AN INVESTIGATION INTO ENVIRONMENTAL EFFECTS OF REUSE OF SEWAGE EFFLUENT AT THE KĀNE'OHE MARINE CORPS AIR STATION KLIPPER GOLF COURSE

by

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ABSTRACT

An investigation of waste water reuse by spray irrigation was conducted at the Kāne'ohe Marine Corps Air Station (KMCAS) Klipper Golf Course on Oahu. The study was conducted in three phases: (1) waste water characterization of the KMCAS Sewage Treatment Plant, (2) groundwater quality analysis, and (3) air quality analysis of indicator bacterial levels during spray irrigation with waste water.

Waste water analyses showed that the KMCAS Sewage Treatment Plant, employing the trickling filter process with a final polishing pond, is capable of removing a high percentage of biodegradable substances and suspended solids. The effluent appears to be of good quality for agricultural irrigation use. High concentrations of sodium and chloride, due to brackish groundwater infiltration into the sewage system, were not considered to be a hazard to the salt-tolerant bermudagrass.

The two predominant soils on the KMCAS Klipper Golf Course, the Ewa silty clay loam (Low Humic Latosols) and the Jaucas (Regosols), appeared to be very effective in removing nitrogen, phosphorus, and fecal coliforms from the applied effluent. The quality of the percolate does not present a hazard to the groundwater quality. Runoff from the golf course does not present a hazard to the adjacent surface waters.

Analyses of spray irrigation fallout samples at the KMCAS Klipper Golf Course resulted in the isolation of coliform bacteria up to 91 m (300 ft) downwind of the sprinkler sources. Coliform bacteria recovery rates depended upon the initial coliform bacterial concentrations in the effluent and upon wind velocities. The presence and concentration of aerosolized coliform bacteria were not considered a public health hazard to golf course users, workers, or nearby residents.

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INTRODUCTION

The Kāne'ohe Marine Corps Air Station (KMCAS) is located on the Mōkapu Peninsula, adjacent to the Class "AA" coastal waters of Kāne'ohe Bay (Fig. 1). The Hawaii State Department of Health (1974, chaps. 37-A, 38) restricts the disposal of point pollution into coastal waters classified "AA". The KMCAS Sewage Treatment Plant (STP) presently disposes its effluent into Kāne'ohe Bay, near the KMCAS small boat harbor (Class "B" waters). However, the KMCAS STP will be redirecting its sewage effluent to the City and County of Honolulu's Mōkapu Outfall (presently under construction) located outside Kailua Bay. The KMCAS will be assessed a service charge for the use and maintenance of the Mōkapu Outfall.

The Air Station has sought an alternative for the disposal of its waste waters because of the restrictions on the disposal of waste waters into Kāne'ohe Bay and the future service charges for the use of the Mōkapu Outfall. Since June 1973, the KMCAS has been irrigating the base golf course with a portion of its secondary treatment plant effluent. Between 29 and 93% of the plant's effluent daily flow has been utilized for the Klipper Golf Course irrigation during a year. Approximately 1,060 m^3 (280,000 gal) of fresh water is saved each day due to the irrigation practice.

During the past two decades, there have been numerous studies on waste water reuse for various applications in industrial, recreational, and agricultural products for human consumption. The reuse of waste waters can be an alternative to the expensive advanced waste treatment facilities that may be required by 1 July 1983 to satisfy the requirements of Public Law 92-500 (U.S. Congress 1972). However, the disposal of waste waters through an irrigation system must be examined to determine if any adverse environmental effects can occur. The reuse of waste water for the irrigation of a recreational facility, such as the Klipper Golf Course, must be carefully evaluated to assure the public health safety.

The purpose of this study was to determine the effects of waste water reuse on groundwater and air quality at the Kāne'ohe Marine Corps Air Station Klipper Golf Course. Specifically, the investigation was to determine the removal of some selected chemical and biological pollutants from waste water percolating through the soils on the golf course and the presence of aerosolized organisms dispersed into the air by spray irrigation practices.

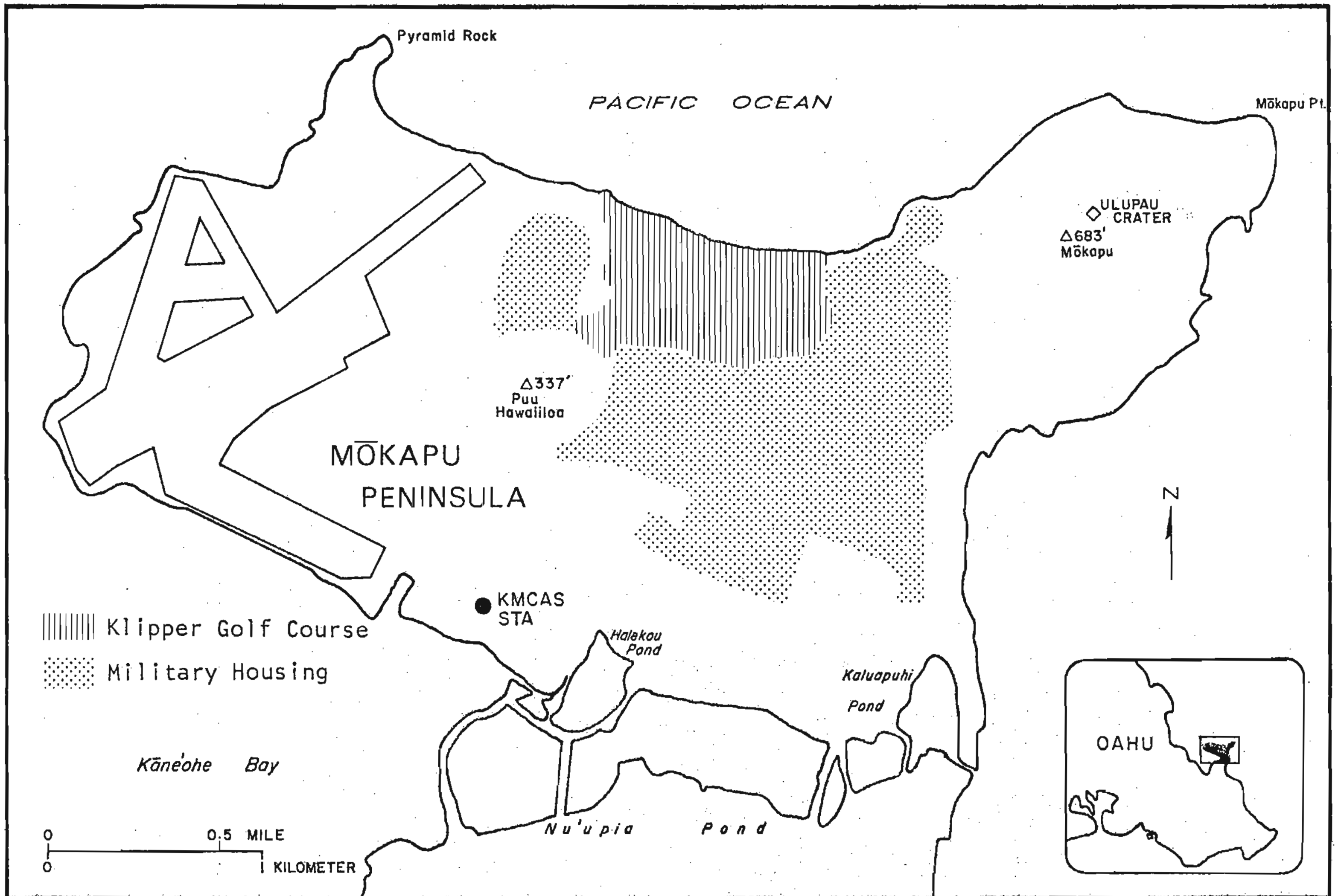

FIGURE 1. KĀNE'OHE MARINE CORPS AIR STATION, MŌKAPU PENINSULA, OAHU

Research in this study was done in three phases: waste water characterization, groundwater quality analysis, and air quality analyses. The waste water characterization of the KMCAS STP was used to determine the quality of the applied sewage effluent on the golf course. Parameters for monitoring the waste water quality included, temperature, dissolved oxygen, pH, biochemical oxygen demand, suspended solids, total dissolved solids, nitrogen (ammonia, organic, nitrate and nitrite), phosphorus, sodium, potassium, chloride, sulfate, and total and fecal coliform bacteria. The groundwater quality below the Klipper Golf course was monitored to determine the effects of the waste water reuse. The parameters for observing the movement of sewage effluent through the two predominant soils (Ewa silty clay loam and Jaucus sand) included, temperature, pH, dissolved oxygen, nitrogen (ammonia, organic, nitrate and nitrite), phosphorus, sodium, potassium, chloride, and fecal coliform bacteria. Parameters for the monitoring of air quality, during the spray irrigation of the golf course, included, temperature, relative humidity, wind velocity and direction, and total coliform and fecal coliform bacteria.

BACKGROUND STUDY

The reuse of man's waste water has been practiced in the United States for at least 75 years. Municipalities and industries in the arid and semiarid areas of the western United States have pioneered reuse systems (Merz 1956). Today, waste waters are being reused in industry, agriculture, and recreation. This reuse provides a practical alternative and method for the disposal of waste waters as well as a supplement to our freshwater demands. In an agronomic sense, waste waters can provide irrigation water of agricultural value for plant crops and recreational areas. In the past, the disposal of waste waters was often considered a major problem. Now, waste waters can be considered as an asset, a recovered resource, when applied through a reuse system.

The reuse of sewage in the state of Hawaii extends back at least 50 years but no documentation has been available on past or most present systems. Various sugar companies located in Wailua and Waimea on Kaua'i and Lahaina on Maui, have indirectly used sewage. Waste waters from the plantation housing were emptied into nearby ditches. The diluted sewage eventually was stored in a reservoir and used for the irrigation of sugarcane. This practice of sewage disposal has probably been used by most of the sugar companies in the past.[1]

Sewage effluents for irrigation have been used at the Royal Kā'anapali Golf Course on Maui and at a baseball park in Kailua, Kona on Hawaii.[2] Since 1969, the Mākaha Nursery on Oahu has obtained septic tank effluent from the Mākaha Inn on Oahu.[3] In 1972, use of oxidation pond effluent as a partial supplement for golf course irrigation began at the Kuilima Hotel on Oahu.[4] At the Kāne'ohe Marine Corps Air Station Klipper Golf Course, use of the trickling filter effluent from the station waste water treatment plant for irrigation began in 1973.[5] Activated sludge effluent has been used at the Hawaii-Kai Golf Course on Oahu since 1973.[6]

The increasing reuse of waste water for agricultural and recreational activities has resulted in many studies on the movement of chemical and biological pollutants through soils. The high removal of various forms of nitrogen in percolating waters through soils has been observed by many investigators (McMichael and McKee 1966; Bouwer, Lance, and Riggs 1974; Lau et al. 1975). However, this removal is often due to the conversion from one form to another. The disappearance of ammonium ion from percolating systems can be partially attributed to oxidation by nitrifying bacteria. Adsorption by clays retains ammonium ions, but this is not necessarily a stable condition because biological oxidation can occur (Lance 1972). This oxidation is merely a conversion of ammonium ion to nitrates. The actual removal of nitrogen from a soil system can be obtained by the reduction of nitrates to nitrogen gas by biological denitrification and the removal of plant tissue from the soil system after plant uptake of the nitrate.

A high removal of phosphorus from percolating waters has been observed in clays. The immobility of phosphorus is attributed to the adsorptive capacity of soils (Taylor 1967). The latosol soils of Hawaii have a high fixing capacity for phosphorus (Fox 1972; Chu and Sherman 1952; Coleman 1944). In some areas, the soil competes with plants for the available phosphorus. Very little movement of adsorbed phosphorus has been observed over a period

[1]Dr. Paul C. Ekern 1975: personal communication.
[2]Dennis Lau 1976: personal communication.
[3]Mākaha Nursery caretaker 1976: personal communication.
[4]Herbert Hirota 1976: personal communication.
[5]Melvyn A. Yoshinaga 1975: personal communication.
[6]Herbert Yamaguchi 1976: personal communication.

of several years. The removal of phosphorus in sand and gravel requires longer underground travel. High concentrations of phosphorus in percolating groundwater, up to 91 m (300 ft) from the source, may be attributed to the lower fixation capacity of sands and gravels (Bouwer, Lance, and Riggs 1974).

Coliform bacteria and viruses have been successfully removed from percolating waste water by sand and gravel as well as by clay soils. The nearly complete removal of the bacteria and viruses has been attributed to surface straining (clogging) and physical adsorption. Laboratory and epidemiological studies on human contact with reclaimed waters have revealed no health hazards (Lau et al. 1975; Houser 1970; Merrell 1968; Tanimoto et al. 1968).

The presence of bacteria has long been associated with waste waters. Aerosolized bacteria have been collected up to 1.6 km (1 mile) downwind of trickling filter and activated sludge units of sewage treatment plants. Laboratory and field studies have found that low temperature, high relative humidity, high wind velocities, and darkness results in higher recoveries and greater downwind travel of coliform bacteria. The mechanism of aerosol formation has been studied by several investigators (Brown et al. 1950; Druet et al. 1953; Woodcock 1955; Wozniack 1976). Water droplets dispersed into the air from spray irrigation may carry bacteria into the atmosphere. Upon evaporation, nuclei of dissolved and suspended matter may be retained in the air. Pathogenic organisms are present in most waste waters and may also become aerosolized. The transfer of waterborne contaminants into the atmosphere may result in gastrointestinal and/or respiratory infections.

Ledbetter and Randall (1969) studied the bacterial emissions from activated sludge units. They used three sampling procedures during their investigations. The most successful procedure, which was also the simplest, consisted of exposing poured agar plates up to 30 m (100 ft) downwind from the aeration tank. They concluded that the bacterial population of air is increased with passage over an activated sludge unit. Despite a rapid die-off of bacteria, the bacterial population increase persisted over a long distance and time. They also found that the distance of bacterial presence was dependent on wind velocity. However, no correlation of bacterial concentrations with either relative humidity or temperature was observed.

Adams and Spendlove in 1970 investigated the aerosols emitted by trickling filter sewage treatment plants and observed the presence of coliforms to a downwind distance of 1.3 km (0.8 mile). High wind velocities, high relative humidity, darkness, and low temperature were determined to produce the greatest recoveries, also at greater downwind distances, of coliforms.

King, Mill, and Lawrence (1973) examined the bacterial emissions from an activated sludge plant. Their recovery scheme also incorporated an identification of colony groups collected. The *Bacillus* species was the most predominant organism upwind and downwind of the aeration unit. *Escherichia coli* was found solely downwind of the aeration unit. *Staphylococcus aureus* was also found and suggested the probability of primary pathogenic bacterial dispersion from the plant process. In general, an in-colony count was observed with an increase of temperature, but only in excess of 24°C (76°F). A combination of low humidity and elevated temperature reduce colony counts more than either factor alone.

Clark (1974) studied the coliform-containing aerosols emitted by activated-sludge (AS) and trickling-filter (TF) units at the Kailua TF and the Maunawili AS treatment plants on Oahu. Fewer coliform organisms were emitted from the trickling-filter unit than from the activated sludge unit. In both cases, colonies were collected as far as a mile downwind of the respective plants.

SAMPLING STATIONS AND FIELD METHODS

Waste Water Characterization

The KMCAS STP is located on the south side of the Air Station, adjacent to Kāne'ohe Bay (Fig. 2). The STP utilizes a single stage trickling filter

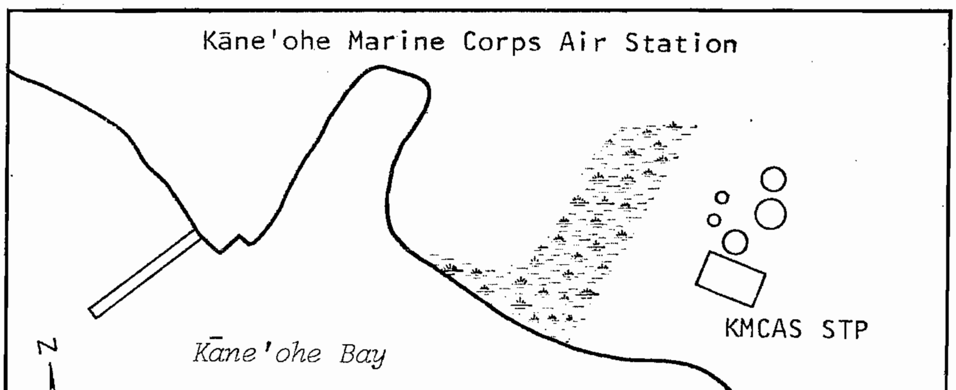

FIGURE 2. LOCATION MAP OF THE KMCAS SEWAGE TREATMENT PLANT

for the biological treatment of the waste water. Following secondary treatment, the effluent is chlorinated and passed through an aerated polishing pond (Fig. 3). Flow from the pond is either pumped to the golf course for irrigation or through an outfall into Kāne'ohe Bay.

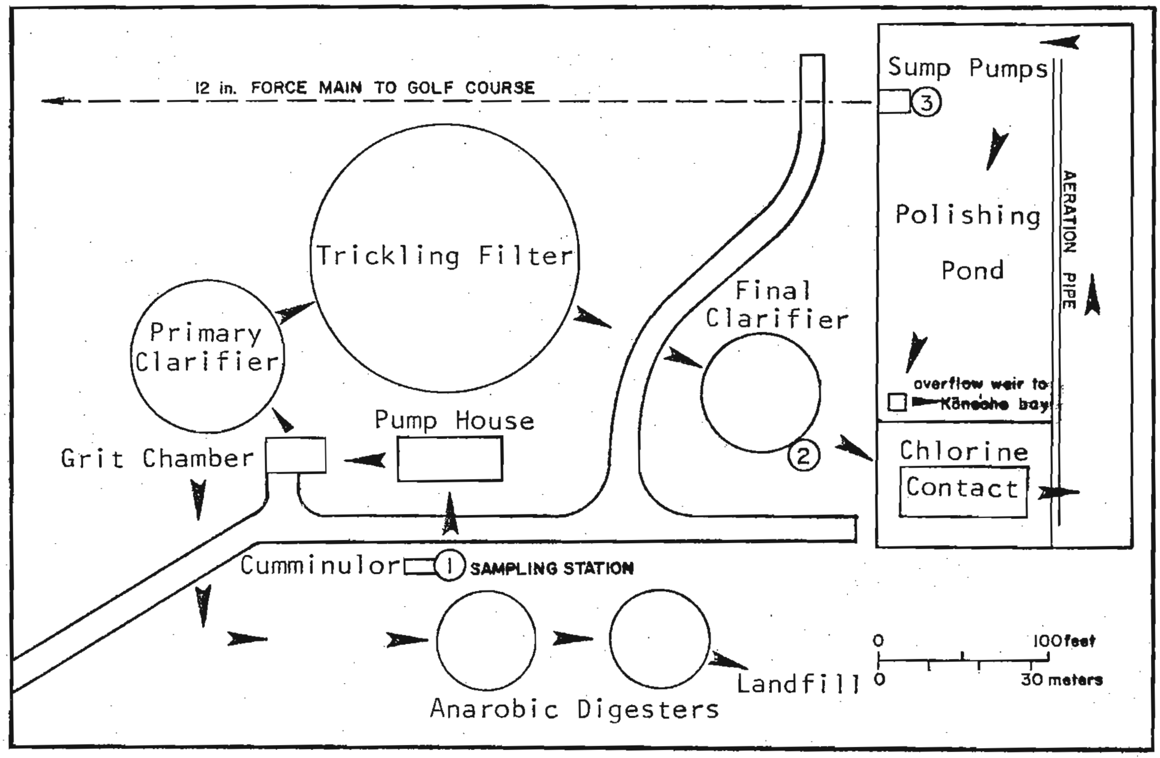

FIGURE 3. KMCAS SEWAGE TREATMENT PLANT LAYOUT

Four, 24-hr composite samples were obtained at the STP on 8 to 9 October 1975, 20 to 21 November 1975, 11 to 12 February 1976, and 12 to 13 July 1976. Three stations were established for grab sampling. Station 1 was located at the raw sewage inflow, prior to comminution, Station 2 was located in the final clarifier at the outlet pipe, and Station 3 was located next to the golf course irrigation pumps in the polishing pond (Fig. 3).

