary Reclamation Facility (ARF). At the site, we met with representatives of Aqua Engineers, Mr. Hugh Strom and Bruce Mitsunaga to learn about the operations of the ARF and to obtain samples. We also reached agreements with Aqua Engineers on how we could obtain samples in the future.

C. Collaborative Scientific Meeting. On February 24, 1997, the Principal Investigators from Arizona, California and Hawaii met at the Lanai Company's Conference Room in a public meeting to explain the goals, and objectives of this collaborative project to representatives of the Lanai Company, Aqua Engineers and other interested people. Approximately 20 people were present to hear presentations made by Dr. Charles Gerba and Mr. Martin Karpiscak from the University of Arizona, Dr. Marylynn Yates from the University of California at Riverside, and from Dr. Roger Fujioka and Fred Bonilla from the University of Hawaii. Two major conclusions were made at this meeting. First, that water samples needed to be monitored for multiple indicators and for pathogens because the fate of a single fecal indicator such as fecal coliform is not predictive of the fate of pathogens. Second, the ability of water hyacinths to reduce the concentrations of sewage borne components are due to uptake of these components by the root system but more importantly by the metabolic activity of the microbial community living in association with the root system. As a result, the recommendation was made that based on data collected in Arizona; the frequency of harvesting the water hyacinths could be reduced as long as the root systems of the water hyacinths were healthy.

D. Project Preliminary Report. On November 25, 1997, Roger Fujioka, Fred Bonilla and Geeta Rijal traveled to Lanai to present a project preliminary report to Vince Bagoyo and to Will Garvin. After the meeting, samples were obtained from the Auxiliary Reclamation Facilities (ARF). During this trip to Lanai, two other arrangements were made to collect other samples. The first arrangement was made with Maui County to visit the Lanai City Wastewater Treatment Plant and to obtain their influent raw sewage sample as well as their effluent samples from the stabilization ponds. Mr. John Oka of Maui County met us at the facility to show and to explain the operation of their facilities. The second arrangement was made with Will Garvin to take us to an area in Lanai where we could sample natural stream water. This area, owned by the Lanai Company, was the only area on the island where an accessible perennial stream flowed. On that day, stream flow was very low. We obtained two stream samples, one from within a tunnel and the second from an open stream.

E. Project Completion Report on Lanai. On August 20, 1998, Roger Fujioka, Fred Bonilla and Geeta Rijal traveled to Lanai to make an oral presentation of the final results of the project Approximately, 20 people representing Lanai Company, Aqua Engineers and Maui County (Lanai City Wastewater Treatment Plant) were present to listen to the project findings. During this trip, dissolved oxygen levels within the water hyacinth ponds at a depth of five feet were measured. However, since the ARF was not in operation for 10 -14 days, the measurements of dissolved oxygen did not reflect the operating oxygen level in the water hyacinth pond. During this trip, we met Brett Lazarick, the project engineer who took Will Garvin's position. We also

met Mr. B. Russell Dooge, Golf Course Superintendent, who showed us the operation of the Koele Golf Course. Mr. Dooge obtained a water sample from one of the monitoring wells within the golf course. We also obtained a water sample from an open pond within the golf course. Turkey droppings were observed next to the ponds indicating that these dropping were entering the pond. Other birds were also observed.

F. Presentation at Water Reuse Conference in Hawaii. The Hawaii Water Reuse 98 Conference was held on Kauai on September 9-11, 1998. Dr. Roger Fujioka was a conference speaker and presented the final results of the Lanai Water Reuse Project on September 10, 1998. Table 7 is an outline of the conference program.

G. Presentation at International Water Reuse Conference in Italy. The final results of the Lanai project was also presented by Roger Fujioka at the 2nd International Water Reuse Conference sponsored by International Association of Water Quality, which was held in Milan, Italy from September 14-16, 1998. Dr. Charles Gerba also presented the results of his studies in Arizona. Both of their written papers were published in the conference proceedings. Table 8 is the conference session agenda where Dr. Gerba and Dr. Fujioka made their oral presentations.

VI. Project Assessment and Conclusions

As stated earlier, all of the data obtained for this project were summarized, discussed and written in a manuscript published in the Proceedings of the Milan Water Reuse Conference. As a result, this document entitled; "The Microbial Quality of a Water Hyacinth Wastewater Treatment Scheme to Produce an Effluent for Unrestricted Reuse" is reproduced and will serve as the project assessment and conclusion section of this final report.

THE MICROBIAL QUALITY OF A WATER HYACINTH WASTEWATER TREATMENT SCHEME TO PRODUCE AN EFFLUENT FOR UNRESTRICTED REUSE

R. S. Fujioka*, A. J. Bonilla* and G. K. Rijal*

* *Water Resources Research Center and Department of Microbiology, University of Hawaii, 2450 Dole Street, Honolulu, HI 96822*

ABSTRACT

An Auxiliary Reclamation Facility (ARF) was constructed to receive stabilization pond treated sewage and further treated it with water hyacinth pond, chemical flocculation, filtration and ultraviolet light disinfection. This was the first facility in Hawaii, which was approved to produce the highest quality reclaimed water using alternative treatment schemes. We assessed the effectiveness of the ARF by monitoring water samples after each of the ARF treatment schemes for five genetically different groups of sewage borne microorganisms (fecal coliform, enterococci, *C. perfringens*, FRNA phage, total heterotrophic bacteria). The concentrations of all fecal indicator microorganisms, especially FRNA phage were low in the influent water to the ARF indicating that extended pond treatment may be especially effective in removing human viruses from sewage. The ARF treatment scheme was calculated to be able to reduce >99.99% of fecal coliform and therefore was able to produce an effluent meeting the non-potable, unrestricted reuse standard of a geometric mean of <1 fecal coliform/100 ml.

KEYWORDS

Fecal coliform, FRNA phage, stabilization pond, water hyacinth pond, water reuse, UV disinfection

INTRODUCTION

Reuse of wastewater is usually implemented because of insufficient supply of potable water and an economic need for water with lower quality. This is the situation on Lanai, the smallest (364 sq. km) and least populated (~3,000) of the six major islands of the State of Hawaii. Lanai was once called the Pineapple Island because its economy was based on growing pineapple. However, this economy failed and today, the economy of this island is based on up-scale tourism. As a result, two world-class resort hotels and golf courses were built. Initially, the golf courses used potable water for irrigation. This new economy has resulted in increase in population, increase in water use and a shortage of potable water supply. As a result, a county

ordinance was passed requiring these golf courses to use non-potable sources of water for irrigation. One of these golf courses (The Experience at Koele) is centrally located on the island and the approximately 1,136 m^3/d of treated sewage from nearby Lanai City wastewater treatment plant (WWTP) was made available for its use. Since irrigation of the golf course will result in water contact with the public and since the golf course is located above the island's potable ground water sources, the State of Hawaii guidelines require that the sewage be treated to meet the highest quality classification (R-1) for non-potable uses (State of Hawaii, 1993). To achieve this quality of reclaimed water, it is recommended that sewage be treated using standard sewage treatment methods which includes primary sedimentation, activated sludge treatment followed by chemical flocculation, filtration and finally disinfection with chlorine (EPA 1992; State of Hawaii, 1993). This recommended series of treatments were devised to produce a final effluent which is essentially free of pathogenic human enteric viruses and consistently contains low to undetectable levels of coliform bacteria. To follow this recommended scheme, the existing Lanai City WWTP which uses stabilization ponds to treat its wastewater would have to be completely renovated at very high cost, especially since the volume of wastewater to be reused is relatively small.

