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Land Treatment and Reuse of Sewage Effluent by Irrigation: A Perspective for Hawaii

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TECHNICAL REPORT

LAND TREATMENT AND REUSE OF SEWAGE EFFLUENT BY IRRIGATION: A PERSPECTIVE FOR HAWAII

By

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EPA Comment

This bulletin was prepared for the U.S. EPA Office of Water Program Operations as one of a series of reports to help supply detailed information concerning studies and current practices involving the utilization and reuse of municipal effluents and sludges. The series will provide in-depth presentations of available information on topics of major interest and concern related to municipal wastewater treatment and sludge management. An effort will be made to provide the most current state-of-the-art information available concerning sewage and sludge processing and disposal/utilization alternatives, as well as costs, transport, and environmental and health impacts.

These reports are not a statement of Agency policy or regulatory requirements. They are being published to assist EPA in complying with the emphasis placed by the Clean Water Act upon the use of land treatment and other systems that reuse municipal wastewater, sludge, and their nutrient resources. They also will provide planners, designers, municipal engineers, environmentalists and others with detailed information on municipal wastewater treatment and sludge management options.

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ABSTRACT

Surrounded by an ocean, the Hawaiian Islands are limited in their natural freshwater resources. The major, readily developable potable sources are the high quality groundwater sources which serve both domestic uses and sugarcane irrigation, although irrigation water does not require so high a quality as does drinking water.

The increasing overall freshwater requirements for the island of Oahu will outstrip the potential yield of natural freshwater sources, as developed by present technology, by the year 2000 according to projections by the Honolulu Board of Water Supply. Water shortage regions on other islands are the leeward, high temperature, low rainfall, cultivated and/or urban-resort areas. Water reuse from sewage effluent for irrigation will augment the natural water resources, furnish supplemental or alternative fertilizer, reduce ocean discharge of pollutants, and the costs of engineering systems.

In cooperative field testing from 1971 to 1975, it was demonstrated that the effluent can be applied as supplemental water for furrow irrigation of sugarcane without detriment to groundwater quality and sugar yield. Studies are in progress to test different dilutions of effluent and their use with chemical ripeners to improve crop yield. Sugarcane plantations on Oahu, Maui, and Kauai are in various stages of water reuse. Reuse is presently practiced for irrigation of golf courses and is being planned for forage crops in Hawaii.

The studies and current practice utilizing land treatment and reuse of sewage effluents as irrigation water in Hawaii are summarized and the probable impact on irrigation practices and

attendant waste water treatment and monitoring are discussed. Such practices could easily serve as a model for other areas in the nation that face future water shortages and increased water demand.

CONTENTS

FIGURES

TABLES

I. RATIONALE FOR WATER REUSE IN HAWAII

Surrounded by the Pacific Ocean, the Hawaiian Islands are limited in their natural freshwater resources. Each major island has its characteristic leeward, high temperature, low rainfall, cultivated and/or urban-resort areas that are susceptible to seasonal water shortages as the water demand increases. Oahu's water situation is more serious than that of the other islands in the state because it accommodates over 600,000 or 80% of the state resident population, most of the 3 million annual influx of tourists, and the military and associated personnel. The water supply problems for Oahu assume an island-wide scale.

The major readily developable water source is the high quality groundwater that is potable without treatment. It supplies presently, in mgd, agriculture (mostly sugarcane), 220; municipal, 140; military, 35; and urban-residential, 30; for a total of 435 mgd and leaving only 65 mgd of the groundwater sources that can be recovered to meet additional demand (Hirata 1977). It is estimated that the developable groundwater supply will be fully committed by the year 2000 (Board of Water Supply 1975). Thus, supplemental water sources must be found.

Now and in the foreseeable future, desalting even brackish groundwater and especially ocean water is not considered economically feasible in view of recent increased energy costs. The catchment of streamflow faces multiple problems, including the limited number of large perennial streams, shortage of reservoir storage space on an island of limited land area, necessity of water treatment if used for drinking, and uncertainty over water rights.