Twenty-four, hourly grab samples of raw sewage at Station 1 were collected during each of the four sampling dates. During the October and November sampling dates, grab samples were collected at Station 2 every four hours. Grab samples were collected every two hours at Station 3 during the October and November sampling dates. During the February sampling period, six grab samples were collected at random at Station 3. During the July sampling period, hourly grab samples were collected at Station 3.

Grab samples from Stations 1, 2, and 3 were collected with a plastic "scoop" bucket and then placed into plastic bottles, for all four sampling dates. During the February and July composites, automatic samplers were used as a supplement for early morning sample collection. A refrigerated sampler (Sigma motor automatic sequential sampler) was used for the February composite and an Isco automatic sequential sampler was used in July.

Individual plastic bottles were used to collect two 500-mℓ samples at Station 1 and two, 1,000-mℓ samples at Stations 2 and 3 for each sampling hour. All samples were kept in iced containers or refrigerated at 4°C. All sample bottles were cleaned with chromic acid and rinsed with distilled deionized water prior to sample collection. Two milliliters of concentrated sulfuric acid were added, as a preservative, to one sample bottle of each sampling for nutrient analysis.

The collected grab samples from each station were analyzed individually. This provided information on the composition as well as the hourly fluctuations of various constituents in the waste water.

Groundwater Quality

SELECTION AND ESTABLISHMENT OF SAMPLING SITES. Three factors determined the location of the wells for groundwater sampling:

1. Soil characteristics of the area (soil descriptions for the Jaucas sand and the Ewa silty clay loam are in App. A)
2. Depth of soil to the groundwater
3. Distance of wells from sprinkler heads.

The location, description, and construction details of the sampling wells are as follows:

Test Well 1. Control well; located 46 m (150 ft) east of the golf course clubhouse, adjacent to the NCO Club building and 38 m (125 ft) from the nearest sprinkler (Fig. 4). A 4-m (13-ft) deep trench was dug using a backhoe from the KMCAS Public Works department. The top 1-ft of soil appeared to be fill material of a different clay group. The surface cover was bermudagrass. The remaining soil down to the groundwater had the characteristic reddish-brown color of the Ewa silty clays. A 4-m long, 3.8-cm (1.5 in.) ID polyvinylchloride (PVC) pipe was positioned vertically in the backfilled trench. The ground surface was at 109.96 (datum plane of 100.00 is mean low water [MLW]). The groundwater level was at 101.8, 2.68 m (8.78 ft) below the ground surface. The bottom cap of the well was 0.98 m (3.20 ft) below the groundwater level (Fig. 5).

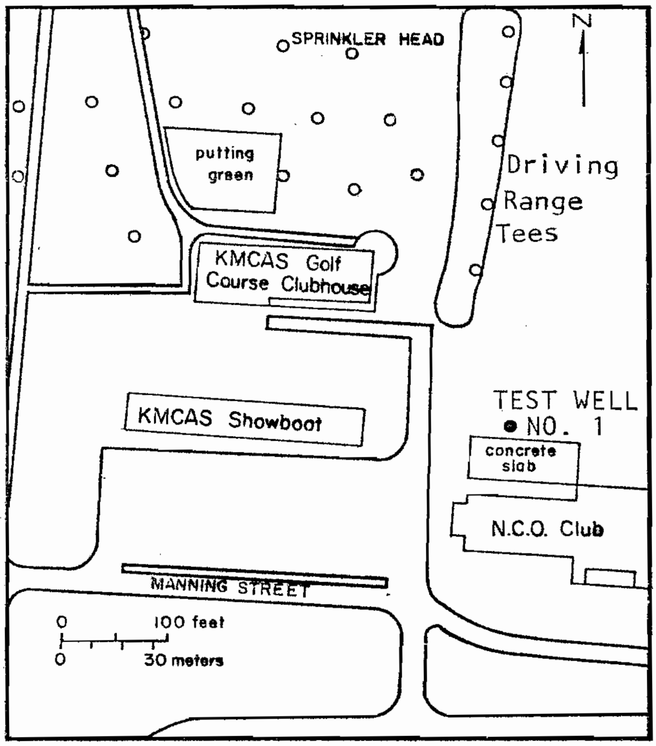

FIGURE 4. LOCATION MAP OF TEST WELL NO. 1

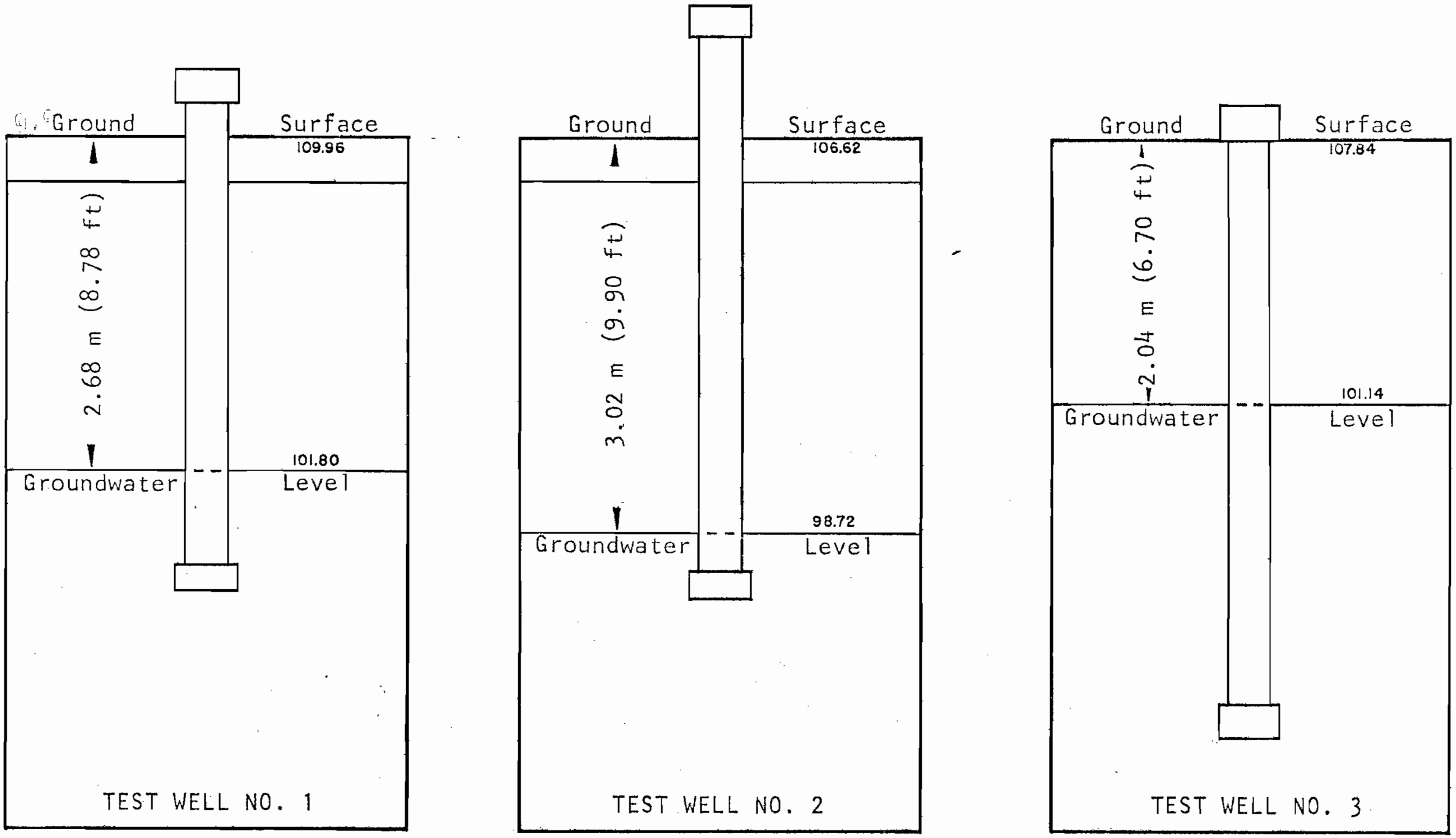

FIGURE 5 SCHEMATIC CROSS SECTIONS OF TEST WELL NOS. 1, 2, and 3

Test Well 2. Located 11 m (35 ft) southeast of the No. 11 tee (Fig. 6). This well was located 0.61 m (2 ft) from a sprinkler head. A hole 3.5 m (11.5 ft) deep was drilled using a 6.4-cm (2.5 in.) diameter hand auger (Fig. 5). The surface cover was bermudagrass and the soil material down to the groundwater was Jaucas sand. A 3.17-cm (1.25-in.) ID PVC pipe was inserted into the hole and the zone around the pipe was compacted. The ground surface was 2.02 m (6.62 ft) above MLW (106.62). The groundwater level was 3 m (9.90 ft) below the ground surface at 96.72. The depth of water in the well was 0.51 m (1.68 ft).

Test Well 3. Located 12.2 m (40 ft) north of the No. 3 women's tee and sprinkler heads (Fig. 7). The surface cover was bermudagrass. The Public Works department's backhoe was used to dig a 4.6-m (15 ft) deep trench at this site (Fig. 5). The soil here resembled a typical Ewa silty clay loam. A 4.9-m (16-ft) long, 3.8 cm PVC pipe was placed vertically into the back-filled trench. The ground surface level was at 107.84 (2.39 m [7.84 ft] above MLW). The groundwater level was 2.0 m (6.70 ft) below the ground surface at 101.14. The depth of water in the well was 2.6 m (8.4 ft).

The PVC pipe served as a casing for the sampling wells. Each casing was capped on the bottom. A series of four, 0.32-cm (0.125-in.) diameter holes were drilled into the PVC pipe at 2.54-cm (1-in.) intervals from the bottom cap. A total of 48 holes (a 30.48-cm [12-in.] section of pipe) provided entry for groundwater infiltration into the sampling wells.

Groundwater from Test Wells 1, 2, and 3 and the sprinkler effluent were collected during March through May 1976. Eighteen sets of test well samples (Test Wells 1, 2, 3) and nine sprinkler effluent samples were collected during the three months. The duration between the collection of sample sets varied from one to fourteen days.

A Masterflex No. 7015 pump head adapted onto a "D.C. Puppy" pump motor (for 12 V battery operation) was used to draw groundwater samples from the test wells. Sprinkler effluent was collected by "tapping" a sprinkler head.

Air Quality

The Klipper Golf Course is spray irrigated daily between 6 PM and 6 AM. All 18 greens and the putting green are irrigated each night. One-half of the fairways and tees are irrigated on alternate nights. The three major factors determining site selection were: accessibility, visibility, and time

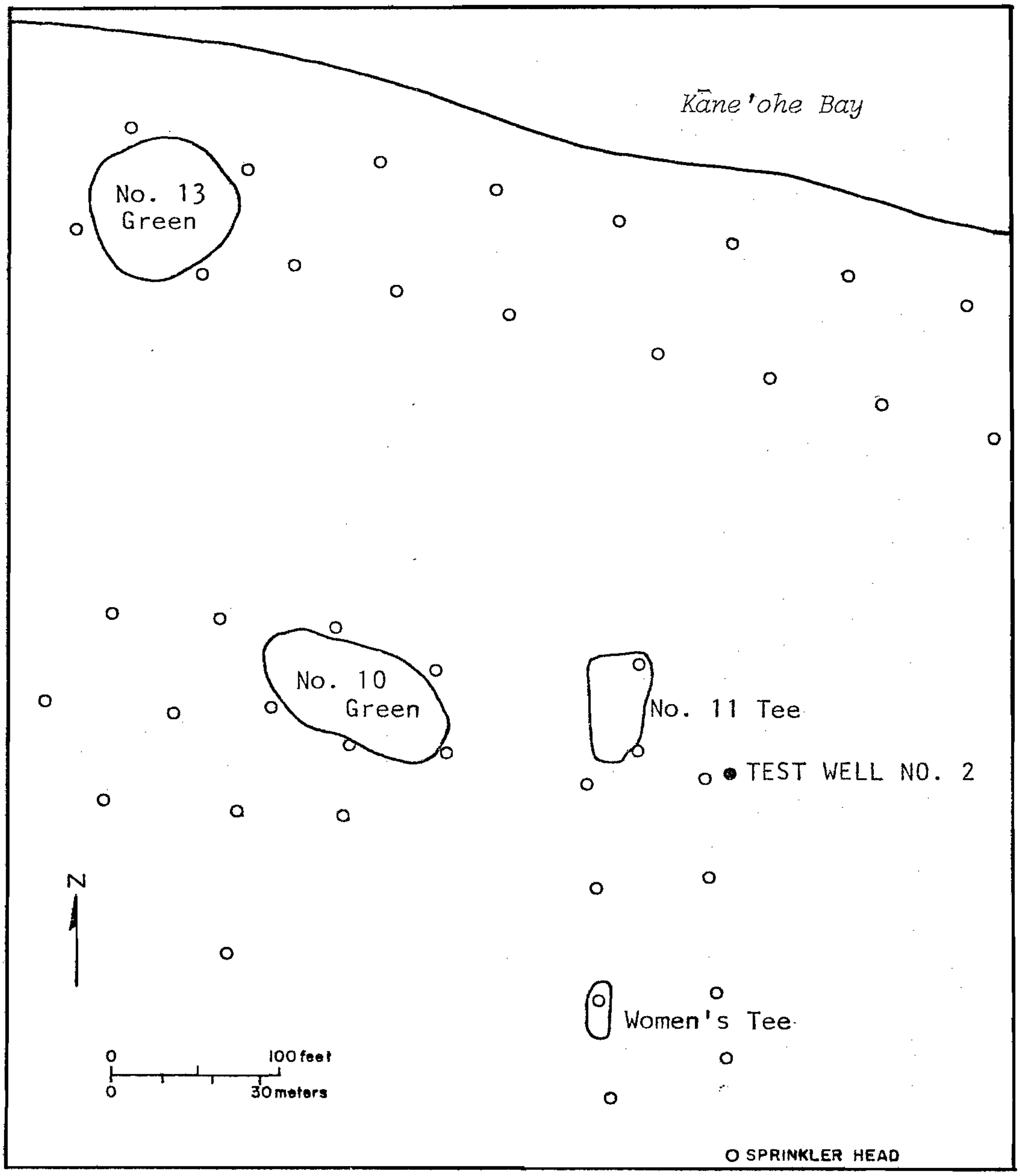

FIGURE 6. LOCATION MAP OF TEST WELL NO. 2

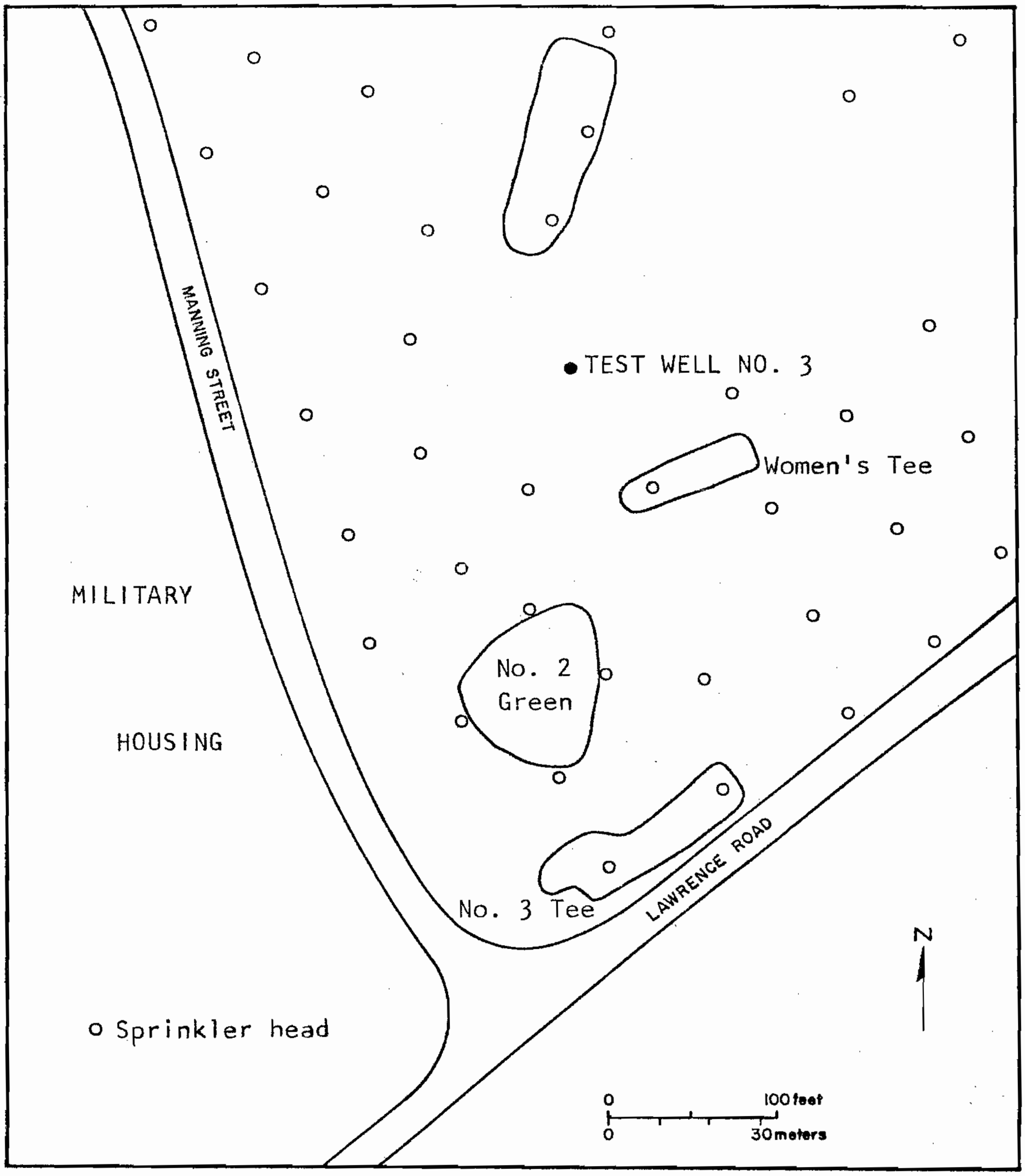

FIGURE 7. LOCATION MAP OF TEST WELL NO. 3

of night.