Based on an consulting engineering assessment, The Lanai Company contracted to build and operate a new and relatively inexpensive Auxiliary Reclamation Facility (ARF) and to use the reclaimed sewage to irrigate their Koele golf course. The design of this ARF was to accept the effluent from the Lanai City WWTP and further treat this sewage effluent using water hyacinth ponds, followed by chemical flocculation, sand filtration and finally disinfection with ultraviolet light. This is the first facility in Hawaii, which uses non-traditional treatment schemes, including the use of water hyacinth ponds, to be approved for production of R-1 quality water. Since there was no preexisting data to indicate the effectiveness of this treatment scheme, the objective of this study was to assess the effectiveness of each step of the ARF treatment scheme in reducing sewage borne pathogens. This was done by analyzing water samples after each of the treatment schemes for the following four genetically different groups of sewage borne bacteria: fecal coliform (gram negative rod), enterococci (gram positive cocci) *C. perfringens* (spore-former), total heterotrophic bacteria (heterogeneous group) and a group of fecal bacterial virus (FRNA phage).

STUDY SITE AND METHODOLOGY

The Lanai City WWTP uses two step (aerobic, facultative anaerobic) stabilization ponds with approximately 50 day retention time to produce 1,136 m^3/d of treated sewage with average BOD quality close to secondary effluent. This final effluent is pumped to the nearby Lanai Auxiliary Reclamation Facility (ARF) where it is the influent to undergo the following treatment schemes to produce a R-1 quality reclaimed water: 1) Slow flow (9 days retention) through two six foot deep ponds covered with water hyacinths (*Eichhornia crassipes*) to allow the algal cells in the influent to settle out (reduce total suspended solids) and to further reduce the BOD levels. 2. Addition of alum and polymers (Cat-floc) to chemically flocculate organic matter. 3. Upward filtration through sand column to remove the flocculated organic matter. 4. Exposure to four successive banks of low intensity UV lamps (Ultratech Inc.) to disinfect

residual microorganisms in the final effluent. The ARF design and sampling points are shown in Figure 1.

Samples from the ARF were obtained using grab method by personnel of the university but more often by personnel of the ARF and collected into sterile 1 liter plastic bottles that were immediately placed into a cooled ice chest. The samples were promptly taken to the airport and flown to the island of Oahu. Personnel from the university picked up the samples at the airport, transported these samples back to the university where they were analyzed within 8-10 hours of collection. The membrane filtration method as described in *Standard Methods* (APHA, 1995) was used to determine the concentrations of fecal coliform, enterococci and total heterotrophic bacteria while *Clostridium perfringens* was enumerated by the method as described by Bisson and Cabelli (1979). FRNA phage was assayed using the direct agar overlay method or the 100 ml pre-concentration method as described by Debartolomeis and Cabelli (1991). The concentrations of bacteria were determined as CFU/100 ml while concentrations of FRNA phages were determined as PFU/100 ml. To calculate geometric mean concentrations of microorganisms after each of the treatment schemes, samples which were recorded as 0/100 ml were given a value of 1 and 1 was subtracted from the final cumulative value.

RESULTS AND DISCUSSION

Routine monitoring data by the Lanai City WWTP indicated that raw sewage entering their plant was typical in quality with an average BOD of approximately 200 mg/l. These results were supported by our data which showed that the raw sewage contained normal concentrations (CFU/100 ml) of fecal coliform (6.8×10^7), enterococci (4.1×10^6) and *C. perfringens* (1.4×10^3) as well as FRNA phages (2.2×10^5 PFU/100 ml). The effluent leaving this plant (the influent to the ARF) was determined to have an average BOD of 32 mg/l, indicating that the plant had treated their sewage to a level similar to secondary treatment. However, the total suspended solids concentration of this effluent (approximately 100 mg/l) was high due to algal cell growth in the ponds. Since sewage borne pathogens represent the major health risk in the reuse of sewage (Asano et al., 1992) and since sewage borne pathogens are too numerous and too difficult to assay for, we analyzed 16 water samples (usually monthly) obtained after each of the treatment schemes of the ARF (see Figure 1) over an 18 month period for concentrations of five genetically different groups of sewage indicator microorganisms.

Table 1 summarizes all analysis for fecal coliform and show that the influent to the ARF had a geometric mean concentration of 2,837 CFU/100 ml and that the water hyacinth treatment reduced that value 88.6% to 323 CFU/100 ml. Following chemical flocculation and filtration, the geometric mean concentration was reduced to 2.2 CFU/100 ml which represented a cumulative 99.9% reduction. After UV treatment, 14/16 samples had undetectable levels of fecal coliform and the geometric mean concentration was reduced to 0.3 CFU/100 ml, which represented a cumulative 99.99% reduction. Since Hawaii's R-1 classification for reclaimed water is based on a geometric mean concentration of <1 fecal coliform/100 ml, these results support the monitoring data obtained by ARF that the final effluent meets the R-1 quality.

Table 1. Reduction of Fecal Coliform Concentrations After Each Treatment Scheme of Auxiliary Reclamation Facility (16 samples over 18 months)

Sample Sites	←----------CFU/100 ml----------→ Range	# 0/100ml/ # samples	Average	Geometric Mean	% Reduction
Influent	40-460,000	0/16	32,994	2,837	Not applicable
Hyacinth	37-4,400	0/16	760	323	88.6
Filtration	0-18	6/16	4.8	2.2	99.92
UV Disinfection	0-40	14/16	2.5	0.3	99.99

Table 2 summarizes all analysis for enterococci and show that the influent to the ARF had a geometric mean of 332 CFU/100 ml and that the water hyacinth treatment reduced that value 83% to 57 CFU/100 ml. Chemical flocculation and filtration removed most of the remaining enterococci as 14/16 samples had undetectable levels of enterococci. The geometric mean concentration of enterococci had been reduced to 0.2 CFU/100 ml, which represented a cumulative 99.94% cumulative reduction. After UV treatment, 14/16 samples had undetectable levels of enterococci and the geometric mean concentration of enterococci had been reduced to 0.05 CFU/100 ml which represented a cumulative 99.99% reduction.