A most feasible supplemental water source is municipal waste water effluent. It is available and dependable, has fertilizer value, and can be successfully used for irrigation if properly managed to avoid groundwater pollution problems and decrease in yields of sensitive crops. If the effluent is not reclaimed and reused for irrigation, the remaining disposal alternatives are discharge into freshwater streams after advanced treatment, which is not economically viable, or ocean disposal through long outfall pipes which are not only costly but also result in the loss of a valuable supplemental water resource.

In summary, the need is real and urgent to seriously consider the reuse of municipal and domestic sewage effluents for irrigation in Hawaii from the standpoint of water conservation and waste water management.

II. CURRENT AND PAST PRACTICE OF REUSE IN HAWAII

In Hawaii municipal waste water treatment systems began with the minimal treatment and discharge of sewage into cesspools which are still in use in sparsely populated rural communities. Even today, there are over 22,000 cesspools on Oahu alone, and 57,000 on all major islands combined (WRRC 1977). The sanitary, rather than combined, sewer system then came into practice; however, most of the sewage was discharged without treatment. The receiving water was, and still is, principally the ocean, and occasionally, streams and lakes. Land application of waste water effluents for reuse in Hawaii, if any, was not documented before 1967 (Young, Lau, and Burbank 1967).

In the early 1970s when stringent receiving water quality regulations were promulgated in Hawaii, effluent injection wells became popular for small facilities in coastal areas where the groundwater is brackish and not suitable as a water supply source (Takasaki 1974). But today attention is focused on reclamation and reuse as a result of present and projected future water shortages, failure of some effluent injection wells, and the stringent regulations expected soon to be promulgated for underground injection systems in Hawaii.

Known systems that reuse sewage for irrigation in Hawaii are mainly in an infant stage: few in number, small in size, and of recent origin. The total quantity of effluent used from 17 systems, most of which are on Oahu, is less than 10 mgd (Tables 1, 2; Fig. 1). Users include sugarcane plantations and golf courses. The existence of some of these systems is principally due to the need for supplemental water. In some cases, the use and application of treated effluent is indirect and only after

TABLE 1

Effluent Reuse for Sugarcane Irrigation

Site	Island	STP	Treatment	Flow (mgd)	Receiving Water/Use	Reference*
1	Kauai	Lihue	Activated Sludge	0.5	Irrigation Ditches	1
2	Kauai	Waimea	Activated Sludge	0.3	Ponds, Irrigation Ditches	1
3	Maui	Kaanapali	Activated Sludge	0.5	Irrigation Ditches, Reservoir; Cane	2
4	Oahu	Makakilo Hts.	Activated Sludge	0.51	Irrigation Ditches, after High Dilution	1, 3, 5
5	Oahu	Nanakai	Extended Aeration	0.05	Irrigation Ditches, after High Dilution	1, 3, 5
6	Oahu	Whitmore Village	Extended Aeration	0.17	Wahiawa Reservoir; Storage Water Used for Irrigation	3
7	Oahu	Wahiawa	Activated Sludge	1.3	Wahiawa Reservoir; Storage Water Used for Irrigation	3
8	Oahu	Schofield	Trickling Filter	1.64	Waikele Stream; Stream Water Diverted Seasonally for Irrigation	3, 4
				4.97		

*1. Dennis Lau (Hawaii State Dept. of Health) 1977: personal communication.
2. George Brown and George Schatenberg (Pioneer Mill Co.) 1977: personal communication.
3. City and County of Honolulu (1972).
4. L. Stephen Lau 1977: personal observation.
5. George Richardson (City and County of Honolulu) 1977: personal communication.