The area near the greens was selected for air quality analysis because of three qualifying factors. Most greens are accessible from adjacent roads. During the month of June, the greens were irrigated during the twilight hours between 6:20 PM and 8 PM when sufficient light was available for the setup and removal of test equipment. The early evening period of sampling was also ideal because there was minimal interference and inconvenience to the residents adjacent to the golf course.

The greens selected for the air quality sampling were Nos. 2, 15, and 16 and the practice putting green.

Once wind speed and direction were determined at each green, a downwind azimuth was selected through the center line of the green (Fig. 8). Covered petri dishes were mounted on 0.91-m (3-ft) long, 0.32-cm diameter wooden dowels. These mounted dishes were then staked into the ground along the determined downwind azimuth. The dishes were placed at distances up to 91 m (300 ft) from the nearest downwind sprinkler (Fig. 9). The only modification of the sampling procedure was at green Nos. 15 and 2. The farthest downwind station was located at 60.96 m (200 ft) because of physical obstructions (a steep hill near No. 15 and residential housing near No. 2).

The petri dishes with M-Endo medium were exposed to the air between 2 and 4 min. prior to the start of the irrigation at a specific green. The petri dishes remained exposed to the atmosphere during the irrigation of the specific green. At the conclusion of the irrigation cycle, the petri dishes were covered and collected beginning at the dish nearest the green.

Between 9 and 16 June 1976, 18 sets of air samples were collected at the four greens.

RESULTS AND DISCUSSION

Waste Water Characterization of the KMCAS Treatment Plant

The primary purpose of the waste water characterization of the KMCAS treatment plant was to determine the quality of sewage effluent that was being used for the irrigation of the air station golf course. A secondary purpose was to determine the overall efficiency of the STP operation. The results of the four waste water composites are reported in Appendix B.

The average waste water flows through the KMCAS STP were 2,233, 1,136, 1,438, and 3,709 m^3/day (0.59, 0.30, 0.38, and 0.98 mgd) for the October,

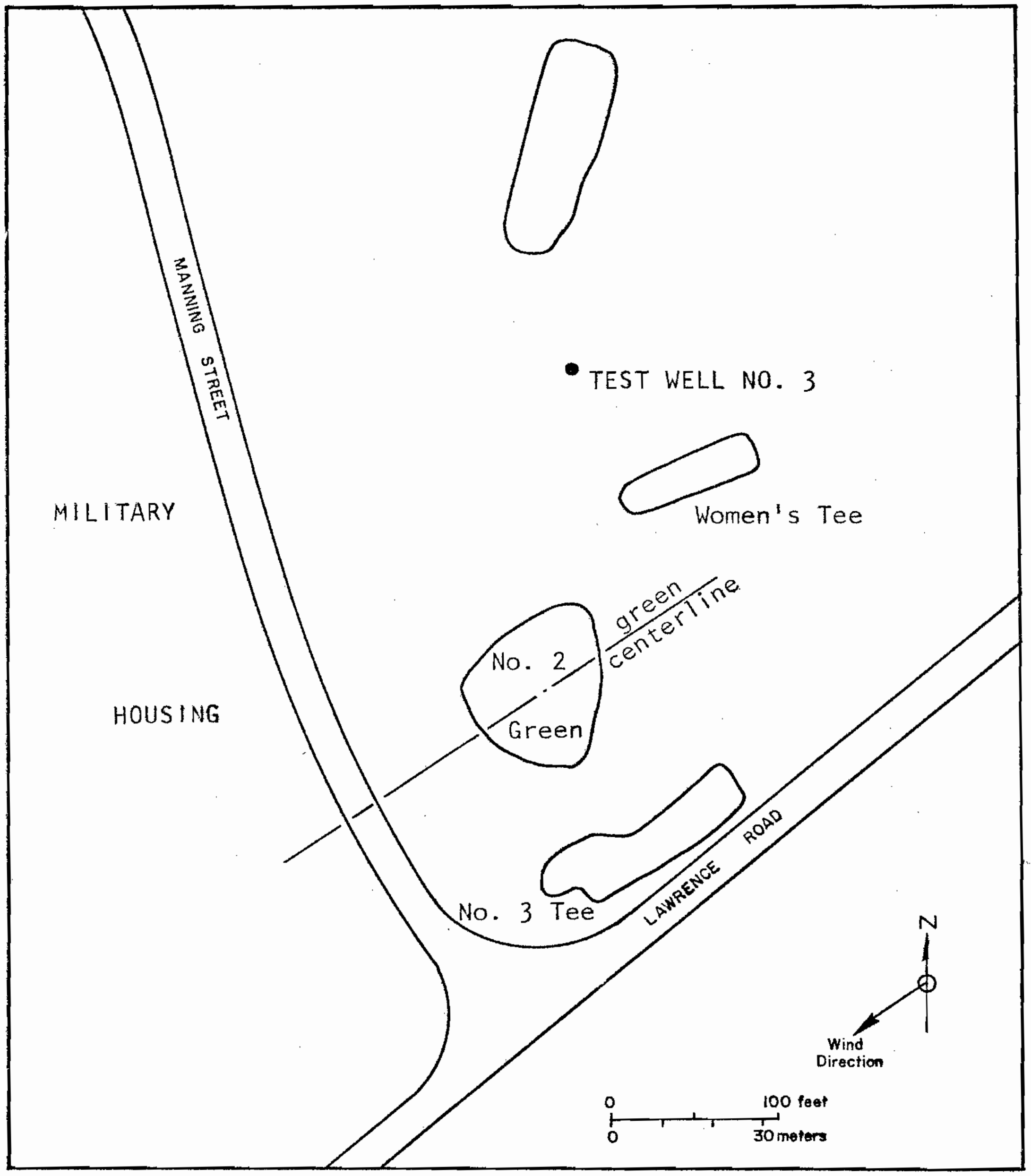

FIGURE 8. DETERMINED DOWNWIND AZIMUTH FOR AIR SAMPLING

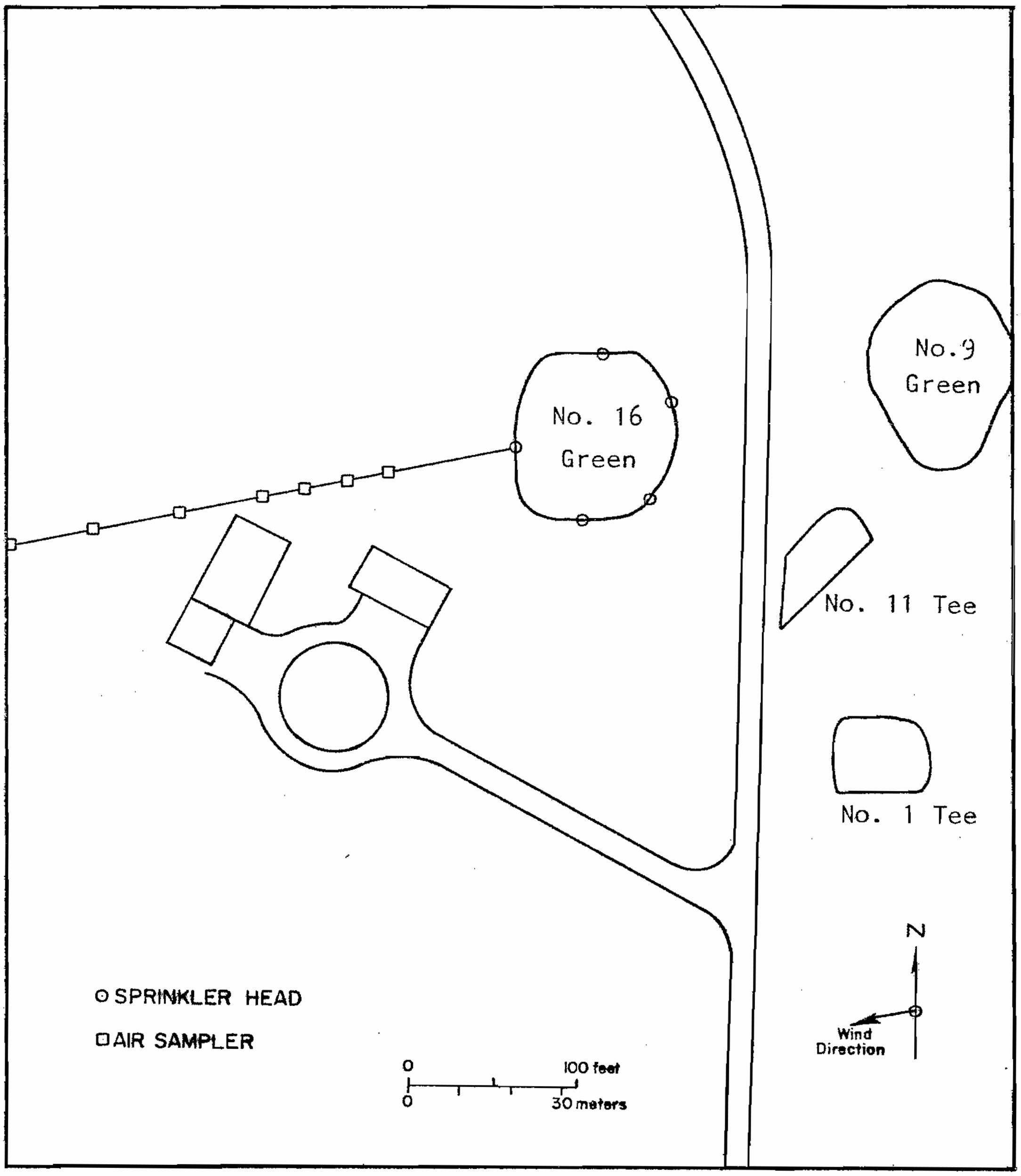

FIGURE 9. AIR SAMPLING CONFIGURATION

November, February, and July composite dates, respectively. The higher flows during the October and July composites can be attributed to higher water usage at the air station. A general trend was observed in the pattern of hourly flow fluctuations during each of the 24-hr composites (Fig. 10). Peak flows occurred at about 7 AM, 1 PM, and 7 PM; the low flow period was between 1 AM and 6 AM.

In general, the raw sewage, secondary effluent, and pond effluent were of fairly uniform composition.

The mean values for BOD_5, suspended solids, total nitrogen, and total phosphorous concentrations in the raw sewage were respectively, 116, 111, 21.6, and 7.2 mg/ℓ. These low concentrations are indicative of a mild or weak domestic sewage (Metcalf and Eddy 1972). The KMCAS sewage system is located close to the brackish water table of the Mōkapu Peninsula. The relatively weak domestic sewage at the KMCAS sewage treatment plant can be attributed to the infiltration of brackish groundwater into the sewage system.

The mean values of chloride concentrations in the raw sewage and groundwater were respectively 450 and 18,000 mg/ℓ. The chloride concentration in the drinking water on the KMCAS was 30 mg/ℓ. Between 20 and 28% of the flow into the STP can be attributed to the infiltration of brackish or saline groundwater.

The KMCAS sewage system is fairly old and its close proximity to the groundwater table results in the high infiltration into the system.

Grab samples of secondary effluent, prior to chlorination, were collected in October and November 1975. The various removal efficiencies of the treatment plant process (raw to secondary effluent, secondary effluent to pond effluent, and raw to pond effluent) are listed in Table 1. Removal of 82% of the BOD_5 and 80% of the suspended solids was accomplished between the influent raw sewage and the trickling filter effluent. These removal rates are typical of many trickling filter plants in Hawaii and the mainland U.S. (Chun, Young, and Anderson 1972; McGauhey 1968).

Removal of an additional 33% BOD_5, 59% suspended solids, and 12.5% organic nitrogen was accomplished in the polishing pond (between the secondary effluent and the polishing pond effluent). This removal of BOD_5 and organic nitrogen can be attributed to the settling of organic solids and biological activity in the pond. Between 17 and 25 kg/day (38 and 54 lb/day) of suspended solids are settling into the pond (Table 2). This accumulation of solids eventually will require the dredging of the polishing pond. However,

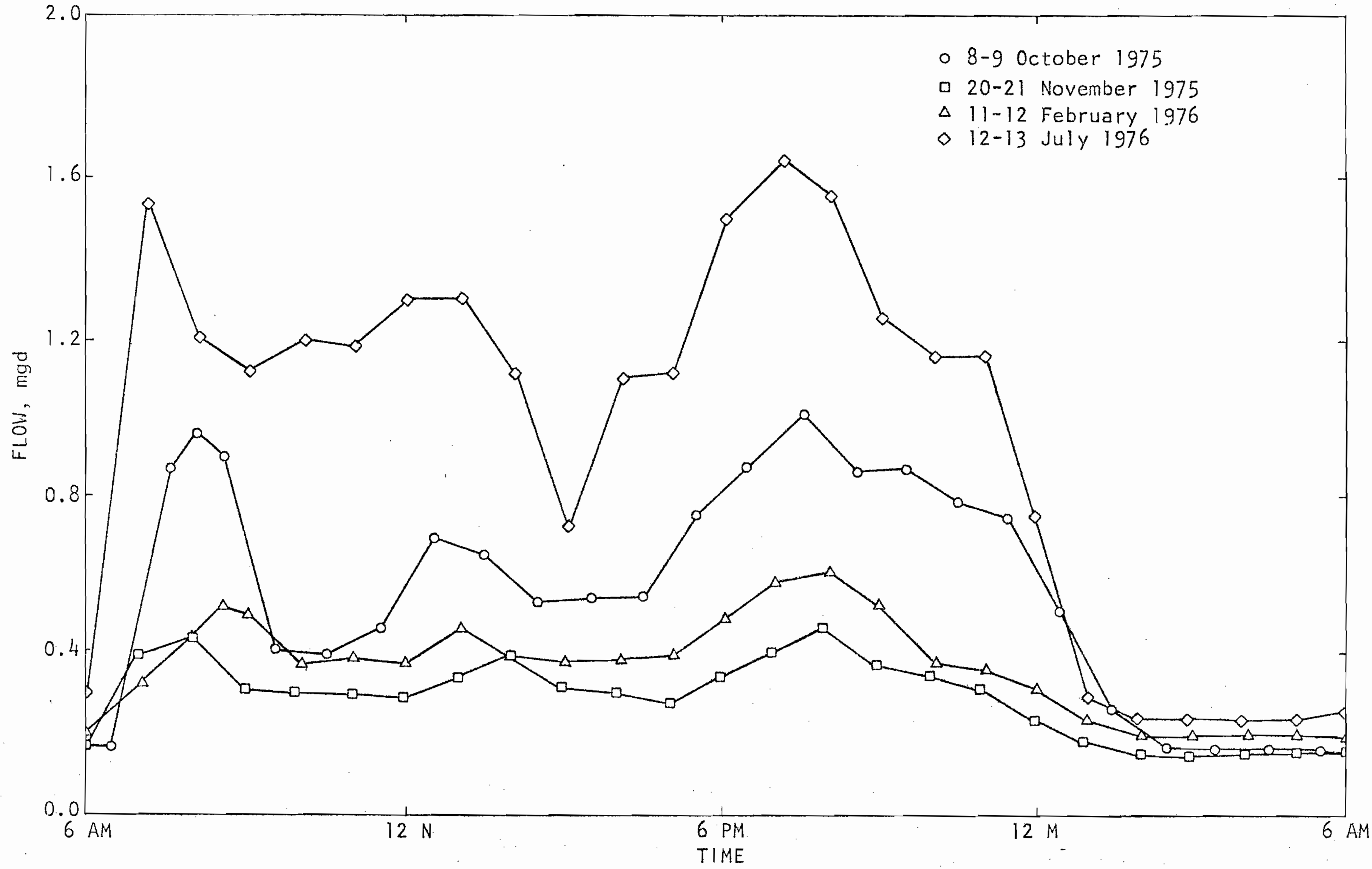

FIGURE 10. HOURLY FLOW PATTERN, KMCAS SEWAGE TREATMENT PLANT

TABLE 1. WASTE WATER ANALYSES OF KMCAS TREATMENT PLANT EFFICIENCIES

Constituent	10/75[a]			11/75[b]			2/76[c]	7/76[d]
	Raw Sewage to Secondary Effluent	Secondary Effluent to Pond Effluent	Raw Sewage to Pond Effluent	Raw Sewage to Secondary Effluent	Secondary Effluent to Pond Effluent	Raw Sewage to Pond Effluent	Raw Sewage to Pond Effluent	Raw Sewage to Pond Effluent
	(mg/ℓ)							
TDS	--	--	--	--	--	--	--	10.1
SS	82.7	57.9	92.7	78.1	60.0	91.2	93.9	88.7
BOD_5	82.3	33.3	88.2	--	--	--	90.3	93.7
NH_3-N	56.7	- 6.8	53.5	45.3	0.0	45.3	33.1	36.8
Org. N	59.7	-25.0	46.3	65.6	25.0	74.2	74.4	62.2
NO_2 + NO_3-N	-99.5	59.5	-98.8	-98.6	65.8	-96.0	-97.1	-98.8
Total N	36.7	15.0	46.2	47.1	14.0	54.5	47.9	42.0
Total P	- 9.4	- 2.7	11.9	7.4	- 1.1	6.4	3.7	-24.5
Na	--	--	--	--	--	--	--	--
K	--	--	--	--	--	--	--	--
Cl^-	20.8	0.8	--	- 7.9	- 1.8	- 9.6	- 1.0	- 7.9
SO_4	--	--	--	--	--	--	--	14.2

NOTE: Constituent reduction reported as percent removal.
[a]Baseline values obtained from App. Tables B.1-B.3.
[b]Baseline values obtained from App. Tables B.4-B.6.
[c]Baseline values obtained from App. Tables B.7-B.8.
[d]Baseline values obtained from App. Tables B.9-B.10.

TABLE 2. SUSPENDED SOLIDS REMOVAL IN THE KMCAS STP POLISHING POND

Date	Avg. Flow	Sec. Eff.	Pond Eff.	Removal	
	(mg/ℓ)			(mg/ℓ)	(lb/day)
Oct. 1975	0.59	19	8	11	54.1
Nov. 1975	0.30	25	10	15	37.5

the polishing pond's major function appears to be that of an equalization and retention basin.

In general, the quality of the effluent used for golf course irrigation is considered good. The overall reduction of BOD_5 and suspended solids (raw sewage to the pond effluent) of 90% is achieved by the sewage treatment plant. The total nitrogen and phosphorous levels of the waste waters are not decreased by the treatment plant operation. This is expected because removal of nitrogen and phosphorus is not among the primary objectives of secondary treatment plants. On 6 June 1976, a single grab sample of chlorinated pond effluent from the STP was collected for preliminary viral analysis. The results of the viral analysis by Dr. Roger S. Fujioka at the University of Hawaii's Virology Laboratory was negative, i.e., no viruses were isolated. The KMCAS STP operation produces a high quality effluent that can be attributed to the relatively weak domestic sewage and the use of the polishing pond.

From an agricultural standpoint, the quality of the applied pond effluent is acceptable for the irrigation of the golf course. According to Dye (1958), sewage effluent containing total solids between 800 and 1,200 mg/ℓ, total nitrogen between 16 and 20 mg/ℓ, total phosphorus between 7 and 13 mg/ℓ, and sulfates between 120 and 180 mg/ℓ is of good agricultural value. The pond effluent at the KMCAS STP has characteristics similar to those cited by Dye. The two major plant nutrients, nitrogen (total N) and phosphorus (total P), have been applied (through the irrigation system) onto the golf course at respective rates of 94 and 66 kg/wk (208 and 145 lb/wk). This application is an additional supplement to regular fertilization.