Table 2. Reduction of Enterococci Concentrations After Each Treatment Scheme of Auxiliary Reclamation Facility (16 samples over 18 months)

Sample Sites	←----------CFU/100 ml----------→ Range	# 0/100ml/ # sample	Average	Geometric Mean	% Reduction
Influent	33-1,400	0/16	622	332	Not applicable
Hyacinth	9-272	0/16	94	57	82.83
Filtration	0-5	14/16	0.5	0.2	99.94
UV Disinfection	0-2.5	14/16	0.1	0.05	99.99

Table 3 summarizes all analysis for *C. perfringens* and show that the influent to the ARF had a geometric mean of 413 CFU/100 ml and that the water hyacinth treatment reduced that value 96% to 15 CFU/100 ml. Chemical flocculation and filtration removed nearly all of the remaining *C. perfringens* as 15/16 samples had undetectable levels of *C. perfringens* and the geometric mean concentration was reduced to 0.04 CFU/100 ml which represented a cumulative 99.99% cumulative reduction. After UV treatment, all 16 samples had undetectable levels of *C. perfringens* and this represented a cumulative of >99.99% reduction.

Table 3. Reduction of *Clostridium perfringens* Concentrations After Each Treatment Scheme of Auxiliary Reclamation Facility (16 samples over 18 months)

Sample Sites	←----------CFU/100 ml----------→ Range	# 0/100ml/ # sample	Average	Geometric Mean	% Reduction
Influent	40-5,100	0/16	867	413	Not applicable
Hyacinth	0-864	2/16	79	15	96.4
Filtration	0-2	15/16	0.06	0.04	99.99
UV Disinfection	0-0	16/16	0.04	0.00	>99.99

Table 4 summarizes all analysis for FRNA phages and show that the influent to the ARF had a low geometric mean concentration of 0.05 PFU/100 ml and FRNA phages could not be detected in 6/16 influent water samples. These results show that the Lanai WWTP stabilization ponds were very effective in removing FRNA phages from sewage. The water hyacinth treatment did not measurably reduce the geometric mean concentration of FRNA phage although the incidence of undetectable levels of this group of phage had increased to 9/16. After flocculation and filtration all 16 samples had undetectable levels of FRNA phage. Due to the low initial concentration of FRNA phages, only a cumulative 99% reduction could be calculated. Similar results (all 16 samples had undetectable levels of FRNA phage) were obtained after UV treatment.

Table 4. Reduction of F RNA Phage Concentrations After Each Treatment Scheme of Auxiliary Reclamation Facility (16 samples over 18 months)

Sample Sites	←----------PFU/100 ml----------→ Range	# 0/100ml/ # sample	Average	Geometric Mean	% Reduction
Influent	0-9.4	6/16	0.73	0.05	Not applicable
Hyacinth	0-9.2	9/16	1.5	0.3	counts too low to
Filtration	0-0	16/16	0.00	0.00	determine %
UV Disinfection	0-0	16/16	0.00	0.00	reduction

Table 5 summarizes all 14 analysis for total heterotrophic bacteria and show that the influent to the ARF had a geometric mean concentration of 19,485,233 CFU/100 ml and that the water hyacinth treatment reduced this value 82% to 3,499,636 CFU/100 ml. Following chemical flocculation and filtration, the geometric mean concentration of total heterotrophic bacteria was reduced to 184,971 CFU/100 ml which represented a cumulative 99% reduction. After final UV treatment, the total heterotrophic bacterial count was reduced to a geometric mean of 4,438 CFU/100 ml which represented a cumulative 99.98% reduction. Interpretation of results of total heterotrophic bacteria is difficult because the population of bacteria may be changing after each treatment scheme. However, this was the only group of bacteria which was present in sufficiently high concentrations to reliably demonstrate that the UV treatment can inactivate at least 99% of the bacteria remaining after all of the earlier treatments. It was determined that most of the bacteria surviving UV treatment were resistant spores.

Table 5. Reduction of Total Heterotrophic Bacteria Concentrations After Each Treatment Scheme of Auxiliary Reclamation Facility (14 samples over 18 months)

Sample Sites	←----------CFU/100 ml----------→ Range	# 0/100ml/ # sample	Average	Geometric Mean	% Reduction
Influent	3,300,000-850,000,000	0/14	84,345,714	19,485,233	Not applicable
Hyacinth	480,000- 21,000,000	0/14	5,249,286	3,499,636	82.0
Filtration	16,000- 14,000,000	0/14	1,253,264	184,971	99.1
UV Disinfection	1,200- 32,000	0/14	6,886	4,438	99.98

SUMMARY AND CONCLUSIONS

The influent entering the ARF was determine to contain low geometric mean concentrations (CFU/100 ml) of fecal coliform (2,837), enterococci (332), *C. perfringens* (413) and especially low concentrations of FRNA phages (0.05 PFU/100 ml). Thus, the Lanai City WWTP stabilization ponds system were effective in reducing most of the concentrations of the fecal indicator microorganisms in the sewage. The exceptional removal of FRNA phages by the stabilization pond system was unexpected and may indicate that the long-term storage in open pond system may be effective in removing human enteric viruses. In this regard, WHO guidelines favor the use of stabilization ponds in reclamation of wastewater (Hespanhol and Prost, 1994). Garcia and Becares (1997) previously reported variable removal rates for different microorganisms in stabilization pond systems. However, this could reflect differences in sunlight conditions (Davies-Colley et al., 1997). The fact that the influent to the ARF contained relatively low concentrations of all fecal indicator microorganisms meant that the ARF treatment scheme was required to achieve a cumulative reduction of greater than 99.99% of fecal coliform to achieve R-1 quality. The data showed that the water hyacinth treatment was effective in reducing the concentrations of fecal indicator bacteria by 82-96% but was less effective in reducing the low concentrations of FRNA phage. The chemical flocculation and filtration treatment could be relied on to reduce the concentration of all remaining sewage microorganisms another 90-99% while the final UV treatment is capable of inactivating all remaining sewage microorganisms another 99%. These conclusions and the successful evaluation of the ARF were possible only because we monitored multiple fecal indicator microorganisms. We therefore, recommend that future studies also include the assessment of multiple groups of fecal indicator microorganisms so one can better compare data and better evaluate the system under consideration. In conclusion, these results show that the ARF treatment scheme to further treat the sewage effluent from Lanai WWTP is effective and can be expected to produce R-1 quality effluent. These results support the use of alternative treatment schemes such as extended stabilization pond and water hyacinth pond treatment. However, the final treatment schemes, which include chemical flocculation, filtration and disinfection with UV, provide reliability to the ARF process.