TABLE 2

Effluent Reuse for Golf Course, Lawns, Fields, and Trees

Site	Island	Location	Treatment	Flow (mgd)	Receiving Water /Use	Reference*
3	Maui	Kaanapali STP	Activated Sludge	0.5	Oxidation Pond; Golf Course	1
9	Oahu	Kaneohe Marine Corps Air Station STP	Trickling Filter	0.56	Golf Course	2
10	Oahu	Hawaii Kai STP	Activated Sludge	1.0	Golf Course	3
11	Oahu	Kuilima Hotel	----------------	----	Oxidation Pond; Golf Course	4
12	Oahu	Church College, Laie	Trickling Filter, Activated Sludge	----	Lawn Irrigation	4, 6
13	Oahu	Wailee Farm, University of Hawaii	----------------	----	Chlorinated Pond; Field Irrigation	4
14	Oahu	Makaha STP	Extended Aeration	0.15	Irrigation	5
15	Hawaii	Kailua-Kona	Activated Sludge	----	Koa Trees	4
16	Hawaii	Mauna Kea Beach Hotel	Activated Sludge	----	Golf Course	4
17	Hawaii	Keauhou	Activated Sludge	----	Golf Course	4
				2.21		

*1. L. Stephen Lau 1977: personal observation.
2. Chang and Young (1977).
3. Zone of Mixing Environmental Impact Statement (1974).
4. Dennis Lau (Hawaii State Dept. of Health) 1977: personal communication.
5. City and County of Honolulu (1972).
6. George Richardson (City and County of Honolulu) 1977: personal communication.