The mean sodium and chloride concentrations in the applied effluent were high (230 mg/ℓ and 342 mg/ℓ, respectively). A high concentration of sodium in irrigation water can produce an undesirable condition in soils. Sodium can react with the clay in some soils to decrease permeability. This is a common occurrence in Hawaiian Vertisols (tropical black earths). However, the Oxisols (low humic latosols) are tropical red earths that are not affected by the high sodium concentration (El-Swaify and Swindale 1968).

Sodium and chloride concentration (salinity) can reduce the growth rates of various types of plants (Ackerson and Younger 1975). The high salt concentration in irrigation water can damage grass. The KMCAS uses various types of bermudagrasses for the golf course. In general, bermudagrasses are salt-tolerant grasses that survive well in coastal areas (Ackerson and Younger

1975). None of the species on the KMCAS golf course have shown adverse effects due to the high salinity of the applied effluent; however, the spray irrigation should be carefully monitored. During hot and sunny days, the rapid evaporation of the effluent may result in the additional concentration of salt on the grass blades. This could cause damage (discoloration) to the bermudagrasses.

Due to the large scale use of sewage effluent for irrigation, runoff from the golf course could result in the contamination of nearby surface waters. On 6 February 1976, surface water runoff was collected during a heavy rainstorm. Runoff samples were collected near the No. 2 and No. 18 greens. Total Kjeldahl nitrogen, combined nitrate and nitrite nitrogen, and total phosphorous analyses were performed on the samples. The results of the runoff analysis (Table 3) indicate that pollution of surface water is not due to runoff from the KMCAS Klipper Golf Course.

TABLE 3. RUNOFF ANALYSIS, KMCAS KLIPPER GOLF COURSE, 6 FEBRUARY 1976

Constituent	No. 2 Green	No. 18 Green	Control Area*
	(mg/ℓ)		
TKN	1.1	1.5	1.3
$NO_2 + NO_3$-N	0.02	0.03	0.02
Total P	0.68	0.69	0.68

*Control area was located 61 m (200 ft) due south of the No. 2 green, and adjacent to a drainage ditch across Lawrence Rd. near the baseball diamond.

Groundwater Quality

The groundwater test wells permitted the observation of the movement of various waste water constituents through the two major soils on the golf course. The Ewa silty clay loam is the predominant soil type over approximately 50% of the golf course. The Jaucas sand is the second most abundant soil type, covering approximately 25% of the golf course. The remaining soil types on the golf course are: Mokuleia clay loam (15%), Makalapa clay (2%), and fill land (8%). Soil descriptions are listed in Appendix A. The Ewa silty clay loam and the Mokuleia clay loam belong to the same soil order (Mollisols). In general, both soils have some similar qualities.

The Ewa silty clay loam and the Jaucas sand were selected for the location of the groundwater test wells. The two soil types were representative of the soil characteristics that are predominant on the KMCAS golf course.

The specific test well sites were selected with respect to the soil depth to the groundwater and their distance to the spray irrigation sprinklers (Fig. 11). The test wells were constructed using a 6-cm (2.5 in.) hand auger and a trench digger (backhoe). These methods of contruction limited the effective depth of the wells to approximately 4.6 m (15 ft). Test Well No. 1 was established as a control well outside the effective range of the sprinklers on the southern boundary of the golf course. Test Well No. 1 was used to examine the quality of uncontaminated groundwater near the golf course. Test Well Nos. 2 and 3 were established within the spray irrigation range of the sprinklers. These two wells were used to examine the quality of groundwater below the spray irrigation system of the golf course. The movement of groundwater appeared to be toward the ocean (south to north across the golf course), thus the use of Test Well No. 1 as a control well.

The determination of the actual quantity of applied effluent proved to be quite difficult. The quantity of waste water applied onto the golf course was controlled by the groundskeeper and varied according to the requirements of each grass species. The automatic sprinkler system controls are usually modified every few months to maintain the desired quality of the greens and fairways. The greens and fairways received different quantities of effluent. The effluent discharge pump system at the STP was not metered.

The quantity of effluent is not necessarily distributed evenly throughout the golf course and the variations in types of sprinkler heads, water pressure, and wind patterns also complicated the analysis of applied effluent applied onto the golf course was indirectly determined. Determination of the application rate was based on the following: (1) number of sprinkler heads on the golf course, (2) average flow of the sprinkler heads, (3) average "on time" of the sprinklers, and (4) average area covered by the sprinkler heads. Approximately 1 cm (0.4 in.) of pond effluent per week is applied on the fairways and tees of the golf course. The greens receive six times as much effluent than the fairways (5.6 cm [2.2 in.] per week).

The Klipper Golf Course receives treated waste water pumped through a 30.5-cm (12 in.) diameter force main. Minor quality changes of pond effluent occurs during the retention time in the force main (Table 4). The most significant change occurs in the concentration of nitrogen. Combined nitrite

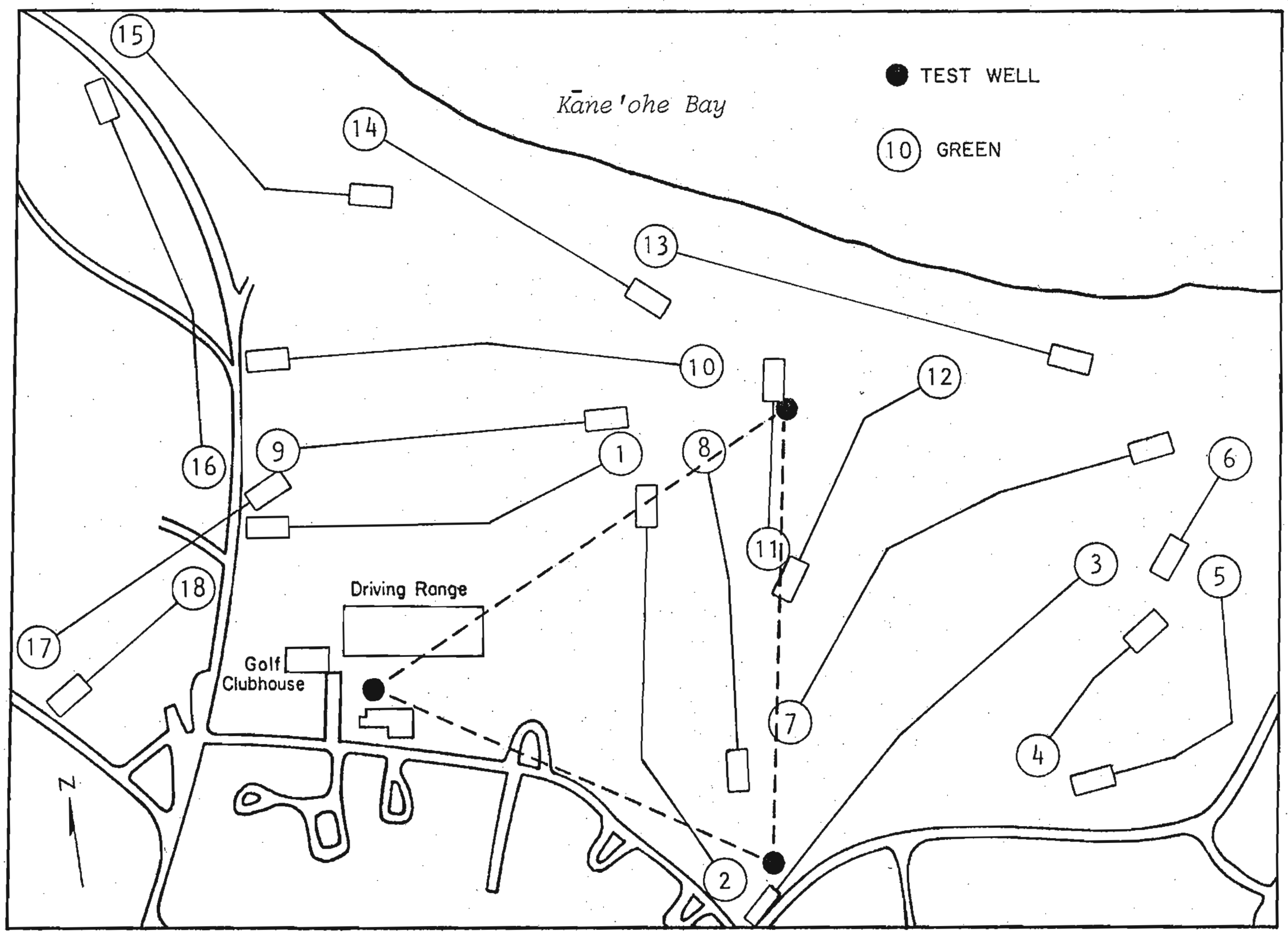

FIGURE 11. KMCAS KLIPPER GOLF COURSE AND GROUNDWATER TEST WELLS

TABLE 4. MEAN CONSTITUENT CONCENTRATION CHANGES BETWEEN KMCAS STP POND EFFLUENT AND KLIPPER GOLF COURSE SPRINKLER EFFLUENT

Constituent	Pond Effluent*	Sprinkler Effluent†	Percent Reduction
	-------(mg/ℓ)	--------	
NH_3-N	7.8	10.9	-28.4
Organic N	2.8	1.84	+34.3
NO_2 + NO_3-N	1.01	0.03	+97.0
Total N	11.39	12.75	-10.7
Total P	7.78	8.9	-12.6
K	20	22	- 9.0
Cl^-	475	329	+30.7

*Baseline values obtained from App. Tables B.3, B.6, B.8, and B.10.
†Baseline values obtained from App. Table C.4.

and nitrate concentration was decreased to 0.01 mg/ℓ. Apparently, denitrification occurs during the retention period. The force main is 1.6 km (1 mile) long and contains 117 m^3 (31,000 gal) of pond effluent. Therefore, only 11% of the total quantity of pond effluent (1,060 m^3 or 280,000 gal used for one night of irrigation) is retained in the force main for the 12-hr period.

The results of the groundwater sampling are listed in Appendix E. Two groundwater testing wells (Nos. 1 and 3) on the Klipper Golf Course are located in Ewa silty clay loam. Test Well 1 was the control well located outside the influence of the spray irrigation system and Test Well 3 was located in the area receiving waste water irrigation. Changes in groundwater quality were observed between Test Wells 1 and 3. Irrigation with waste water resulted in the increase of ammonia nitrogen (0.20 mg/ℓ), organic nitrogen (0.20 mg/ℓ), sodium (177 mg/ℓ), and chloride (10 mg/ℓ) in the groundwater (Table 5).

In Table 6, the change in constituent concentration can be noted with the passage of sewage effluent through the low humic latosol on the KMCAS golf course. Substantial decreases occurred for total nitrogen (98.2%), total phosphorus (100%), and fecal coliforms (100%). Similar results were obtained in the Mililani Recycling Project (King, Mill, and Lawrence 1973; Clark 1974; Metcalf and Eddy, Inc. 1972). The Mililani soil was also a low humic latosol (Lahaina series) in which nitrogen removal of 97.5 to 99.9% was attributed to: (1) sorption to the soil complex, (2) uptake by macro-

TABLE 5. MEAN CONSTITUENT CONCENTRATION CHANGE BETWEEN TEST WELL NOS. 1 AND 3 GROUNDWATER SAMPLES

Constituent	Test Well No. 1*	Test Well No. 2†	Net Increase
	(mg/ℓ)		
NH_3-N	0.10	0.30	+0.20
Organic N	0.43	0.63	+0.20
NO_2 + NO_3-N	0.26	0.16	-0.10
Total N	0.76	1.04	+0.28
Total P	0.66	0.11	-0.55
Cl^-	2087	2097	+10
Na	2041	2218	+177
K	90	82	-8
	(No./100 mℓ)		
Fecal Coliform	0	0	0

*Baseline values obtained from App. Table C.1.
†Baseline values obtained from App. Table C.2.

TABLE 6. MEAN CONSTITUENT CONCENTRATION CHANGE OF EFFLUENT THROUGH LOW HUMIC LATOSOLS ON THE KMCAS GOLF COURSE

Constituent	Pond Effluent*	Low Humic Latosols Perc. Qlty†	Percent Reduction
	(mg/ℓ)		
NH_3-N	10.9	0.20	+98.2
Organic N	1.84	0.20	+89.1
NO_2 + NO_3-N	0.03	--	+100
Total N	12.75	0.28	+97.8
Total P	8.9	--	+100
Cl^-	329	10	+97.0
Na	230	177	+23.0
K	22	--	+100
	(No./100 mℓ)		
Fecal Coliform	160	0	+100

*Baseline values obtained from App. Tables B.3, B.6, B.8, and B.10.
†Baseline values obtained from Table 5.

and microorganisms (including plants), (3) volatilization to ammonia gas at higher pH values, (4) biological oxidation (nitrification of ammonia to nitrate), and (5) denitrification (reduction of nitrates to nitrogen gas).

According to Lance (1972), a significant amount of the removal of nitrogen in soil can be attributed to denitrification and the adsorption of the ammonium ion. Denitrification of nitrate to nitrogen gas can occur in anaerobic pockets in the soil. The adsorption of the ammonium ion is not a stable condition because of biological oxidation which can occur, producing nitrates. However, the temporary adsorption can retain nitrogen in the root zone of the grass. This retention may provide substantial time for the uptake of nitrogen by the grass.

The removal of 99.7% of the phosphorus in the Mililani Recycling Project (Lau et al. 1975) was attributed to soil fixation and/or to uptake by plants (Goudy 1931; Butler, Orlob, and McGauhey 1954). The high fixing capacity of the Hawaiian latosols has been confirmed by Fox (1972). Taylor (1967) observed that phosphorus applied as fertilizer on a clay soil was converted to water-insoluble forms within a few hours.

In Table 7, the change in constituent concentrations can be observed when the sewage effluent passed through the regosol (Jaucas sand at Test Well 2). Losses between 77.2 and 100% of nitrogen, phosphorus, and fecal coliform occurred. The oxidation of ammonium ion to nitrate, as discussed by Lance (1972), accounts for some reduction in ammonia levels and the large increase of combined nitrite and nitrate nitrogen (0.3 mg/ℓ to 1.47 mg/ℓ). Movement of nitrates through the Jaucas sand appeared to be unrestricted as evidenced by the high concentration in the percolate. The high removal of nitrogen can be attributed to plant uptake, biological oxidation, volatilization of ammonia, and possible adsorption by the soil.

TABLE 7. MEAN CONSTITUENT CONCENTRATION CHANGE OF APPLIED EFFLUENT THROUGH JAUCAS SANDS (TEST WELL NO. 2) ON THE KMCAS GOLF COURSE

Constituent	Pond Effluent*	Perc. from Test Well† No. 2	Percent Reduction
	------(mg/ℓ)	---------	
NH_3-N	10.9	0.01	+99.1
Organic N	1.84	0.42	+77.2
NO_2 + NO_3-N	0.03	1.47	-98.0
Total N	12.75	1.82	+85.7
Total P	8.9	0.15	+98.4
Cl^-	329	447	-26.4
Na	230	306	-24.8
K	22	22	0
Fecal	---(No./100 mℓ)	------	
Coliform	160	--	+100

*Baseline values obtained from App. Tables B.3, B.6, B.8, and B.10.
†Baseline values obtained from App. Table C.2.

Phosphorous removal for the Flushing Meadows Project (Bouwer, Lance, and Riggs 1974) was due to the precipitation of calcium phosphate compounds, ammonium magnesium phosphate, and other insoluble compounds because the sand and gravels of the infiltration basin contained no iron and aluminum oxides or other phosphate-fixing material. The high removal of 98.4% phosphorus at Test Well 2 (Jaucas sand) may be due to the alkaline character of the soil attributed to such precipitation as well as plant uptake. However, the short distance of percolate travel (3m [9.9 ft]) is suggestive that phosphorous fixing occurred. In the Flushing Meadows Project, at least 91 m (300 ft) of underground travel was required for 90% removal of phosphorus.

Percolate from the two test wells in the spray irrigation area (Test Wells 2 and 3) contained no fecal coliform bacteria. During the 3-mo. period of analysis (March, April, and May), no fecal coliform organism was isolated from the test wells. These results are comparable to the Flushing Meadows and Mililani projects. Surface straining and adsorption are probably the mechanisms for the removal of fecal coliform bacteria.

Air Quality

The sampling procedure for air quality was very simple. However, the technique was excellent for the collection of air samples in a short time period. Between five and seven air samples could be collected at varying downwind distances from the green being sprayed with effluent. Alternative sampling methods (vacuum and impinger systems) were too bulky and the sampler set-up time too long. This would result in only one air sample collection at each green.

The agar plate air sampling method was selected because of its simplicity, versatility, and effectiveness. M-Endo agar culture media was selected for air sampling. This media provided the recovery of total coliform bacteria that was settling out of the atmosphere. The total coliform bacterial media was selected over fecal coliform media because of the high concentration of total coliform bacteria (15,000 and 400,000 colonies/100 mℓ) in the effluent increased the probability of isolating bacterial aerosols from the spray irrigation. The low concentration of fecal coliform bacteria (20 to 420 colonies/100 m) did not assure the positive recovery of bacterial aerosols.

Air quality analysis at the KMCAS golf course was performed during the early evening hours of June 1976. The meteorological and environmental conditions, during each of the sampling periods, are listed Table 8. The conditions existing at the golf course, during the spray irrigation, were considered to be the optimal conditions for the survival of bacterial aerosols. Adams and Spendlove (1970) obtained the greatest recoveries of bacterial aerosols during periods of high relative humidity, low temperature, high wind velocities, and darkness. Solar radiation during the daylight hours had a deleterious effect on the recovery rates of coliforms. Twilight and evening operation of the sprinkler system eliminated the adverse effect of solar radiation. Clark (1974) also noted that ultraviolet radiation in sunlight may result in the higher death rate of bacteria.

The results of air sampling are reported in Table 9. This actually represents the fallout concentration of coliform bacterial aerosols and not of the concentration of bacteria in the air. The coliform bacteria isolated on the agar dishes are those that are settling out of the atmosphere. A zero colony isolation for this study does not necessarily mean the nonexistence of coliform bacterial aerosols.

The graphical relationship between agar dish densities of total coliform bacteria and the downwind distances from the sprinkler sources are in Figures 12 to 15. No distinct pattern of bacterial fallout is discernable in the graphs. Variations in wind velocities and initial coliform densities (from the sprinkler effluent) resulted in varying recovery rates of the coliform bacteria.

Data plots were normalized in an attempt to dampen the effects of the varied initial coliform concentrations. The highest coliform plate density collected for each sampling set was assigned a value of 100%. This reference plate assignment was independent of the downwind distance from the sprinkler source because the highest plate density occurred at varying downwind distances. All the other coliform plate densities, for the respective set, were then assigned a percentage with respect to the reference plate. Table 10 lists the results of the normalized data.