ACKNOWLEDGMENTS

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VII. Additional Comments and Assessments

A. Increasing the Treatment Efficiency of the Water Hyacinth Ponds. Although the ARF successfully treated the effluent to R-1 quality, the effectiveness was due to the application of multiple treatment processes starting with the long storage time in the stabilization ponds operated by the Lanai Wastewater Treatment Plant and the ARF treatment schemes (water hyacinth ponds, flocculation, filtration, disinfection). In assessing each of the treatment process, it was determined that the water hyacinth pond treatment reduced the fecal coliform and enterococci concentrations by less than 90% and therefore this appears to be the most inefficient treatment for the reduction of fecal indicator bacteria. If this treatment process can be made more efficient there would be greater assurance that more pathogens and fecal indicator would be inactivated by the ARF facility. The obvious problem appears to be the observation that the root systems of the water hyacinths in these ponds are not long enough and therefore most of the water is passing through the ponds without sufficient contact with the root systems. As stated earlier, the root system and the microbial communities associated with the root system are responsible for most of the biological transformation and removal of the inorganic and organic components in the sewage effluent.

In summary, we recommend that an assessment be made to increase the efficiency of the water hyacinth ponds by initially taking steps to ensure that the hyacinths will produce longer root systems which will allow more of the water in the pond to be in direct contact with the hyacinth root systems. Obvious things to consider are the appropriate depth of the pond and whether the conditions at the bottom of the ponds are becoming inhospitable for the growth of the hyacinth roots. Measurements of dissolved oxygen and pH can be used to characterize the water in the bottom phase of the ponds. In this regard, on August 20, 1998, we measured the dissolved oxygen level in the water hyacinth pond at a depth of five feet. The levels measured ranged from 0.4 to 0.6 mg/l of dissolved oxygen. These readings were low but did not reflect operating conditions since the ARF had not been operating for 10-14 days. We recommend that measurements of dissolved oxygen be made at the four sampling sites of the ARF and especially in water samples from the bottom portions of the ponds. The toxicity level of water from the lower levels of the ponds, which includes the sediments, should also be assessed. In this regard, the impact of returning the filter backwash to the water hyacinth ponds should be determined.

B. Ambient Bacteriological Quality of Streams on Lanai. In previous studies conducted by our laboratory, we have determined that the ambient quality of all streams on Oahu contains naturally high concentrations of fecal indicator bacteria (fecal coliform, *E. coli*, and enterococci) because the source of most of these fecal indicator bacteria in streams is from the environment (soil) rather than sewage. In Hawaii, the fecal bacteria are able to grow in the soil environment and rain washes these bacteria into the streams. To determine if this same phenomenon is occurring on Lanai, we requested to obtain water samples from two stream sites on Lanai. On November 25, 1997, Will Garvin guided us to an area of Lanai owned by Lanai Company and informed us that this is the only place where perennial streams can be readily obtained. The first stream sample was obtained from water flowing from a small natural tunnel which probably represents water percolating through some soil embankment. The second stream

sample was from an open stream. However, the stream flow on that day was very low. The concentrations of fecal indicator bacteria in these two stream samples are summarized as follows:

Microbial Indicators (CFU/100 ml)	Open Stream Site	Stream in Tunnel
Fecal Coliform	139	400
Enterococci	41	11
C. perfringens	2	0

The EPA recreational water quality standards for streams are 200 CFU/100 ml of fecal coliform, 33 CFU/100 ml of enterococci or 126 CFU/100 ml of *E. coli*. The concentrations of fecal coliform and enterococci in the two Lanai streams are elevated as compared to EPA standards and are similar to streams on Oahu, which are flowing through mountainous and non-urbanized areas of Oahu. The low levels of *C. perfringens* are consistent with the results obtained in non-polluted streams on Oahu. Since, this represent results from one sample only; definitive conclusions cannot be made. However, the results suggest that the multiplication of fecal coliform and enterococci, which has been documented on Oahu also, occur on Lanai. In this regard, analyzing soil samples from within the golf courses as well as soil samples from backyards and parks would be advisable.

C. Preliminary Assessment of Pond and Well Water Quality at Koele Golf Course. Throughout the study, we only analyzed the sewage effluent being treated at the ARF for irrigation of the Koele Golf Course. We did not analyze any of the water samples obtained from Koele Golf Course. On August 20, 1998 we obtained water samples from a pond and from a monitoring well within Koele Golf Course. The results are summarized as follows:

Indicator Microorganisms (CFU or PFU/100 ml)	Surface Pond	Monitoring Well
Fecal Coliform	33	126
Enterococci	44	20
C. perfringens	480	548
FRNA Phage	0	0
DNA Phage	0	0
Total heterotrophic bacteria	$>10^{10}$	4.5×10^{10}

Since the results obtained are from a single set of samples, definitive conclusions should not be drawn from these results. However, the available data reveals some interesting data. First, very high concentrations of *C. perfringens* and moderate concentrations of fecal coliform and enterococci were detected in both the surface pond and the monitoring well samples. It should be noted that concentrations of C. *perfringens*, fecal coliform and enterococci were at undetectable levels in the effluent from the Auxiliary Reclamation Facility, which is the source of the water to fill the pond and to flow into the monitoring well. Second, these same pond and well water samples contained un-detectable levels of FRNA phage and DNA phage. In this regard, FRNA bacterial virus was also non-detectable in the effluent from the Auxiliary Reclamation Facility.

Third, both the pond and monitoring well water contained very high concentrations of total heterotrophic bacteria indicating that bacterial regrowth in the pond water at Koele Golf Course had taken place.

The most likely explanation for the results obtained are that there was another source of fecal contamination at the pond and this contamination was not sewage because sewage contains high concentrations of FRNA phage. Since flocks of turkeys were observed roaming the golf course and since turkey droppings were observed next to the pond, turkey feces is the most likely source for the presence of high concentrations of *C. perfringens*, in the pond and in the monitoring well. *C. perfringens* is known to be present in feces from most warm blooded animals and moreover, will survive for longer periods in the pond environment than fecal coliform and enterococci. The absence of FRNA phage in pond water sample is consistent with contamination with feces as this bacterial virus is generally undetectable in feces of animals but is present in high concentrations in raw sewage. The high concentration of total heterotrophic bacteria is expected since the pond is now a natural water system and many kinds of bacteria will grow in any natural water environment.

Finally, many of the conclusions must be considered preliminary because they were based on limited data. To verify these conclusions, we recommend more water samples from monitoring well, from pond water, from turkey dropping and from soil samples near and away from the ponds be analyzed for the various fecal bacteria and FRNA phage.