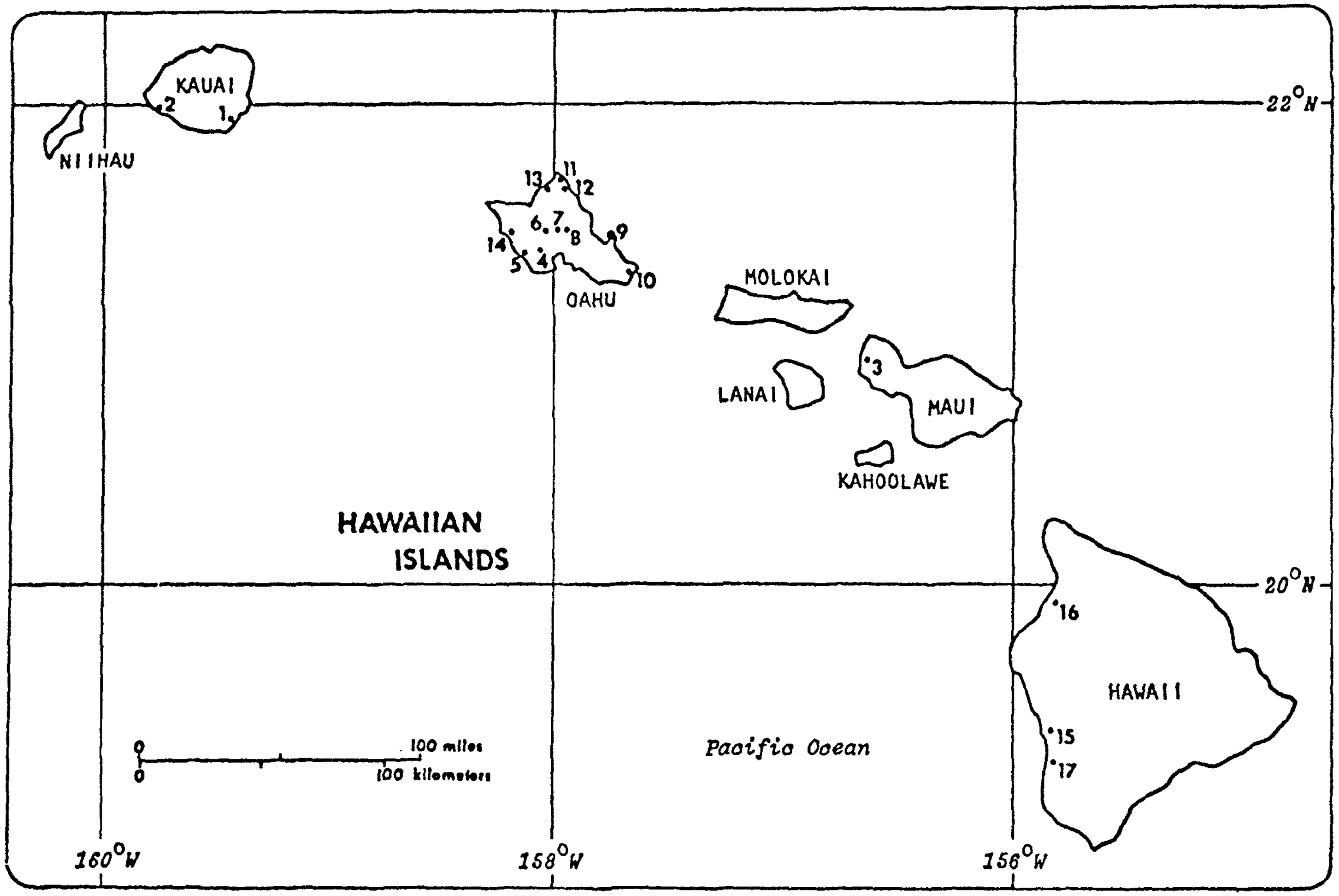

FIGURE 1. Sites of Water Reuse from Sewage Effluent by Irrigation: Kauai, Maui, Oahu, and Hawaii

dilution by stream or reservoir water. The oldest system in use since 1967 is the Pioneer Mill Company's Kaanapali system on Maui that uses about 0.5 mgd of chlorinated effluent from the Kaanapali STP for furrow irrigation after high dilution (3-12%) with groundwater. None of these reuse systems had prior benefit of scientific research and development in land treatment technology for water reuse.

The Kaanapali system on Maui is mentioned here because it is the oldest in use since 1967, and illustrates the dire need and keen competition for water. Kaanapali is a typical dry leeward coastal area with a mean annual rainfall of 15 inches (Fig. 2). The Pioneer Mill Company traditionally uses ditch water intercepted in the high rainfall West Maui Mountains and groundwater pumped from the basal water to irrigate its sugarcane fields on Maui. Since 1967, the company has irrigated about 400 acres of sugarcane furrows with 0.5 mgd of chlorinated effluent from the Kaanapali STP after mixing with groundwater: 12% effluent after mixing with Pump G water and 3% effluent after mixing with Pump D water. The total nitrogen concentration was diluted by the groundwater to 12.3 and 2.2 mg/l, but the total dissolved solids concentration increased to 896 mg/l after the final mixing with Pump G water. The company has experienced a gradual decline in yields from the fields, including those irrigated with the highlydiluted effluent in that general area over the last 10 to 15 years. This decline has been attributed to the gradual increase in chloride of the pumped groundwater from 600 mg/l in 1957 to 1,000 mg/l in 1976 due to an increase in sea water encroachment. It is generally agreed that the use of the highlydiluted effluent has imparted no detrimental effects to the yields. The plantation is committed to continue the use of effluent for irrigation and will accept the effluent from Maui County's planned secondary STP that will produce about 6 mgd in the early 1980s and about 14 mgd in the year 2000.