The normalized air quality data was plotted with respect to the downwind distances (Figs. 16 to 19). In Appendix D, the graphs were grouped with respect to the various initial effluent coliform concentrations (15,000 to 20,000 colonies/100 mℓ, 46,000 colonies/100 mℓ, and 319,000 to 400,000 colonies/100 mℓ). Appendix E presents the normalized data with respect to the varying wind velocities (0 to 8 kn, 9 to 12 kn, and 13 to 18 kn). In all

TABLE 8. METEOROLOGICAL, ENVIRONMENTAL, AND BACTERIOLOGICAL CONDITIONS DURING AIR SAMPLING ON THE KMCAS KLIPPER GOLF COURSE

Date (1976)	Time* (PM)	Green (No.)	Temp. (°F)	Rel. Humidity (%)	Wind Vel. and Range (kn)	Wind Dir.	Total Coliform† (#/100 mℓ)
June 9	6:45	16	75	76	10 9-12	ENE	15,000
June 9	7:30	2	75	76	2 1-8	ENE	15,000
June 10	6:45	16	76	69	7 6-8.5	ENE	16,000
June 10	7:00	15	76	69	10 8-11	ENE	16,000
June 11	6:20	PG‡	76	66	4 3-5	ENE	17,000
June 11	6:45	16	76	66	4 3-5	ENE	17,000
June 11	7:00	15	76	66	4 3-5	ENE	17,000
June 12	6:20	PG‡	76	69	4 3-5	ENE	319,000
June 12	7:00	15	76	69	5 5-7	ENE	319,000
June 14	6:20	PG‡	76	79	9 8-11	ENE	46,000
June 14	6:45	16	76	79	9 8-11.5	ENE	46,000
June 14	7:00	15	76	79	10 9-13	ENE	46,000
June 14	7:30	2	76	79	7 6-9.5	ENE	46,000
June 16	6:20	PG‡	75	87	10 9-14.5	ENE	400,000
June 16	6:45	16	75	87	10 9-14.5	ENE	400,000
June 16	7:00	15	75	87	14 12-18	ENE	400,000
June 16	7:30	2	75	87	9 7-13	ENE	400,000

*Starting time for the 15-min spray irrigation of the greens.
†Initial concentration found in the sprinkler effluent.
‡Putting green.

TABLE 9. AIR SAMPLING RESULTS OF AEROSOLIZED COLIFORM BACTERIA COLLECTED AT THE KMCAS KLIPPER GOLF COURSE

Date (1976)	Time (PM)	Green (No.)	Upwind Control	Downwind Distance[1] (in ft) -75	-100	-125	-150	-200	-250	-300
				(No. total coliform colonies/plate)						
June 9	6:45	16	0	4	2	*	0	0	0	0
June 9	7:30	2	0	7	1	*	0	0	*	*
June 10	6:45	16	0	2	1	2	3	2	0	*
June 10	7:00	15	0	15	13	0	0	*	*	*
June 11	6:20	PG†	0	*	1	0	*	*	*	*
June 11	6:45	16	0	10	3	10	0	1	0	1
June 11	7:00	15	0	9	7	2	0	4	*	*
June 12	6:20	PG†	0	5	5	2	2	0	1	0
June 12	6:45	16	0	4	5	12	2	2	5	1
June 12	7:00	15	0	64	24	19	7	5	*	*
June 14	6:20	PG†	0	11	6	8	8	2	10	0
June 14	6:45	16	0	37	42	80	43	21	10	6
June 14	7:00	15	0	311	86	36	4	14	*	*
June 14	7:30	2	0	107	25	25	12	7	*	*
June 16	6:20	PG†	0	12	10	8	5	3	2	1
June 16	6:45	16	0	77	36	38	38	35	13	8
June 16	7:00	15	0	109	*	1	2	25	*	*
June 16	7:30	2	0	86	75	95	21	15	*	*

[1]From sprinkler source.
*No sample collected
†Putting green.

TABLE 10. NORMALIZED DATA FOR THE AIR SAMPLING AT THE KMCAS KLIPPER GOLF COURSE

Date (1976)	Green (No.)	Downwind Distance (in ft) -75	-100	-125	-150	-200	-250	-300
June 9	16	100	50	*	0	0	0	0
June 9	2	100	14	*	0	0	*	*
June 10	16	67	33	67	100	67	0	*
June 10	15	100	87	0	0	*	*	*
June 11	PG†	*	100	0	*	*	*	*
June 11	16	100	30	100	0	10	0	10
June 11	15	100	78	22	0	44	*	*
June 12	PG†	100	100	40	40	0	20	0
June 12	16	33	42	100	17	17	42	8
June 12	15	100	38	30	27	8	*	*
June 14	PG†	100	55	73	73	18	91	0
June 14	16	46	53	100	54	26	13	8
June 14	15	100	28	12	1	5	*	*
June 14	2	100	23	23	11	7	*	*
June 16	PG†	100	83	67	42	25	17	8
June 16	16	100	48	49	49	45	17	10
June 16	15	100	*	1	2	23	*	*
June 16	2	91	80	100	22	16	*	*

*No sample collected.
†Putting green.