Table 6 Design Specifications for Lanai Auxiliary Reclamation Facility

DESIGN FLOW	
Average Flow	0.40 MGD
BOD_5 LOAD	
Anticipated BOD_5 Load	67 lbs/day
Average Concentration	32 mg/l
SUSPENDED SOLIDS LOAD	
Anticipated SS Load	171 lbs/day
Average Concentration	82 mg/l
INFLUENT PUMPS	
Number of Units	2
Type	Submersible. Constant Speed
Capacity (each pump)	280 gpm @ 26.5' TDH
BHP	5.0 hp @ 60% Efficiency
WATER HYACINTH PONDS	
Number of Ponds	2
Dimension (each pond)	680' (L) x 92' (W) x 9' (D)
Slope of the Bank	3:1
Top Water Depth	7 feet
Water Surface Dimension (each pond)	668' (L) x 80' (W)
Total Water Surface Area	2.45 acre
Total Volume	4.0 million gallons
Design Organic Loading	27.3 lbs BOD_5/ac/day
Design Hydraulic Loading	0.1 mgd/ac
Design Hydraulic Retention Time	9.0 days
TRANSFER PUMPS	
Number of Units	2
Type	Variable Speed Self Priming
Capacity (each pump)	280 gpm @ 37.5' TDH
BHP	10 hp @ 60% Efficiency
COAGULATION	
Design Flow Rate	280 gpm (pumping rate)
Alum Dosage	90 mg/l
Alum Demand	302 lbs/day
Polymer Dosage	1.0 mg/l (Max 2 mg/l)
Polymer Demand	3.4 lbs/day (Max 6.8 lbs/day)
Mixing	In-Line Mixing

Table 7 Hawaii Water Reuse '98 Conference Recycled Non Potable Water. How Can It Be Used? Thursday, September 10, 1998

TIME	SESSION #	TECHNICAL SESSION
8:00 - 9:00		Registration & Refreshments
9:00 - 9:15		**Opening Remarks** Mayor Mary Ann Kusaka County of Kauai
9:15 - 10:00		**Keynote Speaker** Bruce Anderson Department of Health
10:00 - 10:45	1	**Water Reuse Legislative Issues** Peter Maclaggan WateReuse Association, California
10:45 - 11:00		BREAK
11:00 - 11:45	2	**Reclaimed Water Pricing** Richard Cuthbert R.W. Beck
11:45 - 12:45	3	**Luncheon** **Hawaii Water Reuse Public Education Outreach Project** Steve Parabicoli Hawaii Water Environment Association
12:45 - 1:30	4	**The Microbial Quality of a Water Hyacinth Wastewater Treatment Scheme to Produce An Effluent for Unrestricted Reuse** Roger Fujioka University of Hawaii Water Resources Reseaerch Center
1:30 - 2:15	5	**Filtering Algae Laden Pond Effluents How Do They Do That?** John Harrison Consultant
2:15 - 2:30		BREAK
2:30 - 3:15	6	**Indirect Water Reuse by Groundwater Recharge** Ron Crites Brown and Caldwell
3:15 - 4:00	7	**The Lanai Experience** Vince Bagoyo Lanai Company
4:15 - 6:30		**Pau Hana Gathering**

Table 8 2nd International Conference of IAWQ, Advanced Wastewater Treatment, Recycling and Reuse. Milan, Italy --- September 14-16, 1998

Session on Natural Treatment
Tuesday, September 15, 1998

Chair:	*W. Harder (The Netherlands); Co-chair: G. Navazio (Italy)*
14.00	Optimization of artificial wetland design for removal of indicator microorganisms and pathogenic protozoa *C.P. Gerba, J.A. Thurston, J.A. Falabi, P.M. Watt, M.M. Karpiscak (USA)*
14.30	Modeling of an extensive wastewater treatment plant (lagoon), based on a 2 year intensive follow-up *C. Bonvillain, D. Benyamina, M. Schaegger, A. Pauss, O. Bernard, D. Dochain (France, Belgium)*
15.00	Reclamation of effluents from municipal wastewater treatment plants: use of partially aerated reed bed systems *M. Bisello, P. Ragazzo, G. Navazio (Italy)*
16.00	The microbial quality of a water hyacinth wastewater treatment scheme to produce an effluent for unrestricted reuse *R.S. Fujioka, A.J. Bonilla, G.K. Rijal (USA)*
16.30	The use of free surface constructed wetland as an alternative process treatment train to meet unrestricted water reclamation standards *R.A. Gearheart (USA)*
17.00	Advanced nitrogen removal by rotating biological contactors, recycle and constructed wetlands *P. Griffin, P. Jennings, E. Bowman (UK)*