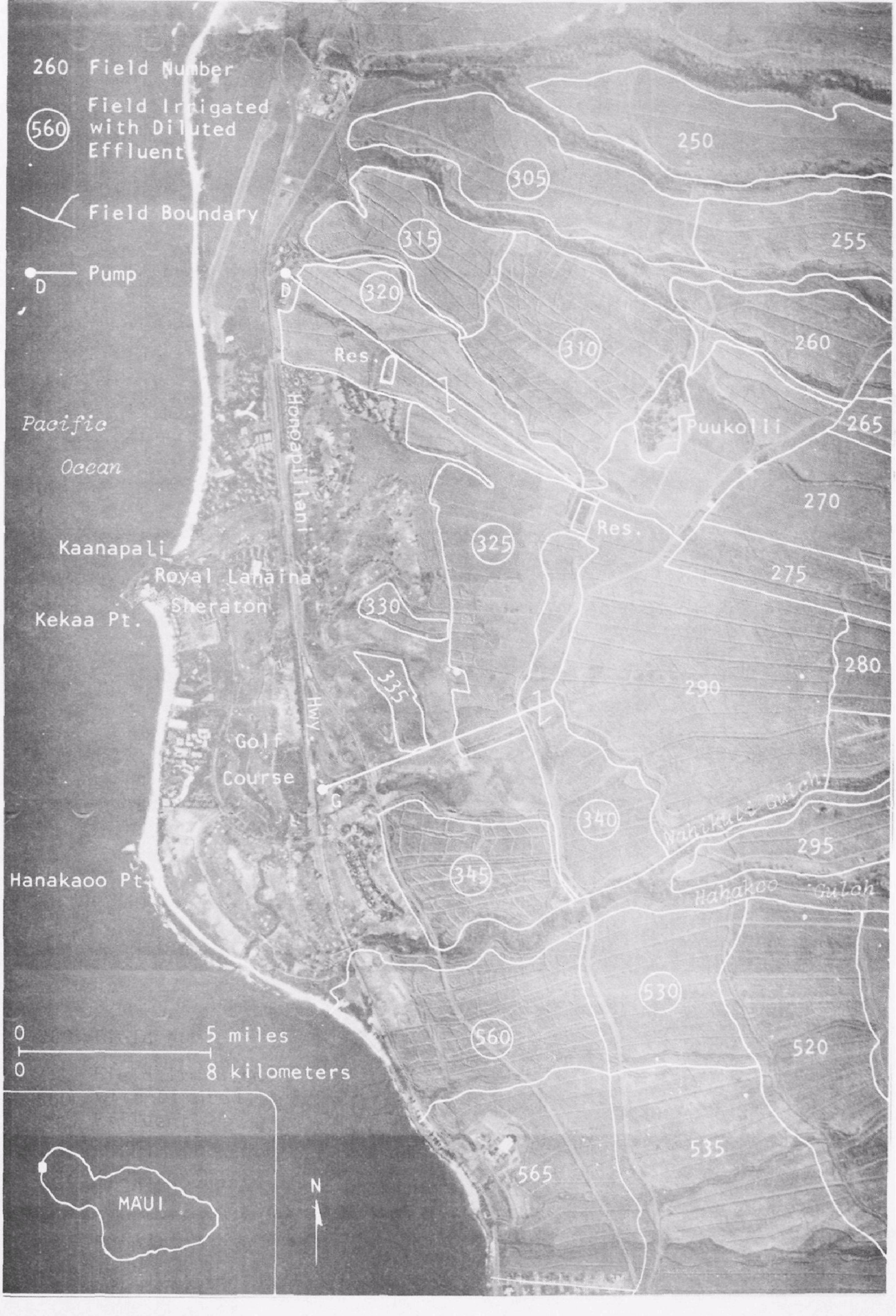

FIGURE 2. KAANAPALI EFFLUENT-IRRIGATED CANE FIELDS, WEST MAUI, HAWAII

III. CONTRIBUTION FROM SCIENTIFIC RESEARCH AND DEVELOPMENT

Prior to 1971 there was no known organized research on land treatment and the reuse of water from sewage for irrigation in Hawaii. However, a series of process-type studies concerning the interaction between individual chemical and microbiological water quality parameters in sewage and tropical soils and rocks were completed by the Water Resources Research Center in the mid-sixties (Young, Lau, Burbank 1967; Koizumi, Burbank, Lau 1966; Kumagai 1967a, b; Eto et al. 1967; Ishizaki, Burbank, Lau 1967; Tanimoto et al. 1968; Hori et al. 1970). While these studies contributed considerably to the basic scientific understanding of land treatment systems for municipal waste water treatment in Hawaii, including the effectiveness of the removal of chemical quality constituents and the inactivation of bacteria and limited types of viruses in the tropical agricultural soils, none of the studies directly addressed crop production by waste water irrigation and reuse.

The single most important and comprehensive study in reuse by irrigation for both sugarcane and grassland in pilot field scale began at Mililani, Oahu, in 1971 and was completed in 1975 as Phase I by the Water Resources Research Center under the sponsorship of the Board of Water Supply, Department of Public Works, City and County of Honolulu; Hawaiian Sugar Planters' Association; and Oahu Sugar Company (Lau et al. 1972, 1974, 1975). Phase II began in 1976 with a study to examine the crop yield as may be affected by different dilutions of effluent and continued with still another study on the post-treatment of secondary effluent necessary for drip irrigation (Lau et al. 1977). Both Phase II studies are supported by the same agencies but with the Department of Health, State of Hawaii, as an added sponsor for the post-treatment study.