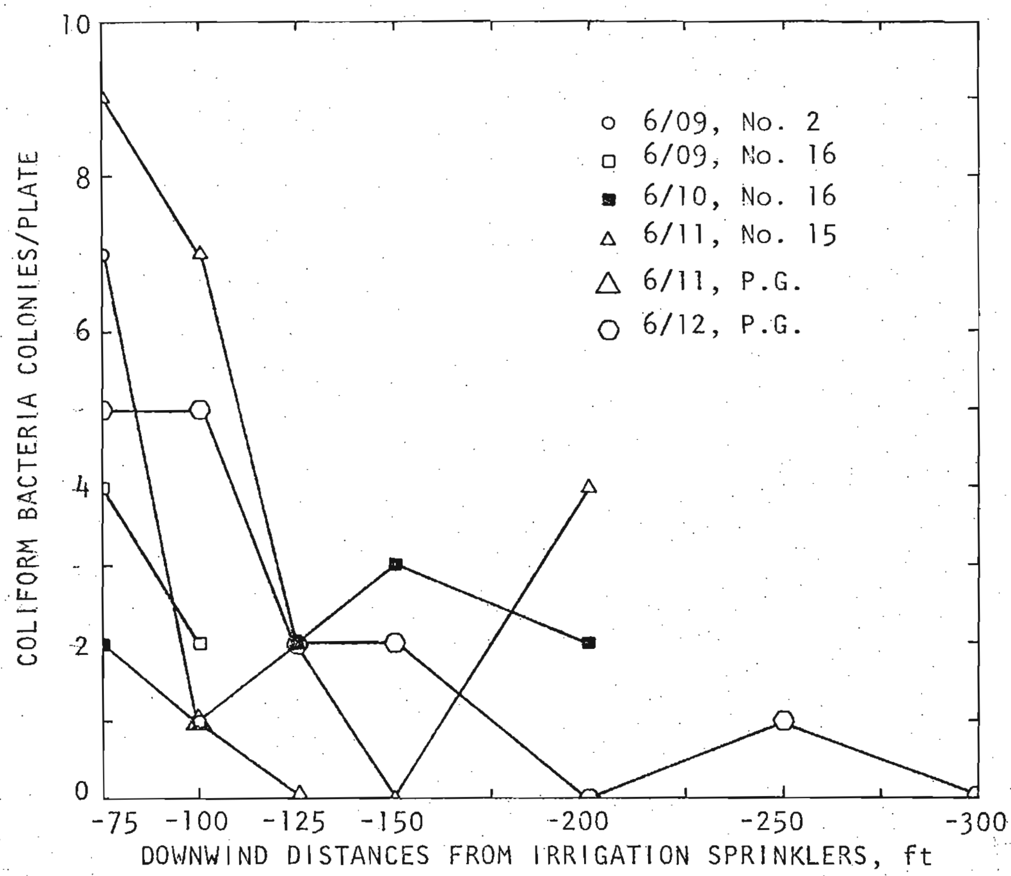

FIGURE 12. COLIFORM BACTERIA DENSITIES DOWNWIND OF SPRAY IRRIGATION SOURCE

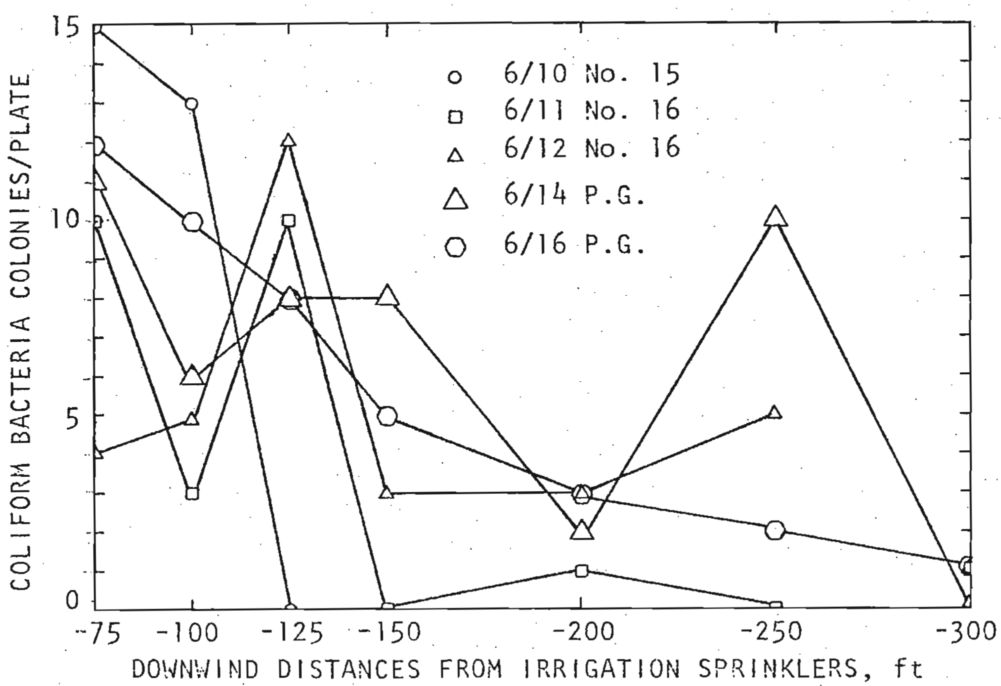

FIGURE 13. COLIFORM BACTERIA DENSITIES DOWNWIND OF SPRAY IRRIGATION SOURCE

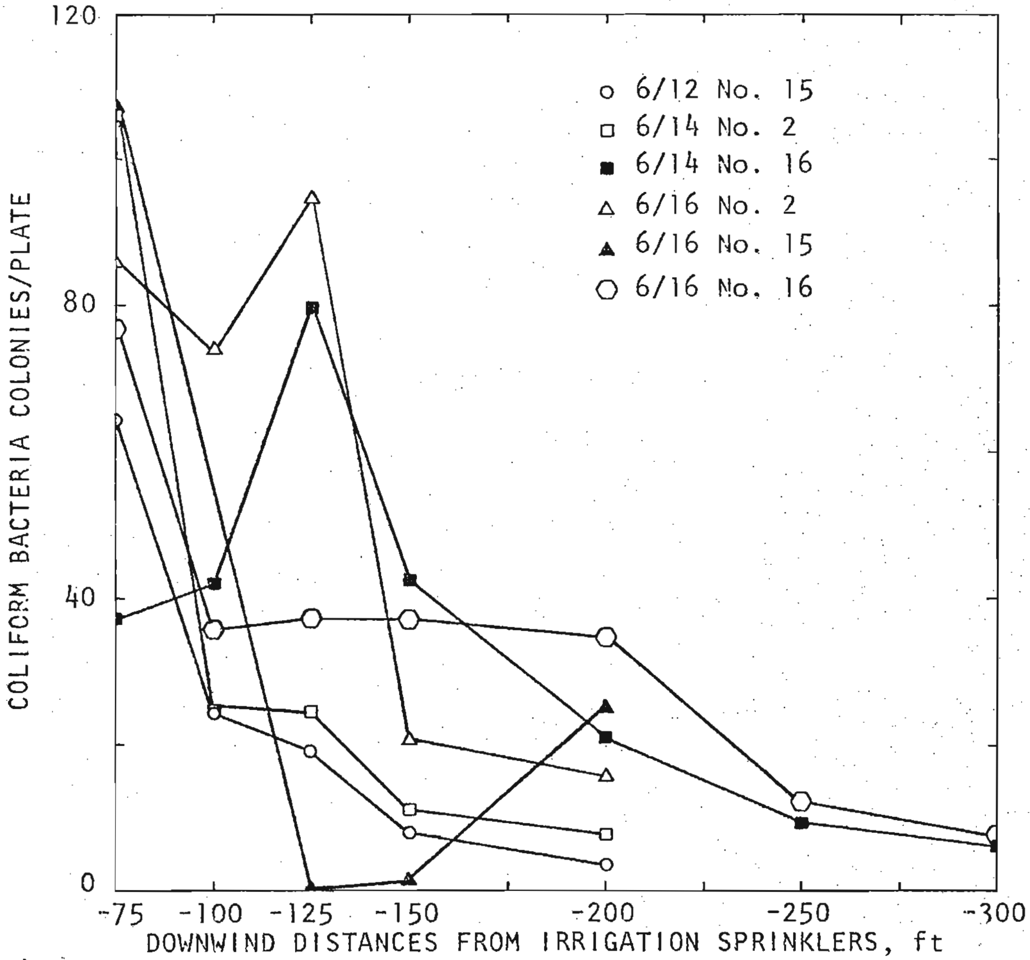

FIGURE 14. COLIFORM BACTERIA DENSITIES DOWNWIND OF A SPRAY IRRIGATION SOURCE

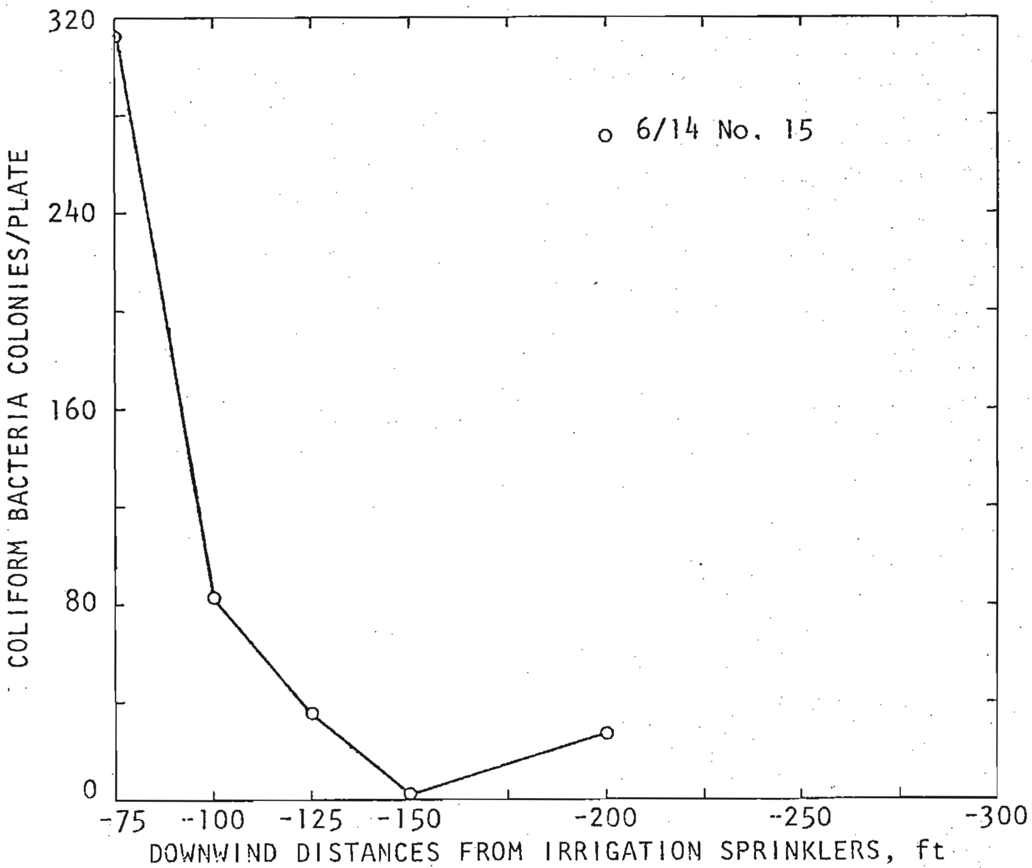

FIGURE 15. COLIFORM BACTERIA DENSITIES DOWNWIND OF A SPRAY IRRIGATION SOURCE

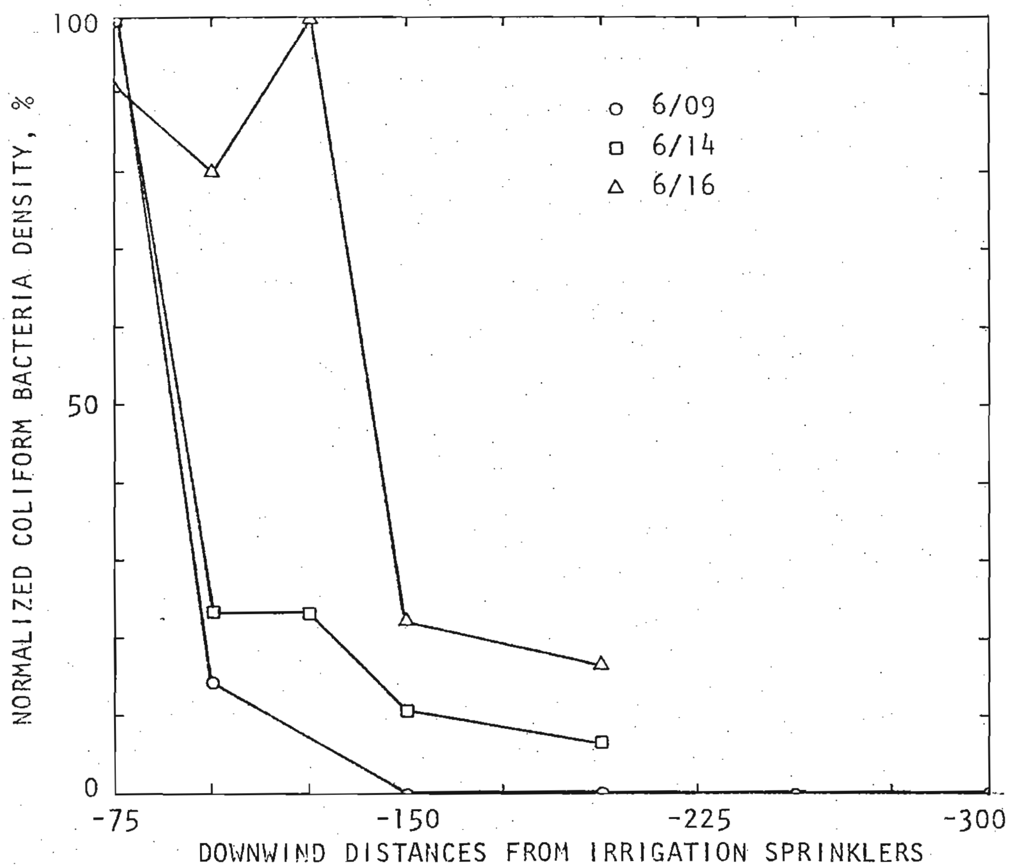

FIGURE 16. NORMALIZED AIR QUALITY DATA FOR THE NO. 2 GREEN

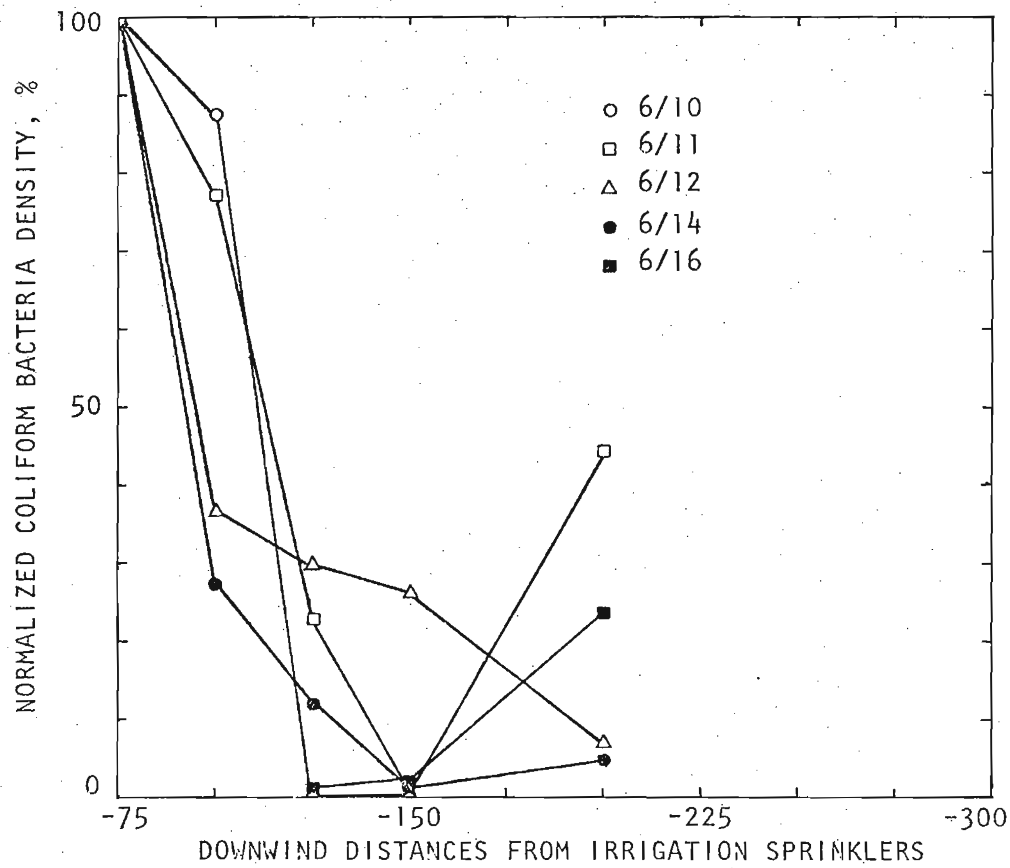

FIGURE 17. NORMALIZED AIR QUALITY DATA FOR THE NO. 15 GREEN

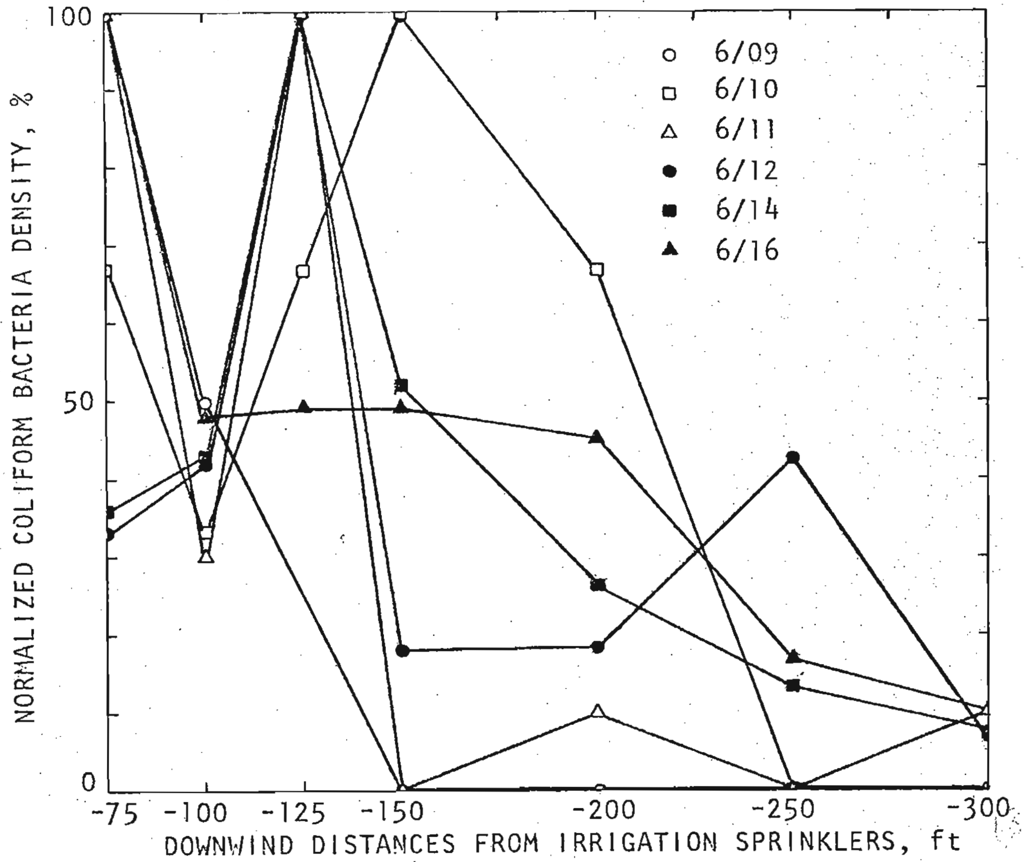

FIGURE 18. NORMALIZED AIR QUALITY DATA FOR THE NO. 16 GREEN

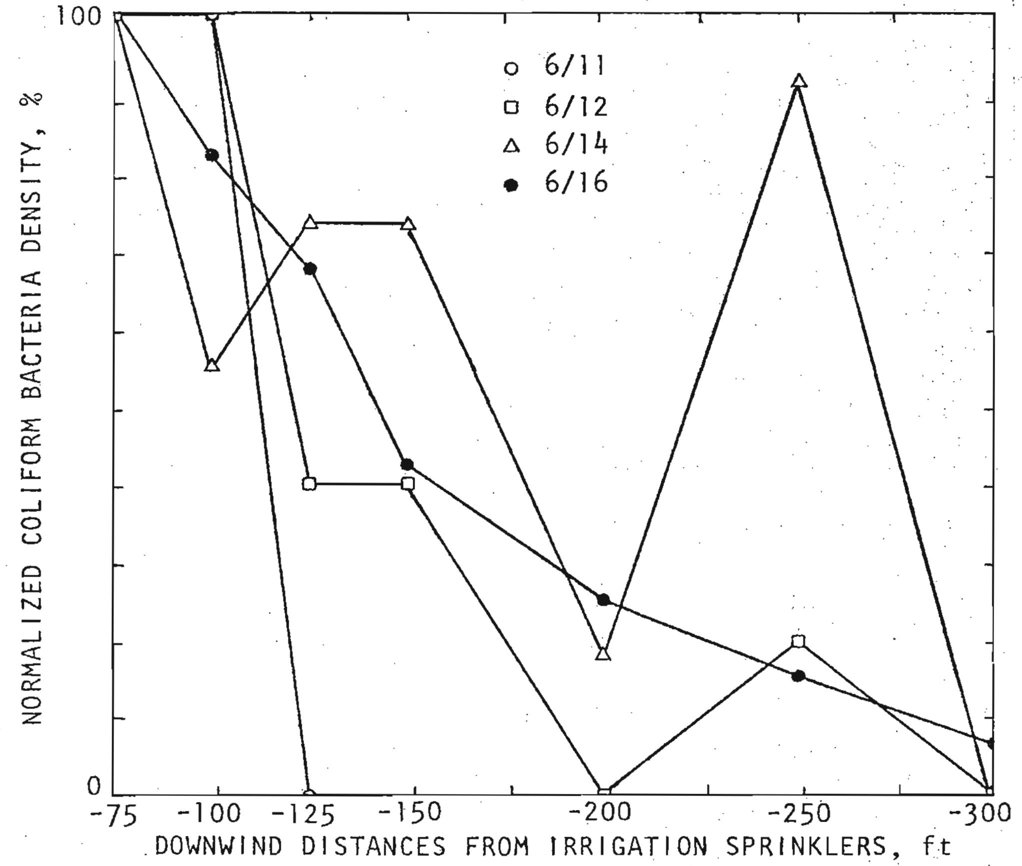

FIGURE 19. NORMALIZED AIR QUALITY DATA FOR THE PUTTING GREEN

three cases, there was still no distinct pattern in the distribution of aerosols containing coliform bacteria. However, general trends can be observed in the normalized curves. An approximately 90% decrease in coliform bacteria concentration was observed within 91 m downwind of sprinkler heads. Wind velocities during the air sample collection affected the recovery patterns. Wind velocity ranges of 0 to 8 kn (low) and 13 to 18 kn (high) resulted in a rapid decrease in bacterial aerosols within 46 m (150 ft) downwind of the sprinklers. The mid-range wind velocity (9 to 12 kn) did not appear to follow the pattern. It is possible that, between 9 and 12 kn, more irregular "gusting" may occur. This could result in the "masking" of the normal settling pattern of the bacteria.

The presence of aerosols containing pathogenic organisms can only be implied by this study. The presence of aerosols of coliform bacteria may or may not be indicative of the presence of pathogens in these aerosols. However, even the presence of coliform bacteria in the air poses a very serious question: is the continued use of the KMCAS STP effluent for spray irrigation on the golf course safe?

The health hazards from the spray irrigation system must be similar to that from other systems that generate aerosolized coliform bacteria. In past studies, activated sludge and trickling filter plants have been examined, and found to be positive, for the emission of aerosols of coliform bacteria (Ledbetter and Randall 1965; Adams and Spendlove 1970; King, Mill, and Laurence 1973).

From the present air sampling results at the KMCAS Klipper Golf Course, three observations can be made:

1. Aerosols of coliform bacteria can be found at least 91 m downwind from the spray irrigation sprinkler source.
2. Higher concentrations of coliform bacteria in the sprinkler effluent resulted in recovery of a greater concentration of aerosolized bacteria and at greater distances from the source.
3. The downwind transport of aerosolized coliform bacteria was dependent on wind velocity. Higher wind velocities for a similar effluent concentration of coliform bacteria resulted in the isolation of bacteria at greater distances from the source.

The results of the air quality analysis were obtained at the optimum condition (high relative humidity, high wind velocities, darkness, and mild temperatures) for the recovery of bacteria emitted by spray irrigation with sewage effluent; therefore, this probably represents the extreme condition for public health and safety. However, at this extreme condition, the levels and range of indicator bacterial emissions from the KMCAS spray irrigation system are still lower than those reported for most trickling filter and activated sludge units at waste water treatment plants. The incidence of disease directly due to bacterial aerosols to sewage treatment plant workers has not been reported in the literature (Hickey and Reist 1975). On this basis, the continued use of sewage effluent for spray irrigation at the KMCAS Klipper Golf Course should not be considered a health hazard.

CONCLUSIONS

The following conclusions may be drawn from the results of this study:

1. The KMCAS raw sewage is a weak sewage of fairly consistent quality
2. The KMCAS sewage treatment plant achieves a high overall efficiency through its biological process and final polishing pond
3. Settling of organic matter and the biological uptake resulted in the decrease of BOD_5, suspended solids, and organic nitrogen in the KMCAS STP polishing pond
4. The quality of the effluent from the KMCAS STP appears to be a good source of irrigation water for the KMCAS Klipper Golf Course
5. The effective removal of nitrogen, phosphorus, and fecal coliform bacteria on the KMCAS golf course can be attributed to the bermudagrass soil cover, the Ewa silty clay (low humic latosol soil group), and the Jaucas sand (regosols soil group)
6. On the basis of nitrogen, phosphorus, and fecal coliform bacteria, the quality of the percolate from the effluent-irrigated golf course soil does not detrimentally alter the quality of the groundwater.
7. On the basis of total Kjeldahl nitrogen, combined nitrate and nitrite nitrogen, and total phosphorus, the quality of runoff from the KMCAS golf course is not a source of contamination for the adjacent surface waters
8. Airborne coliform bacteria were isolated up to 91 m downwind of various effluent sprinkler sources. Higher concentrations of coliform bacteria in the sprinkler effluent resulted in greater recovery of bacterial aerosols and at farther distances downwind from the

source. Coliform bacteria density downwind from the source was also dependent on wind velocity.

9. The reuse of sewage effluent for the spray irrigation of the KMCAS golf course is an effective method of waste water disposal and can be continued, as well as expanded, to other areas of the KMCAS.

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APPENDICES

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TABLES

APPENDIX A. KMCAS GOLF COURSE SOIL DESCRIPTIONS

APPENDIX TABLE A.1. SOIL DESCRIPTIONS OF THE KMCAS KLIPPER GOLF COURSE, MŌKAPU PENINSULA, OAHU

Ewa Series[1]

Location: Test Well No. 3 Classification: Mollisols, Torroxic Haplustolls (Low Humic Latosols)

Description: This series consists of well-drained soils in basins and on alluvial fans on the island of Oahu. These soils developed in alluvium derived from basic igneous rock. They are nearly level to moderately sloping.

Ewa Silty Clay Loam, moderately shallow, 0 to 2% (EmA) and 2 to 6% (EmB) slopes. In a representative profile, the subsurface layer is dark reddish-brown silty clay loam about 46 cm (18 in.) thick. The subsoil, about 107 cm (42 in.) thick, is dark reddish-brown and dark red silty clay loam with subangular blocky structure. The substratum is coral limestone, sand, and gravelly alluvium. Permeability is moderate, runoff is slow, and the erosion hazard is slight. The depth to coral limestone is 51 to 127 cm (20 to 50 in.) deep.

The underlying materials had the following properties: 0 to 152 cm (0 to 60 in.), dark reddish-brown silty clay loam, dark reddish-brown when dry; cloddy, breaking to weak, fine, and very fine granular structure; hard, friable, sticky and plastic; abundant fine and very fine roots. 152 to 457 cm (60 to 180 in.), silty clay loam, dark red; fine subangular blocky structure; hard, friable, sticky and plastic; fine tubular pores; sand grains.

Jaucas Series

Location: Test Well No. 2 Classification: Entisols, Typic Ustipsamments (Regosols)

Description: This series consists of excessively-drained, calcareous soils that occur as narrow strips on coastal plains, adjacent to the ocean. They developed in wind- and water-deposited sand from coral and seashells.

Jaucas Sand, 0 to 15% slopes. In a representative profile, the soil is single grained, pale brown to very pale brown, sandy, and more than 3 m (11 ft) deep. In many places the surface layer is dark brown as a result of accumulation of organic matter and alluvium. The soil is neutral to moderately alkaline throughout the profile. Permeability is rapid, and runoff is very slow to slow. The hazard of water erosion is slight but wind erosion is a severe hazard where vegetation has been removed. Workability is slightly difficult because the soil is loose and lacks stability for use of equipment.

The underlying materials had the following properties: 0 to 30 cm (0 to 12 in.), pale brown sand, light yellowish-brown when dry; single-grained, loose, nonsticky and nonplastic; and plentiful roots. 30 to 61 cm (24 in.), light yellowish-brown sand, very pale brown when dry; single-grained, loose, nonsticky and nonplastic; and few roots. 61 to 274 cm (108 in.), very pale brown sand; single-grained; loose, nonsticky and nonplastic. 274 to 335 cm (132 in.), very plae brown sand; moist, single-grained; loose, nonsticky and nonplastic. 335 to 351 cm (138 in.), very pale brown sand, organic matter, and alluvium; moist granular clay; firm, sticky and plastic.

APPENDIX TABLE A.1—CONTINUED

	Mokuleia Series
Classification:	Mollisols, Typic Haplustolls (Alluvial)
Description:	This series consists of well-drained soils along the coast of Oahu. These soils are formed in recent alluvium deposited over coral sand. They are shallow and nearly level.
Mokuleia Clay	Loam (Mt). In a representative profile, the surface layer is very dark grayish-brown clay loam about 41 cm (16 in.) thick. The next layer, 86 cm (34 in.) to more than 122 cm (48 in.) thick, is dark brown and light gray, single-grained sand and loamy snad. Permeability is moderate in the surface layer and rapid in the subsoil. Runoff is very slow, and the erosion hazard is more than slight.
	Makalapa Series
Classification:	Vertisols, Typic Chromusterts (Dark Magnesium Clays)
Description:	This series consists of well-drained soils on uplands of the Mōkapu Peninsula. These soils are formed in volcanic tuff. They are gently sloping to moderately steep.
Makalapa Clay,	6 to 12% slopes (MdC). In a representative profile the surface layer is very dark grayish-brown clay about 20 cm (8 in.) thick. The next layer, 20 to 91 cm (36 in.) thick, is very dark grayish-brown clay to silty clay loam with subangular blocky structure. It is underlain by light gray to dark grayish-brown, weathered volcanic tuff. The clays are very sticky and very plastic, and crack widely upon drying. Permeability is slow; runoff is slow to medium; the erosion hazard is slight to moderate. Workability is difficult because the clay is very sticky and very plastic; the shrink-swell potential is high.
	Fill Land (FL)
Description:	This land type occurs mostly near the ocean. It consists of areas filled with material dredged from the ocean or hauled from nearby areas and general material from other sources. Generally, these materials are dumped and spread over marshes, low-lying areas along the coastal flats, coral sand, coral limestone, or areas shallow to bedrock.

[1]Foote et al. (1972).