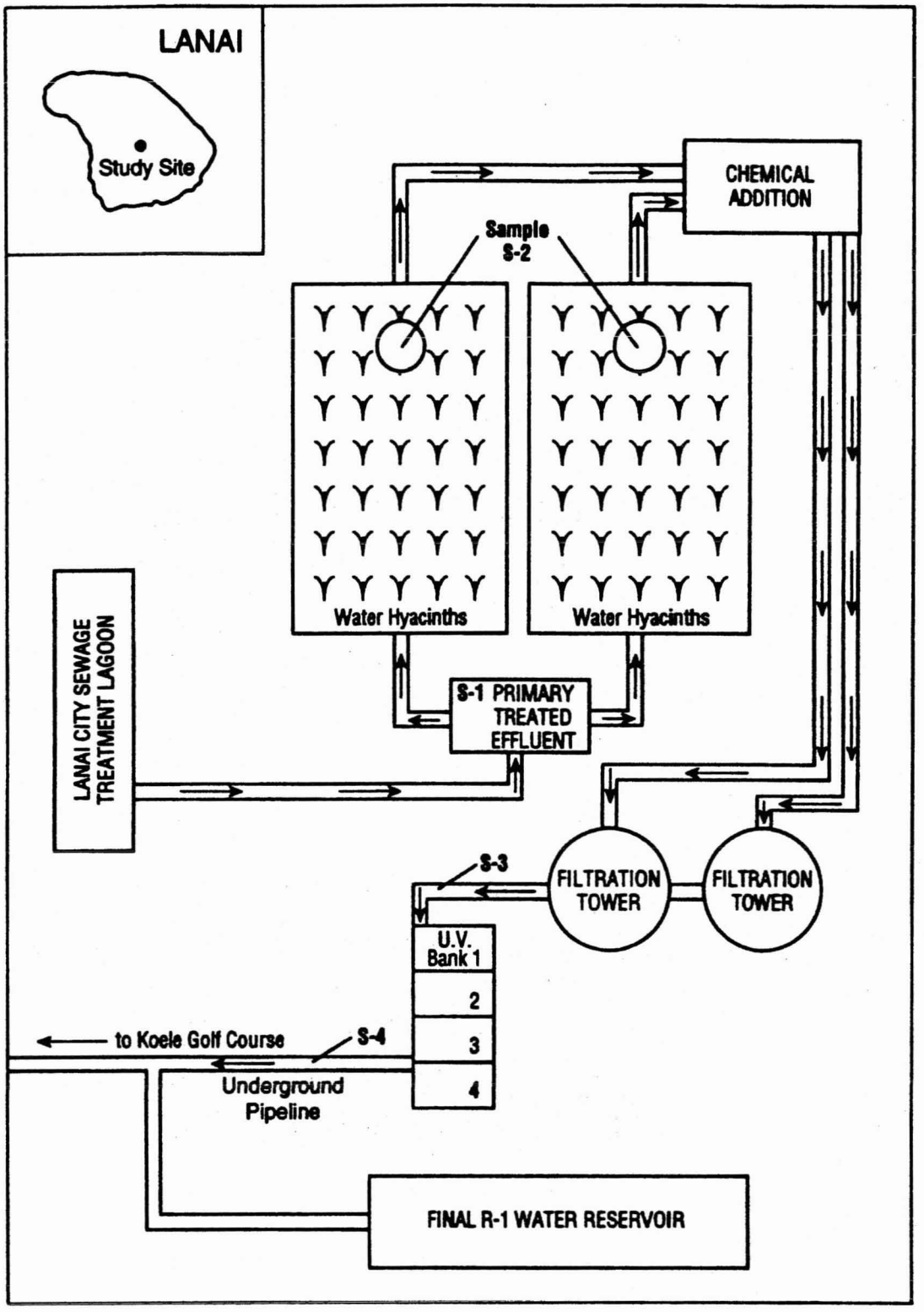

Figure 1. Treatment Schemes and Sampling sites (S1-S4) at Lanai Auxiliary Reclamation Facility