REUSE BY SUGARCANE IRRIGATION

The Mililani project included field and laboratory studies of changes in water quality factors, viral content in the applied and percolating water and in the soil, and sugar yields and quality when sugarcane fields as well as grasslands are irrigated with sewage effluent. An overall evaluation was achieved, together with the proposal of principles and guidelines for irrigation of sugarcane and grasslands with sewage effluent in Hawaii was achieved.

The central Oahu project site area is located near the Mililani Sewage Treatment Plant (STP), which in 1977 received approximately 1.3 mgd of essentially domestic sewage from the nearby expanding Mililani Town development (Fig. 3). The STP utilized until October 1977 the Rapid Bloc activated sludge process (secondary treatment). The generally acceptable performance of the plant is demonstrated by the data of a typical analysis of the raw sewage and the chlorinated effluent of the plant (Table 3). The project soils of the Oxisol order are similar to that on which approximately 90% of the sugarcane cultivated under irrigated conditions on Oahu is grown. The general project site area receives an average annual rainfall of approximately 40 in., and is situated at an elevation approaching 500 ft.

The research objectives were to investigate the groundwater pollution potential and effects on sugarcane yields by applying effluent as irrigation water. The research activities were grouped into four major areas: soils and irrigation, viral analysis, water quality analysis, and crop growth monitoring and yield analysis. In general, the values of guideline chemical parameters for the Mililani STP effluent are below the maximum value for irrigation of sensitive crops (Table 4). Pesticides and heavy metal concentrations were either below the levels of concern or of detectability (Tables 5 and 6).