APPENDIX B. WASTE WATER QUALITY ANALYSIS, KMCAS STP

APPENDIX TABLE B.1. MEANS, STANDARD DEVIATIONS, MEDIANS, MINIMUMS, AND MAXIMUMS OF WATER QUALITY PARAMETERS OF 24-HR RAW SEWAGE COMPOSITE, 8-9 OCTOBER 1975, KĀNE'OHE MARINE CORPS AIR STA. STP

Constituent	No. of Samples	Mean (mg/ℓ)	Std. Dev.	Median	Mini-mum	Maxi-mum
				(mg/ℓ)		
TDS	--	--	--	--	--	--
SS	24	110	± 71	100	74	264
BOD_5	24	102	± 38	105	44	204
NH_3-N	23	12.7	± 3.7	12.9	5.0	19.4
Organic N	24	6.7	± 2.3	7.3	2.5	10.6
NO_2 + NO_3-N	24	0.02	± 0.02	0.02	0	0.08
Total N	23	19.54	± 5.34	20.97	2.83	29.68
Total P	24	7.19	± 2.76	7.67	2.32	11.47
Na	--	--	--	--	--	--
K	--	--	--	--	--	--
Cl^-	24	596	±181	540	370	950
SO_4	--	--	--	--	--	--

APPENDIX TABLE B.2. MEANS, STANDARD DEVIATIONS, MEDIANS, MINIMUMS, AND MAXIMUMS OF WATER QUALITY PARAMETERS OF 24-HR SECONDARY EFFLUENT COMPOSITE, 8-9 OCTOBER 1975, KĀNE'OHE MARINE CORPS AIR STA. STP

Constituent	No. of Samples	Mean (mg/ℓ)	Std. Dev.	Median	Mini-mum	Maxi-mum
				(mg/ℓ)		
TDS	-	--	--	--	--	--
SS	6	19	± 2	19	15	21
BOD_5	6	18	± 3	18	13	21
NH_3-N	6	5.5	± 1.1	5.9	3.6	6.6
Organic N	6	2.7	± 0.5	2.9	1.8	3.1
NO_2 + NO_3-N	6	4.15	± 0.30	3.99	3.89	4.66
Total N	6	12.37	± 1.23	12.79	10.06	13.64
Total P	6	7.94	± 0.38	7.94	7.76	8.13
Na	-	--	--	--	--	--
K	-	--	--	--	--	--
Cl^-	6	472	±54	470	370	510
SO_4	-	--	--	--	--	--

APPENDIX TABLE B.3. MEANS, STANDARD DEVIATIONS, MEDIANS, MINIMUMS, AND MAXIMUMS OF WATER QUALITY PARAMETERS OF 24-HR POND EFFLUENT COMPOSITE, 8-9 OCTOBER 1975, KĀNE'OHE MARINE CORPS AIR STA. STP

Constituent	No. of Samples	Mean (mg/ℓ)	Std. Dev.	Median	Minimum	Maximum
				-----------	(mg/ℓ)	---------
TDS	--	--	--	--	--	--
SS	24	8	± 3	10	3	13
BOD_5	24	12	± 3	13	3	17
NH_3-N	18	5.9	± 0.5	6.0	5.0	6.9
Organic N	18	3.6	± 1.5	2.9	2.2	6.9
NO_2 + NO_3-N	24	1.68	± 0.30	1.72	0.88	2.07
Total N	24	10.51	± 0.61	10.47	9.37	11.95
Total P	24	8.16	± 0.36	8.08	7.34	9.01
Na	--	--	--	--	--	--
K	--	--	--	--	--	--
Cl^-	24	468	±30	480	420	510
SO_4	--	--	--	--	--	--

APPENDIX TABLE B.4. MEANS, STANDARD DEVIATIONS, MEDIANS, MINIMUMS, AND MAXIMUMS OF WATER QUALITY PARAMETERS OF 24-HR RAW SEWAGE COMPOSITE, 20-21 NOVEMBER 1975, KĀNE'OHE MARINE CORPS AIR STA. STP

Constituent	No. of Samples	Mean (mg/ℓ)	Std. Dev.	Median	Minimum	Maximum
				-----------	(mg/ℓ)	----------
TDS	--	--	--	--	--	--
SS	24	114	± 92	104	20	332
BOD	24	123	± 58	124	40	261
NH_3-N	24	15.2	± 2.9	14.8	9.2	21.0
Organic N	24	9.3	± 4.2	8.6	2.8	20.4
NO_2 + NO_3-N	24	0.02	± 0.01	0.02	0.01	0.05
Total N	24	24.54	± 6.86	23.32	12.01	41.43
Total P	24	8.00	± 2.77	8.83	3.00	14.75
Na	--	--	--	--	--	--
K	--	--	--	--	--	--
Cl^-	24	444	±156	420	240	840
SO_4	--	--	--	--	--	--

APPENDIX TABLE B.5. MEANS, STANDARD DEVIATIONS, MEDIANS, MINIMUMS, AND MAXIMUMS OF WATER QUALITY PARAMETERS OF 24-HR SECONDARY EFFLUENT COMPOSITE, 20-21 NOVEMBER 1975, KĀNE'OHE MARINE CORPS AIR STA. STP

Constituent	No. of Samples	Mean (mg/ℓ)	Std. Dev.	Median	Minimum	Maximum
				---(mg/ℓ)---		
TDS	-	--	--	--	--	--
SS	6	25	± 7	26	17	36
BOD_5	-	--	--	--	--	--
NH_3-N	6	8.3	± 0.7	8.5	7.0	9.2
Organic N	6	3.2	± 0.5	3.3	2.4	3.8
$NO_2 + NO_3$-N	6	1.46	± 0.18	1.38	1.31	1.78
Total N	6	12.99	± 0.73	13.16	11.61	13.66
Total P	6	7.41	± 0.49	7.62	6.73	7.93
Na	-	--	--	--	--	--
K	-	--	--	--	--	--
Cl^-	6	482	±35	480	440	520
SO_4	-	--	--	--	--	--

APPENDIX TABLE B.6. MEANS, STANDARD DEVIATIONS, MEDIANS, MINIMUMS, AND MAXIMUMS OF WATER QUALITY PARAMETERS OF 24-HR POND EFFLUENT COMPOSITE, 20-21 NOVEMBER 1975, KĀNE'OHE MARINE CORPS AIR STA. STP

Constituent	No. of Samples	Mean (mg/ℓ)	Std. Dev.	Median	Minimum	Maximum
				---(mg/ℓ)---		
TDS	--	--	--	--	--	--
SS	12	10	±2	9	8	15
BOD_5	--	--	--	--	--	--
NH_3-N	12	8.3	±0.3	8.3	7.8	8.7
Organic N	12	2.4	±0.2	2.4	2.1	2.7
$NO_2 + NO_3$-N	12	0.50	±0.01	0.50	0.40	0.59
Total N	12	11.17	±0.22	11.21	10.84	11.54
Total P	12	7.49	±0.45	7.50	7.10	8.00
Na	--	--	--	--	--	--
K	--	--	--	--	--	--
Cl^-	12	491	±9	490	480	500
SO_4	--	--	--	--	--	--

APPENDIX TABLE B.7. MEANS, STANDARD DEVIATIONS, MEDIANS, MINIMUMS, AND MAXIMUMS OF WATER QUALITY PARAMETERS OF 24-HR RAW SEWAGE COMPOSITE, 11-12 FEBRUARY 1975, KĀNE'OHE MARINE CORPS AIR STA. STP

Constituent	No. of Samples	Mean (mg/ℓ)	Std. Dev.	Median	Mini- mum	Maxi- mum
				-----------	(mg/ℓ)	----------
TDS	--	--	--	--	--	--
SS	24	115	± 68	97	30	341
BOD_5	24	113	± 42	119	42	189
NH_3-N	24	13.8	± 5.7	12.9	3.9	26.3
Organic N	24	8.6	± 3.4	8.4	3.9	20.2
NO_2 + NO_3-N	24	0.03	± 0.02	0.02	0.01	0.03
Total N	24	22.4	± 8.26	21.96	8.92	42.03
Total P	24	7.64	± 2.05	7.85	4.19	11.07
Na	--	--	--	--	--	--
K	--	--	--	--	--	--
Cl^-	24	485	±143	460	300	900
SO_4	--	--	--	--	--	--

APPENDIX TABLE B.8. MEANS, STANDARD DEVIATIONS, MEDIANS, MINIMUMS, AND MAXIMUMS OF WATER QUALITY PARAMETERS OF 24-HR POND EFFLUENT COMPOSITE, 11-12 FEBRUARY 1975, KĀNE'OHE MARINE CORPS AIR STA. STP

Constituent	No. of Samples	Mean (mg/ℓ)	Std. Dev.	Median	Mini- mum	Maxi- mum
				-----------	(mg/ℓ)	----------
TDS	-	--	--	--	--	--
SS	5	7	± 1	7	6	8
BOD_5	5	11	± 1	11	9	13
NH_3-N	5	8.4	± 0.2	8.5	8.1	8.7
Organic N	5	2.2	± 0.2	2.1	2.1	2.5
NO_2 + NO_3-N	5	1.02	± 1.5	1.04	0.84	1.23
Total N	5	11.66	± 0.36	11.66	11.14	12.03
Total P	5	7.36	± 0.62	7.00	6.77	8.05
Na	-	--	--	--	--	--
K	-	--	--	--	--	--
Cl^-	5	490	±10	490	480	500
SO_4	-	--	--	--	--	--

APPENDIX TABLE B.9. MEANS, STANDARD DEVIATIONS, MEDIANS, MINIMUMS, AND MAXIMUMS OF WATER QUALITY PARAMETERS OF 24-HR RAW SEWAGE COMPOSITE, 12-13 JULY 1976, KĀNE'OHE MARINE CORPS AIR STA. STP

Constituent	No. of Samples	Mean (mg/ℓ)	Std. Dev.	Median	Mini-mum	Maxi-mum
				-----------	(mg/ℓ)	-----------
TDS	24	1227	±366	1124	656	2212
SS	24	106	± 65	106	31	326
BOD_5	24	127	± 55	132	44	260
NH_3-N	24	13.6	± 4.2	13.4	4.5	23.5
Organic N	24	7.4	± 2.5	8.4	2.8	10.6
NO_2 + NO_3-N	24	0.01	± 0.01	0.01	0.00	0.05
Total N	24	21.06	± 5.95	21.56	7.31	32.52
Total P	24	6.11	± 2.57	6.62	1.54	9.85
Na	24	351	±115	316	223	643
K	24	25	± 4	22	22	33
Cl^-	24	478	±155	326	313	851
SO_4	24	113	± 25	106	81	192

APPENDIX TABLE B.10. MEANS, STANDARD DEVIATIONS, MEDIANS, MINIMUMS, AND MAXIMUMS OF WATER QUALITY PARAMETERS OF 24-HR POND EFFLUENT COMPOSITE, 12-13 JULY 1976, KĀNE'OHE MARINE CORPS AIR STA. STP

Constituent	No. of Samples	Mean (mg/ℓ)	Std. Dev.	Median	Mini-mum	Maxi-mum
				-----------	(mg/ℓ)	-----------
TDS	24	1103	±30	1109	996	1147
SS	24	12	± 2	13	8	14
BOD_5	24	8	± 4	9	3	15
NH_3-N	16	8.6	± 0.5	8.6	8.0	9.3
Organic N	16	2.8	± 0.5	2.6	2.5	4.6
NO_2 + NO_3-N	24	0.85	± 0.11	0.83	0.67	1.10
Total N	16	12.21	± 0.61	12.22	11.25	13.65
Total P	12	8.09	± 0.59	7.99	7.08	9.31
Na	--	--	--	--	--	--
K	12	20	± 0.6	20	19	21
Cl^-	24	450	± 7	450	440	460
SO_4	12	97	± 7	96	92	120

APPENDIX C. GROUNDWATER QUALITY ANALYSIS, KMCAS KLIPPER GOLF COURSE

APPENDIX TABLE C.1. MEANS, STANDARD DEVIATIONS, MEDIANS, MINIMUMS, AND MAXIMUMS OF WATER QUALITY PARAMETERS OF GROUNDWATER TEST WELL NO. 1, KMCAS GOLF COURSE

Constituent	No. of Samples	Mean	Std. Dev.	Median	Mini-mum	Maxi-mum
		(mg/ℓ)		(mg/ℓ)		
NH_3-N	16	0.10	± 0.04	0.10	0.06	0.17
Organic N	16	0.43	± 0.21	0.39	0.22	1.12
NO_2 + NO_3-N	18	0.26	± 0.19	0.22	0.03	0.80
Total N	14	0.76	± 0.22	0.70	0.41	1.34
Total P	18	0.66	± 0.08	0.69	0.44	0.75
Na	18	2041	±186	1934	1747	2371
K	18	90	± 5	87	87	104
Cl^-	7	2087	±196	2153	1761	2250
		(#/100 mℓ)		(#/100 mℓ)		
Fecal Coliform	18	0	0	0	0	0

APPENDIX TABLE C.2. MEANS, STANDARD DEVIATIONS, MEDIANS, MINIMUMS, AND MAXIMUMS OF WATER QUALITY PARAMETERS OF GROUNDWATER TEST WELL NO. 2, KMCAS GOLF COURSE

Constituent	No. of Samples	Mean	Std. Dev.	Median	Mini-mum	Maxi-mum
		(mg/ℓ)		(mg/ℓ)		
NH_3-N	16	0.01	± 0.01	0.01	0.01	0.05
Organic N	18	0.42	± 0.19	0.39	0.22	0.78
NO_2 + NO_3-N	17	1.47	± 0.52	1.43	0.94	3.24
Total N	14	1.75	± 0.30	1.67	1.36	2.30
Total P	18	0.15	± 0.10	0.12	0.06	0.45
Na	17	306	±22	311	273	360
K	18	22	0	22	22	22
Cl^-	7	447	±52	489	391	489
		(#/100 mℓ)		(#/100 mℓ)		
Fecal Coliform	18	0	0	0	0	0

APPENDIX TABLE C.3. MEANS, STANDARD DEVIATIONS, MEDIANS, MINIMUMS, AND MAXIMUMS OF WATER QUALITY PARAMETERS OF GROUNDWATER TEST WELL NO. 3, KMCAS GOLF COURSE

Constituent	No. of Samples	Mean (mg/ℓ)	Std. Dev.	Median	Mini-mum	Maxi-mum
				(mg/ℓ)		
NH_3-N	16	0.30	± 0.10	0.31	0.08	0.49
Organic N	18	0.62	± 0.22	0.53	0.34	1.01
NO_2 + NO_3-N	18	0.16	± 0.18	0.09	0.01	0.62
Total N	16	1.04	± 0.42	0.84	0.47	1.79
Total P	18	0.11	± 0.03	0.10	0.06	0.16
Na	17	2218	±186	2226	1914	2454
K	17	82	± 6	79	79	104
Cl^-	7	2097	± 95	2055	1957	2250
		(#/100 mℓ)		(#/100 mℓ)		
Fecal Coliform	18	0	0	0	0	0

APPENDIX TABLE C.4. MEANS, STANDARD DEVIATIONS, MEDIANS, MINIMUMS, AND MAXIMUMS OF WATER QUALITY PARAMETERS OF SPRINKLER EFFLUENT, KMCAS GOLF COURSE

Constituent	No. of Samples	Mean (mg/ℓ)	Std. Dev.	Median	Mini-mum	Maxi-mum
				(mg/ℓ)		
NH_3-N	12	10.9	± 1.1	10.9	9.6	13.8
Organic N	12	1.84	± 0.21	1.79	1.40	2.24
NO_2 + NO_3-N	12	0.03	± 0.04	0.01	0.01	0.13
Total N	12	12.75	± 1.12	12.77	11.63	15.71
Total P	10	8.9	± 1.2	8.7	7.3	10.8
Na	12	230	± 10	230	218	240
K	12	22	0	22	22	22
Cl^-	6	329	± 12	328	323	342
		(#/100 mℓ)			(#/100 mℓ)	
Fecal Coliform	8	160	±150	111	--	420

APPENDIX D. NORMALIZED AIR QUALITY DATA FOR VARIOUS INITIAL COLIFORM BACTERIA DENSITIES IN THE SPRINKLER EFFLUENT

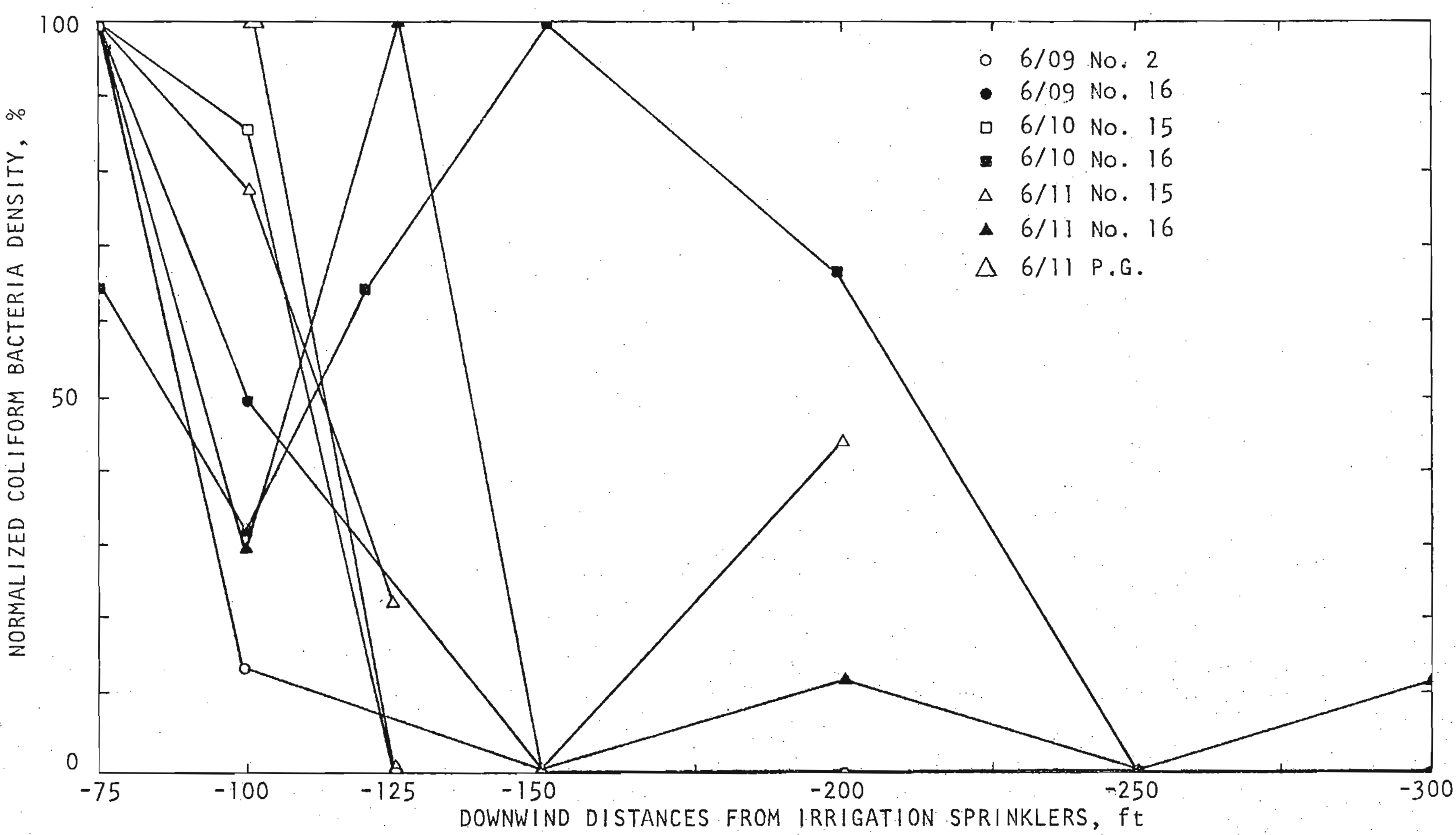

FIGURE D.1. NORMALIZED AIR QUALITY DATA FOR INITIAL COLIFORM BACTERIA CONCENTRATION BETWEEN 15,000 AND 20,000 COLONIES/100 mℓ