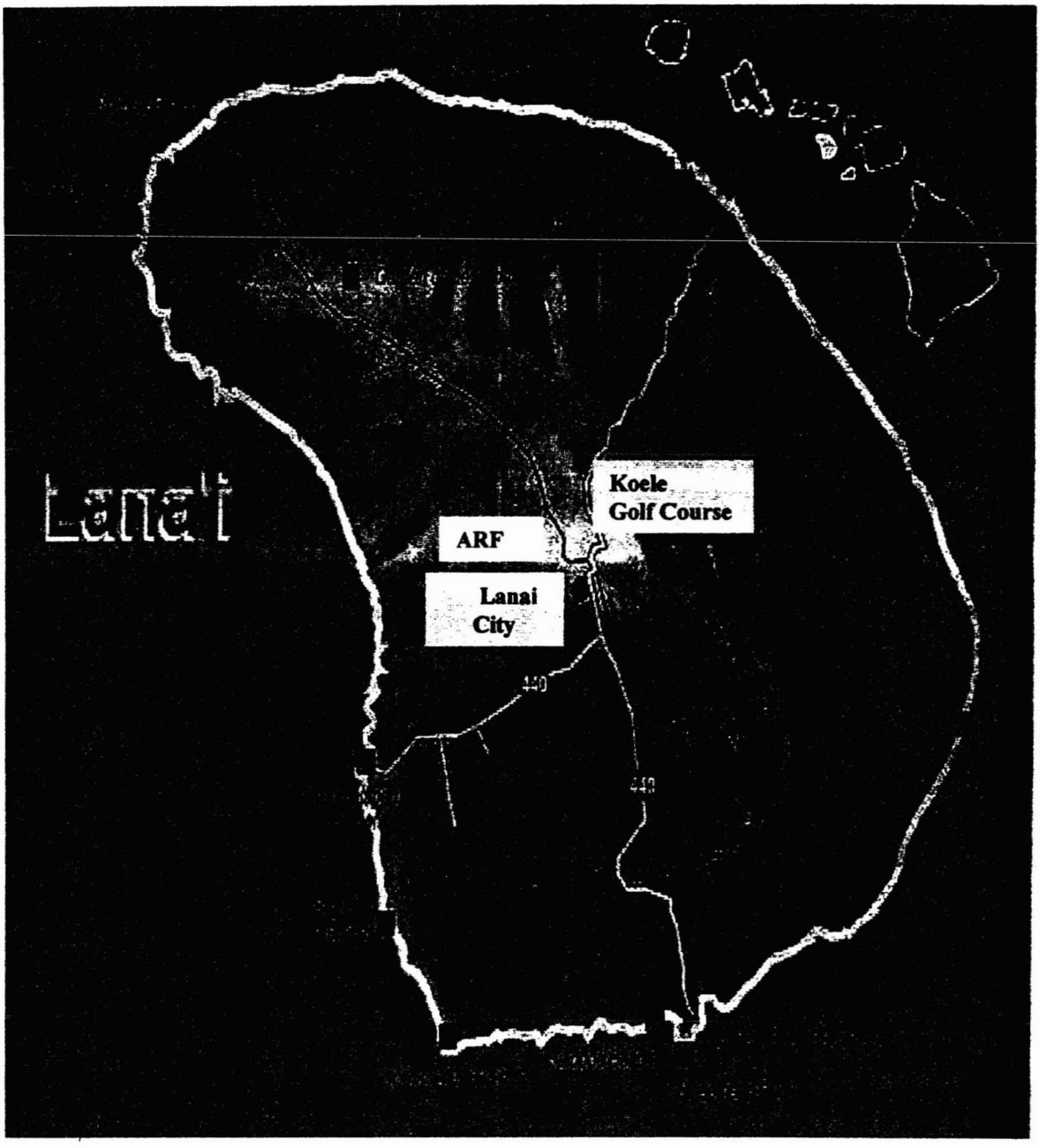

FIG. 2 THE ISLAND OF LANAI

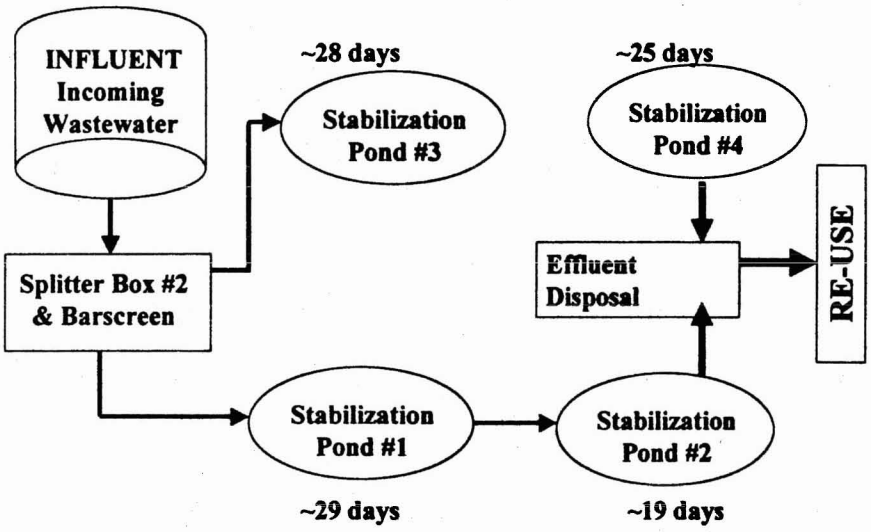

FIG.3 PRETREATMENT DIAGRAM OF THE LANAI WASTEWATER

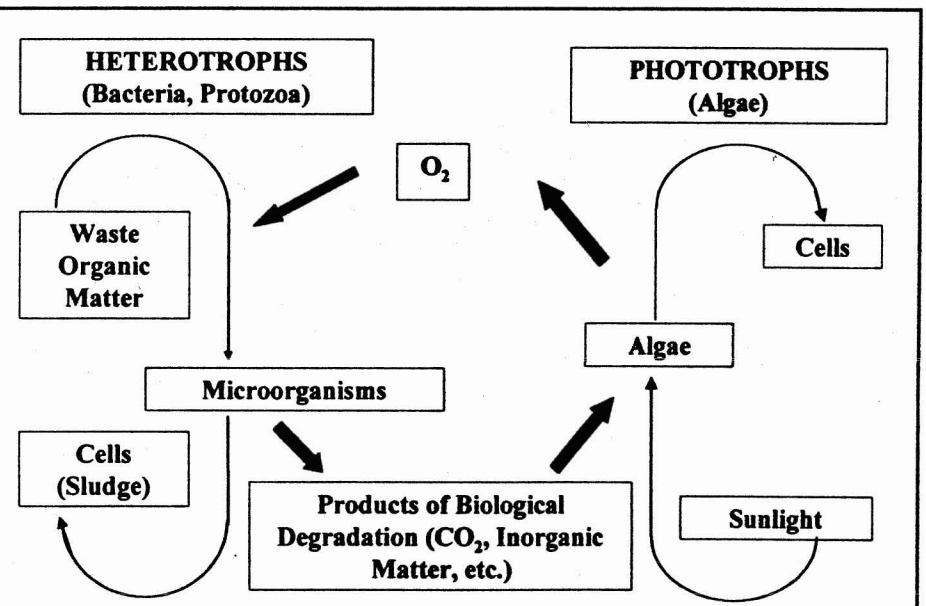

FIG. 4 BIOLOGICAL DECOMPOSITION OF WASTEWATER

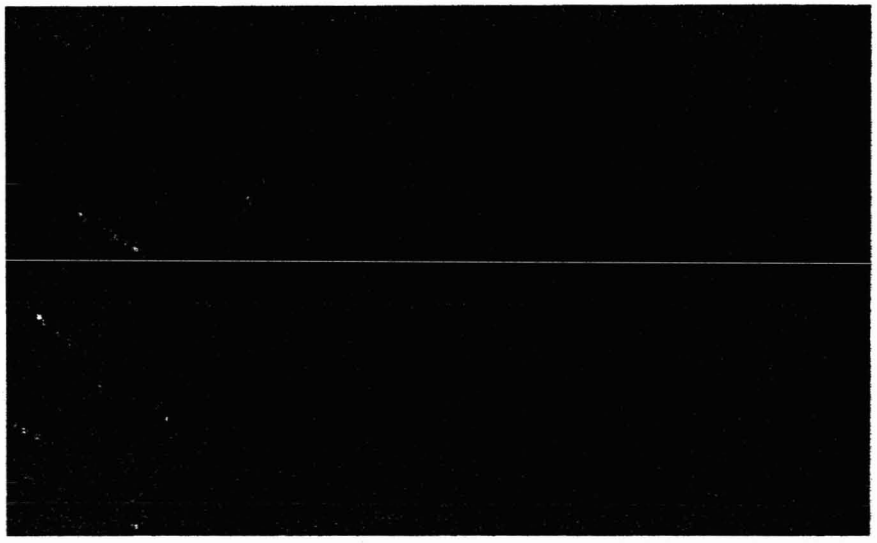

FIG. 5 PRE-TREATMENT BY STABILIZATION POND

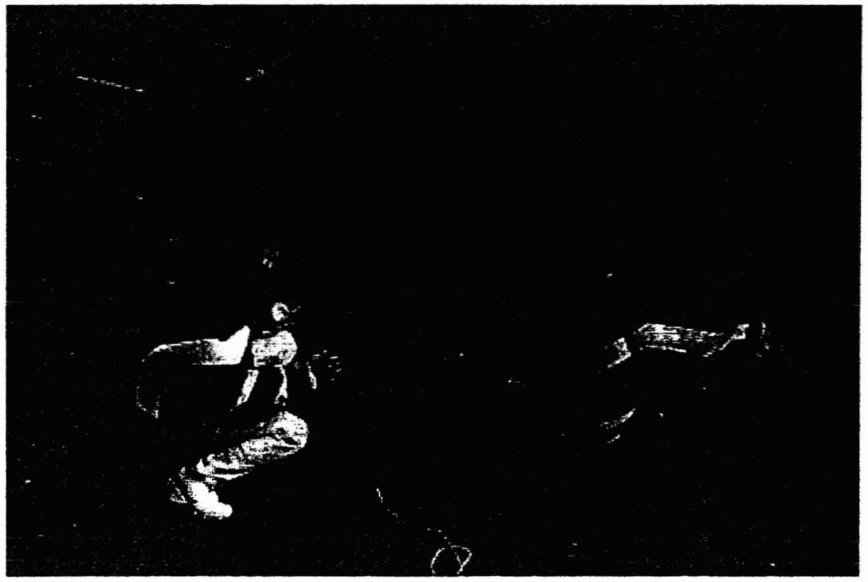