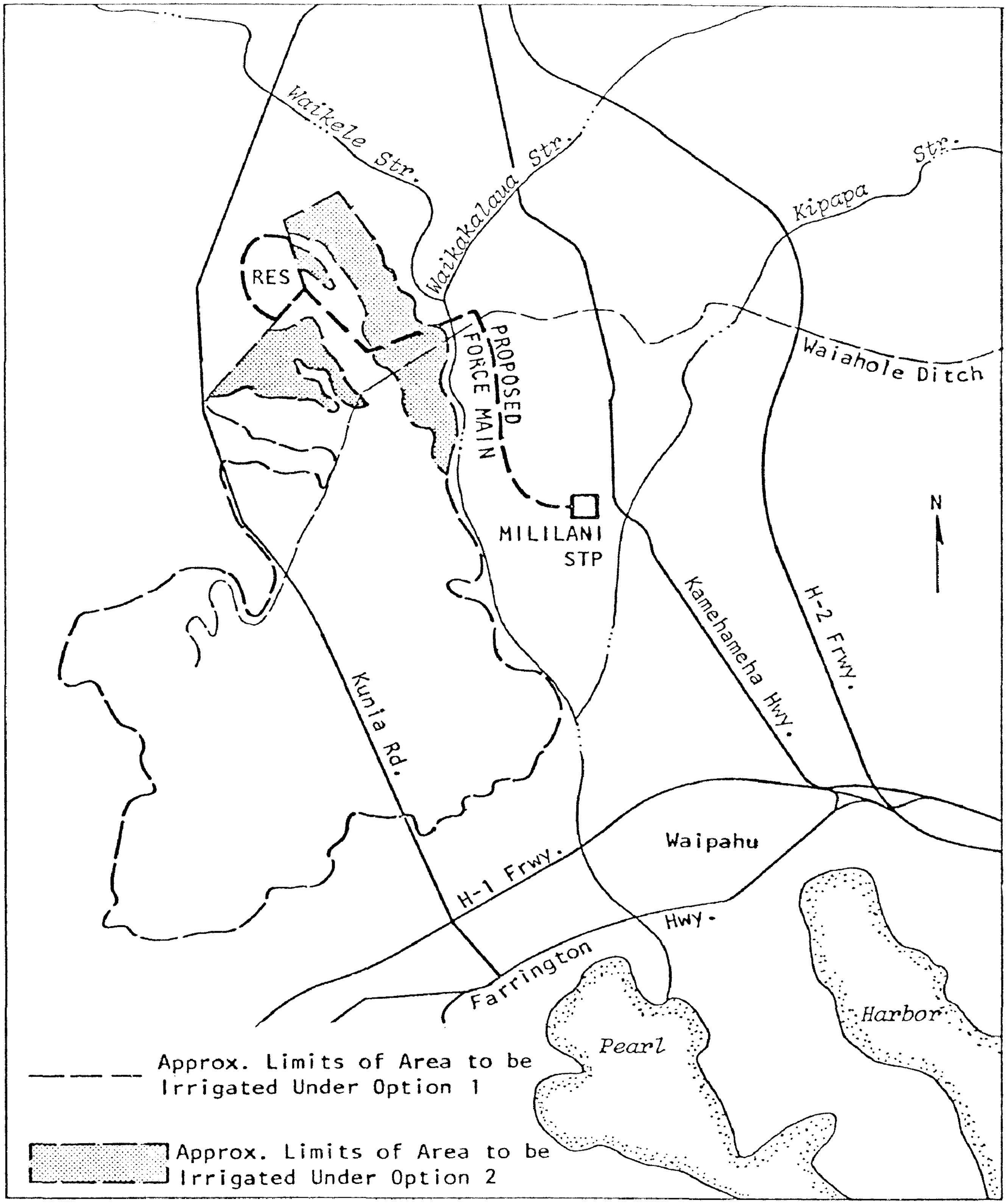

Figure 3. Mililani Reclamation-Reuse System for Irrigation

TABLE 3

Weighted Composite Mililani STP Analysis

Constituent*	Raw Sewage	Chlorinated Effluent	% Change in Constituent
	13 JANUARY 1975†		
pH Range	6.7-8.1	6.4-7.0	--
Conductivity Range (μmhos/cm)	460-700	440-540	--
Dissolved Oxygen Range	0	2.7-3.4	--
Oxygen-Reduction Potential Range (mV)	(-230)-(+75)	150-285	--
Suspended Solids	159	6	-96
Total Dissolved Solids	411	333	-19
Total Volatile Solids	252	65	-74
Volatile Suspended Solids	135	3	-98
BOD_5	241	12	-95
Chloride	48	55	+15
Sulfate	76	33	-57
MBAS Range	1.5-19.0	0.3-0.9	--
Total Kjeldahl Nitrogen	36.4	13.9	-62
NO_2 + NO_3 Nitrogen	0.02	3.62	+18000
Total Nitrogen	36.42	17.52	-52
Orthophosphate Phosphorus	15.9	13.5	-15
Sodium	50	55	+10
Potassium	10.0	9.2	-8
Calcium	10	11	+10
Magnesium	6.6	7.9	+20
Alkalinity ($CaCO_3$)	52	60	+15
Silica (SiO_2)	84	81	-3.6
Residual Chlorine Range	--	0.7-3.0	--
Total Coliform Range (No./100 mℓ)	1.3×10^7- 1.3×10^9-	52-650	--
Fecal Coliform Range (No./100 mℓ)	2.4×10^6- 1.0×10^8	0-260	--
Fecal Streptococcus Range (No./100 mℓ)	3.0×10^5- 4.0×10^8	0-62	--

*All units in mg/ℓ unless noted otherwise.
†16-hr composite samples.

TABLE 4

Median Constituent Values* of Secondary Sewage Effluent,

Mililani STP, Oahu, Hawaii

Dates	No. of Samples	Total N	PO_4-P	K	Na	Ca	Mg	SO_4	SiO_2	Cl	TDS	Elec. Cond.
		mg/ℓ										μmhos/cm
Apr. 1973 to Dec. 1974	74	20.1	10.83	9.7	54	10	9	42	72	50	327	440

*Median of 21 monthly medians.