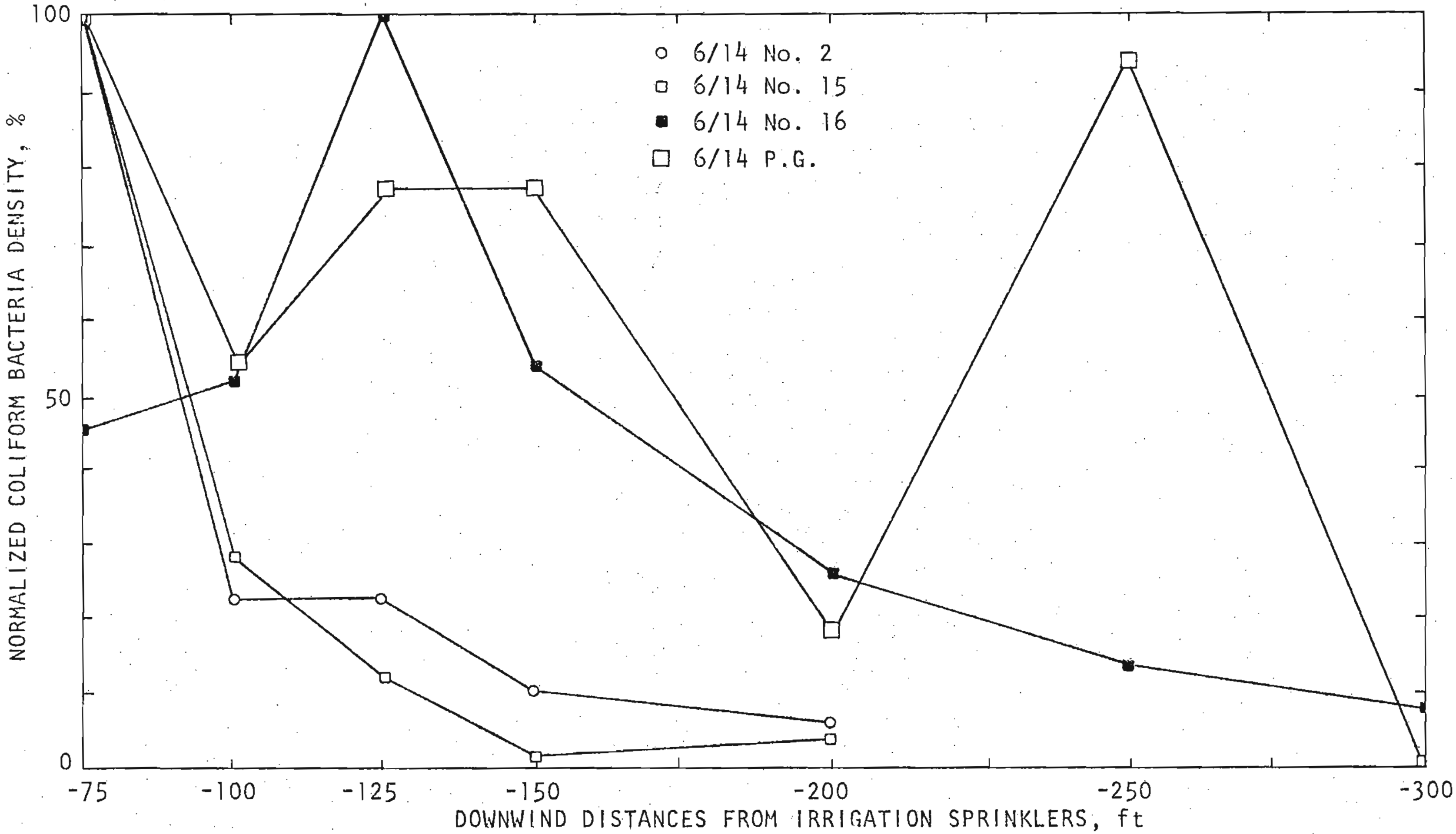

FIGURE D.2. NORMALIZED AIR QUALITY DATA FOR INITIAL COLIFORM BACTERIA CONCENTRATION OF 46,000 COLONIES/100 mℓ

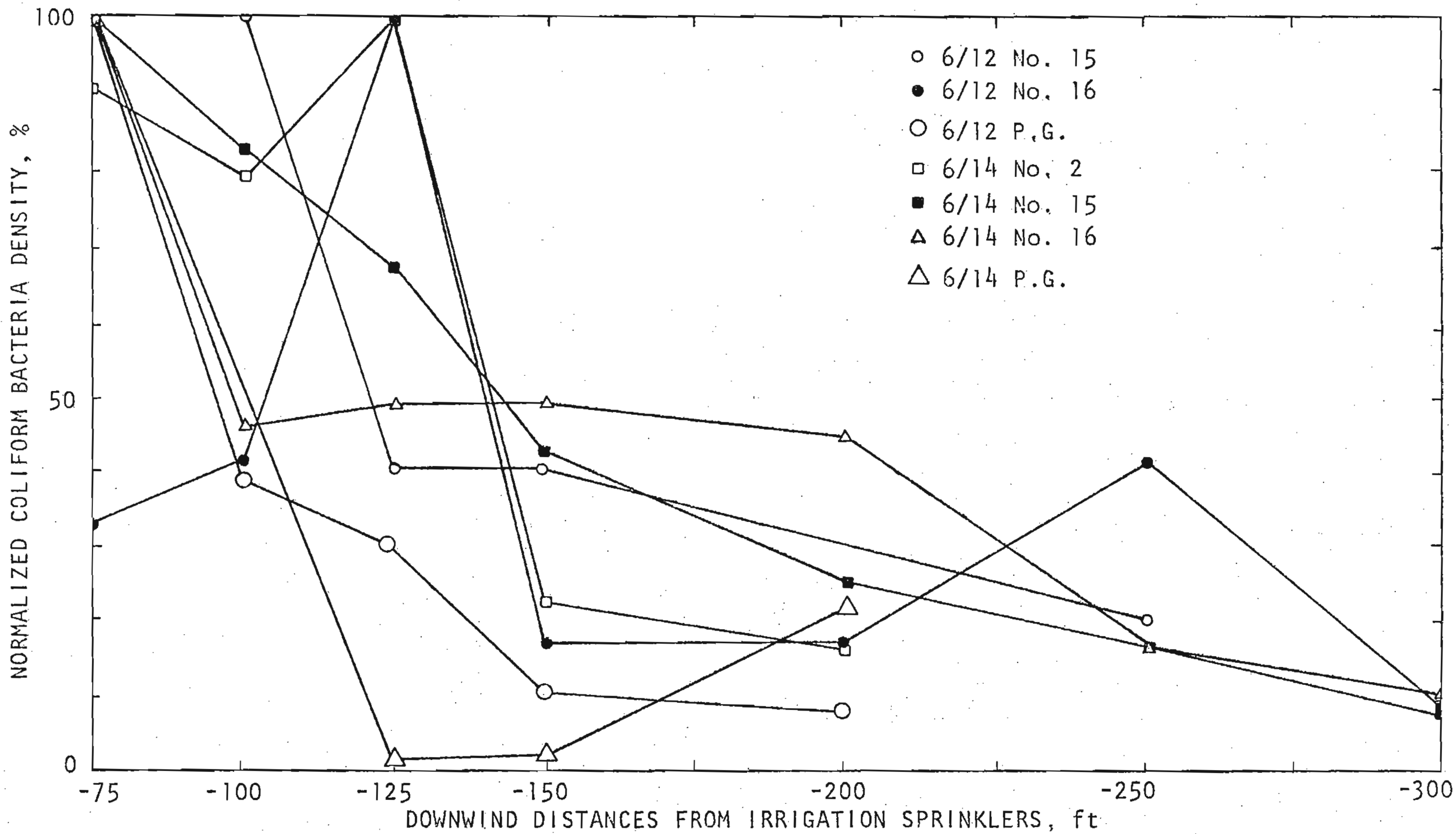

FIGURE D.3. NORMALIZED AIR QUALITY DATA FOR INITIAL COLIFORM BACTERIA CONCENTRATION BETWEEN 319,000 AND 400,000 COLONIES/100 mℓ

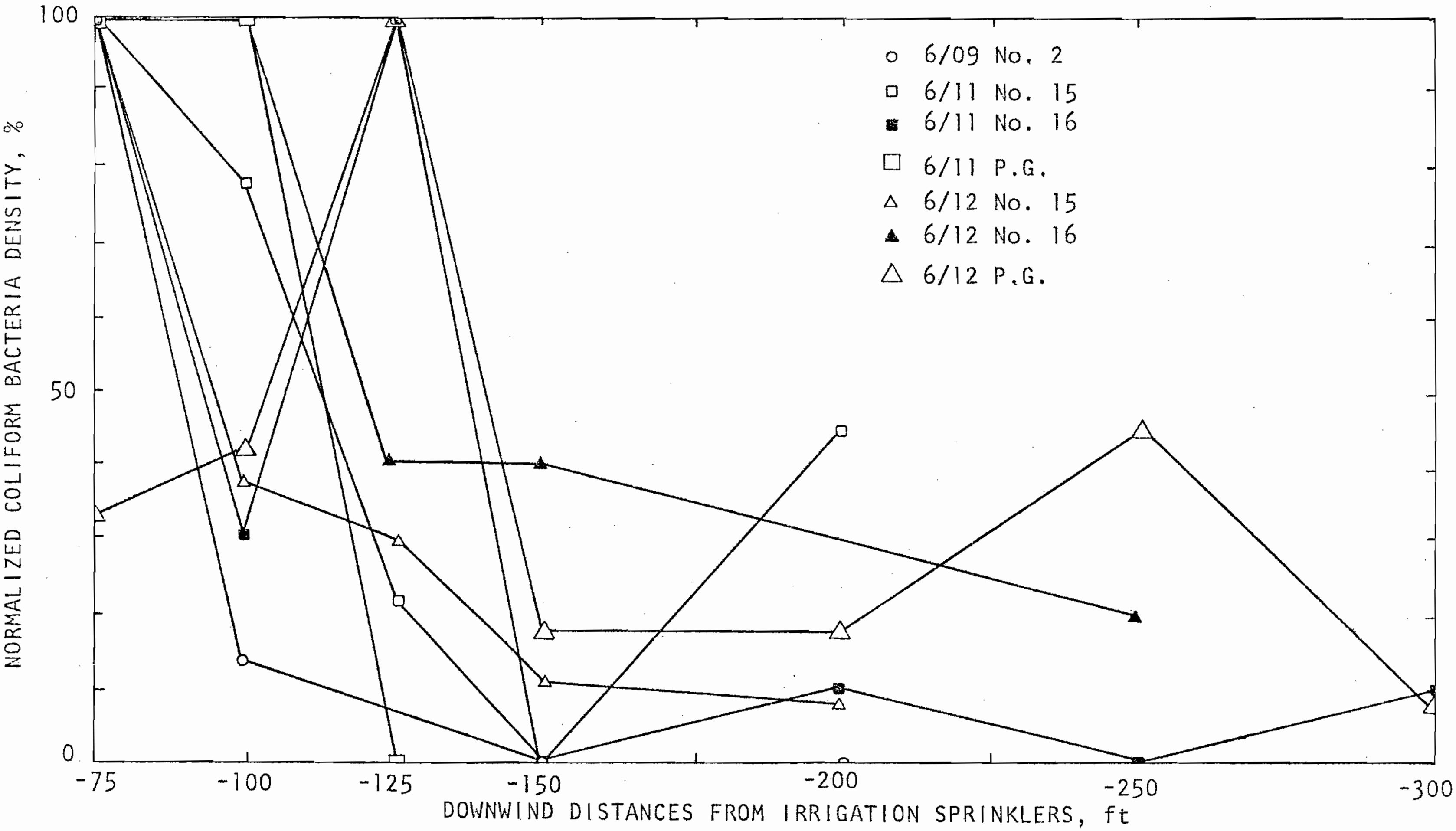

FIGURE E.1. NORMALIZED AIR QUALITY DATA FOR WIND VELOCITIES BETWEEN 0 AND 8 KNOTS

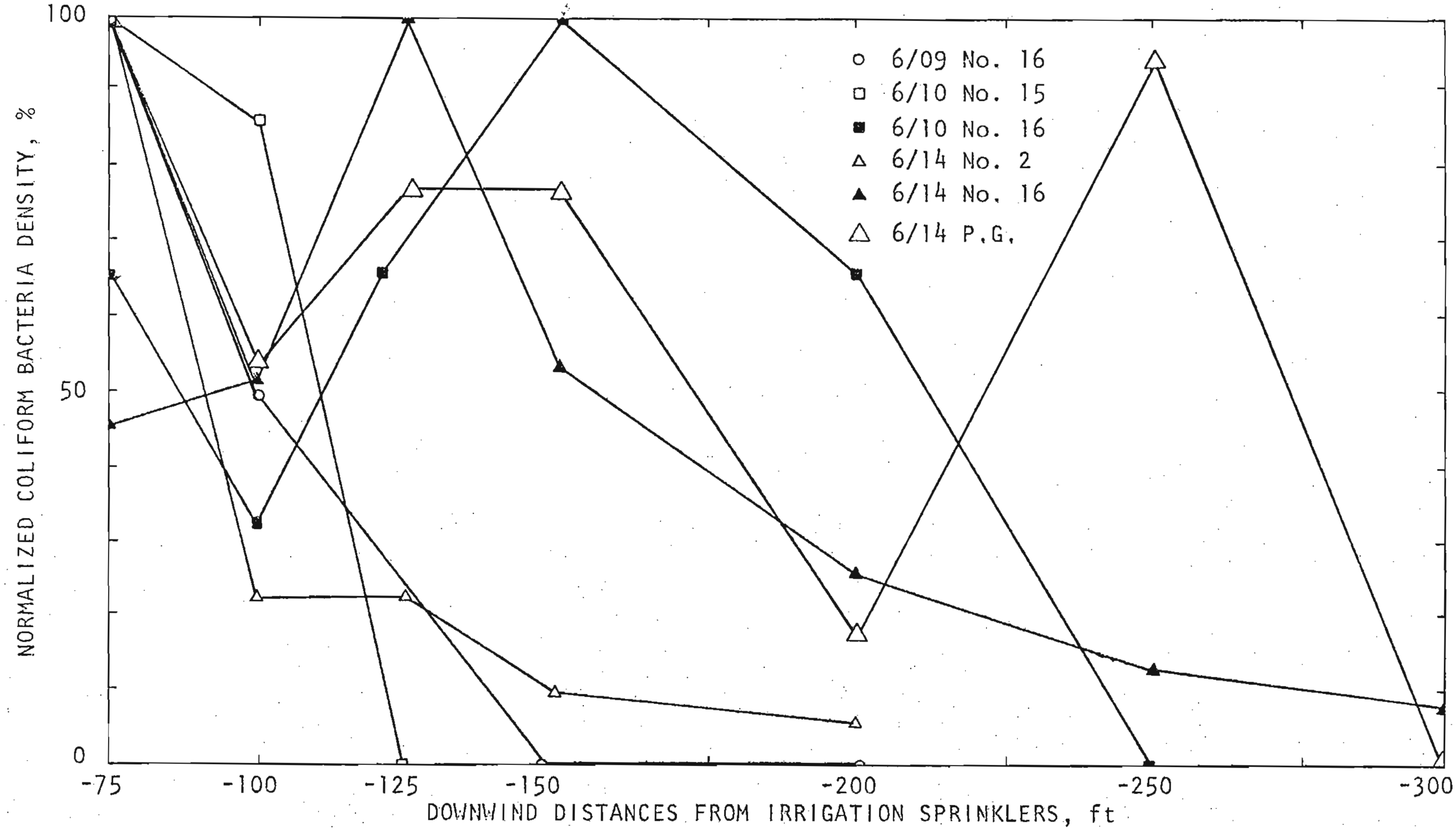

FIGURE E.2. NORMALIZED AIR QUALITY DATA FOR WIND VELOCITIES BETWEEN 9 AND 12 KNOTS

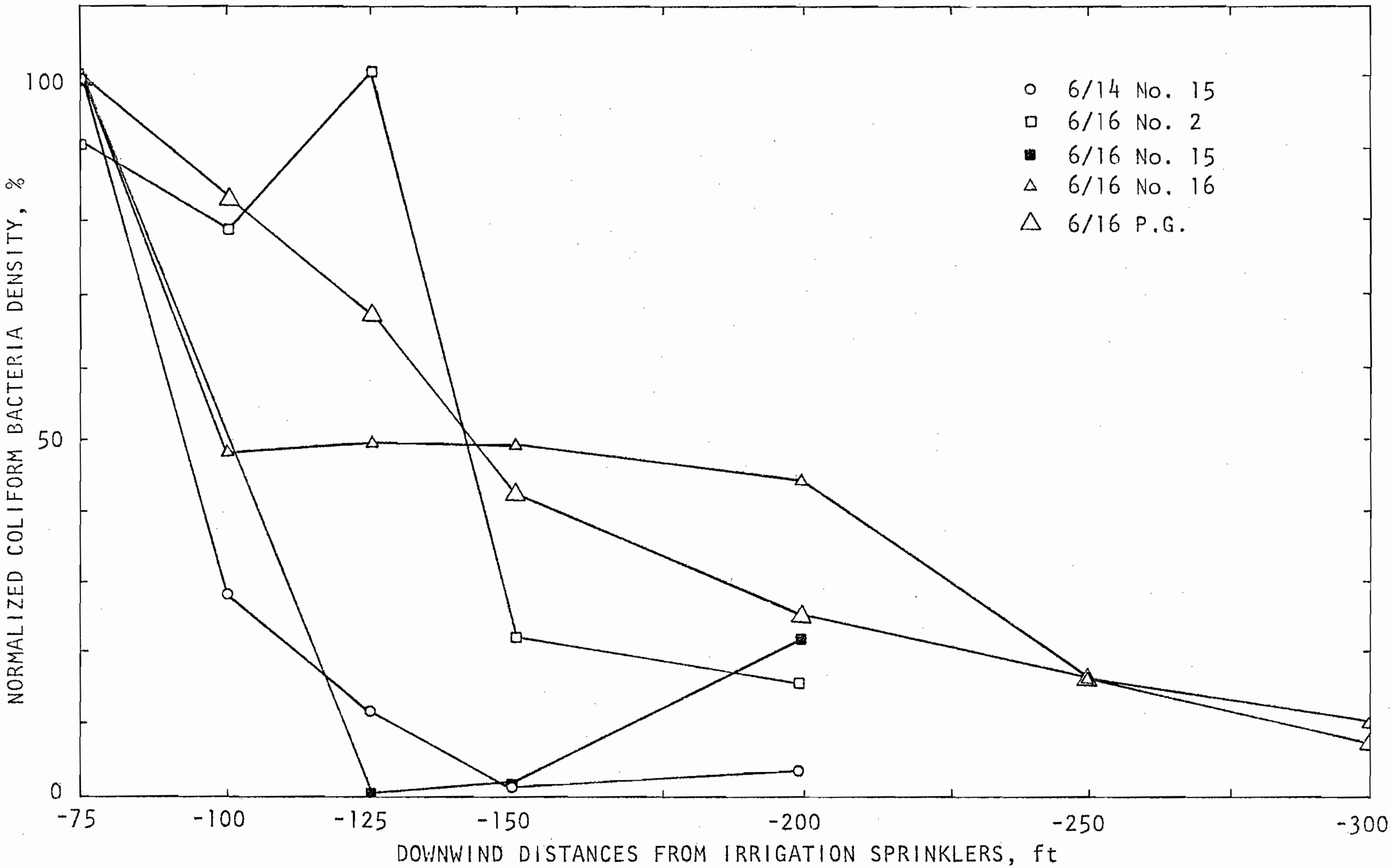

FIGURE E.3. NORMALIZED AIR QUALITY DATA FOR WIND VELOCITIES BETWEEN 13 and 18 KNOTS