FIG. 6 SAMPLING EFFLUENT STABILIZATION POND

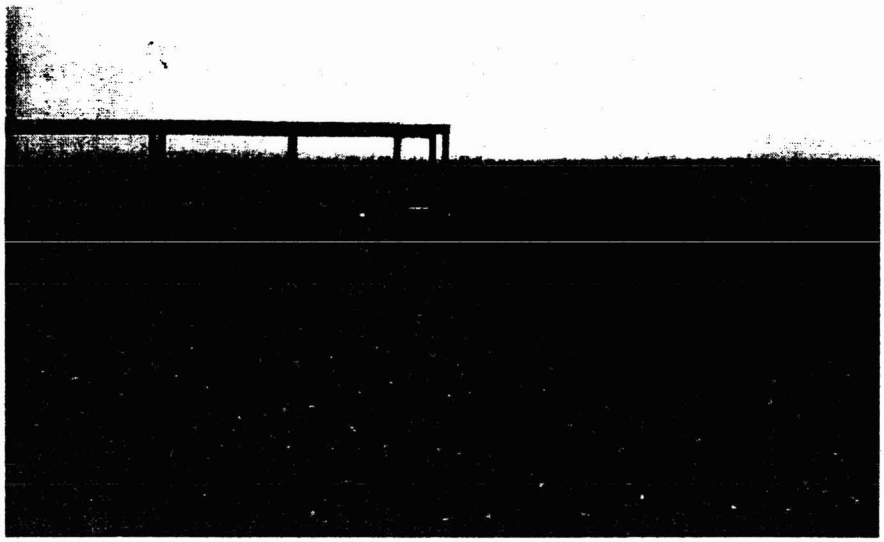

FIG. 7 HYACINTH POND

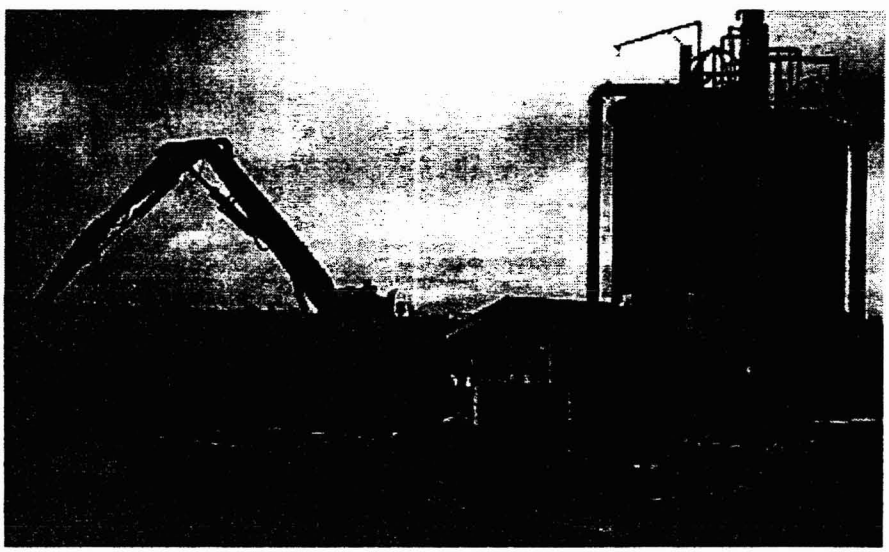

FIG. 8 HYACINTH HARVESTING

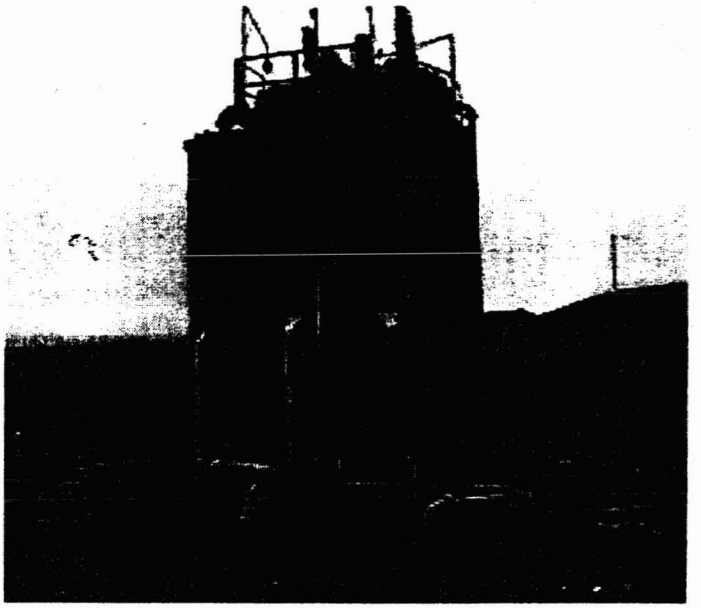

FIG. 9 FILTRATION SYSTEM

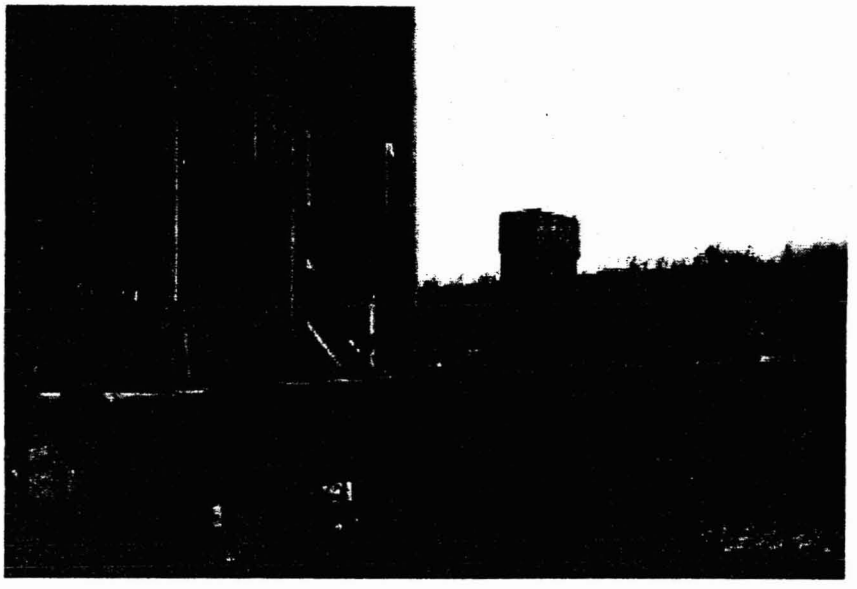

FIG. 10 UV DISINFECTION SYSTEM

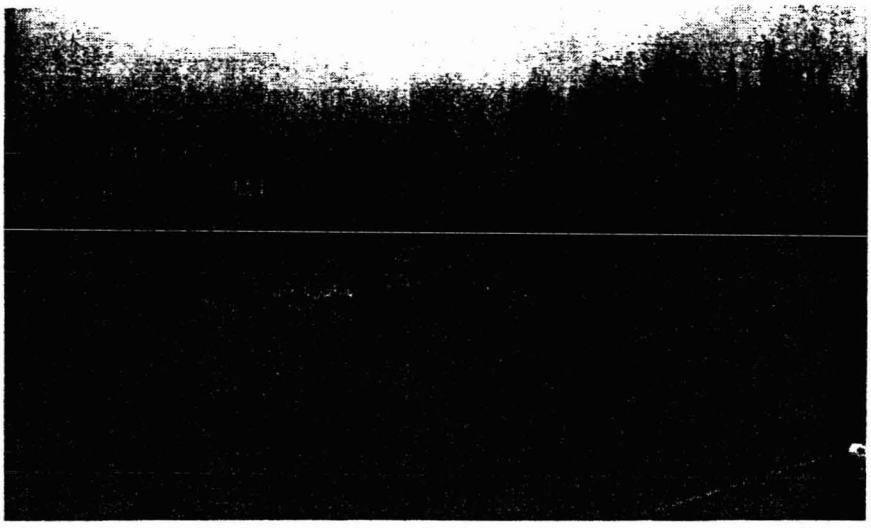

FIG. 11 WATER REUSE : GOLF COURSE IRRIGATION