TABLE 5

Pesticide Analyses of Raw Sewage and Unchlorinated Secondary Effluent, Mililani STP, Oahu, Hawaii

PESTICIDE	SAMPLING DATE									
	22-23 Oct. 1971[a]		9 Aug. 1972[b]		2 Oct. 1973[b]		26 Aug 1974[b]		13 Jan. 1975[b]	
	Raw	Effl.	Raw	Effl.	Raw	Effl.	Raw	Effl.	Raw	Effl.
	mg/ℓ									
Lindane	0.000295	0.000032	0.000180	0.000146	0.000176	0.000024	0.000131	0.000075	0.000160	0.000120
Heptachlor	--	--	ND	ND	ND	ND	ND	ND	ND	ND
Heptachlor Epoxide	--	--	ND	ND	ND	ND	ND	ND	ND	ND
Aldrin	--	--	ND	ND	ND	ND	ND	ND	ND	ND
Dieldrin	0.000051	0.000017	0.000054	0.000020	0.000019	0.000013	0.000032	0.000022	0.000015	0.000010
DDE	--	--	ND	ND	ND	ND	ND	ND	ND	ND
DDD	0.000042	0.000008	ND	ND	ND	ND	ND	ND	0.000011	ND
DDT	0.000003	0.000002	0.000010	0.000014	0.000008	0.000025	0.000025	0.000006	0.000018	0.000010
α Chlordane	0.000013	0.000006	ND	ND	ND[c]	0.000018	0.000081	0.000014	0.000038	0.000100
γ Chlordane	0.000025	0.000004	ND	ND	ND[c]	0.000010	0.000035	0.000006	0.000021	0.000050
PCP	0.003245	0.000730	0.002360	0.000910	0.000592	0.000672	0.001060	0.001590	0.000600	0.000300
PCB	--	--	--	--	0.000220[d]	0.000040[d]	ND	ND	--	--
Mirex	--	--	---	--	ND	ND	--	--	--	--

NOTE: ND = nondetectable.
[a]24-hr composite sample.
[b]16-hr composite sample.
[c]May have been present but undetected due to interfering peaks.
[d]Arochlor (Monsanto compound polychlorinated biphenyl) 1254 detected.

TABLE 6

Heavy Metal Analyses of Raw Sewage and Unchlorinated Secondary Effluent, Mililani STP, Oahu, Hawaii

HEAVY METAL	SAMPLING DATE					
	22-23 Oct 1971[1]		2 Oct 1973[2]		13 Jan 1975[2]	
	Raw	Effl.	Raw	Effl.	Raw	Effl.
	(mg/ℓ)					
Cadmium	0.004	0.005	ND	ND	ND	ND
Lead	0.028	0.047	0.003	ND	--	--
Mercury	ND[3]	ND[3]	ND[3]	ND[3]	ND	ND
Copper	--	--	0.021	0.010	ND	0.00024
Zinc	--	--	0.025	0.027	ND	0.0037
Nickel	--	--	0.015	0.015	ND	0.0065
Iron	--	--	0.432	0.164	--	--
Aluminum	--	--	0.592	0.532	--	--
Chromium	--	--	--	--	ND	ND

NOTE: ND = nondetectable.
[1]24-hr composite sample.
[2]16-hr composite sample.
[3]Nondetectable below 0.003 mg/ℓ.

Nitrogen was given special emphasis for several reasons: its use as a major component of most fertilizers; its known adverse effect of lowering sugar yields on maturing sugarcane; its essential solubility in the nitrite and nitrate forms; its relationship in concentrations above 10 mg/l nitrate as N to methomoglobinemia; and its potential role in the eutrophication of open bodies of water receiving excessive nitrogen loads. The median concentration of N, P, and K in the effluent applied throughout the cycle was approximatley 20, 11, and 10 mg/l, respectively. The Mililani STP secondary treated and chlorinated domestic and municipal sewage effluents containing insignificant amounts of toxic chemicals are rated a generally usable irrigation water supply for sugarcane and grasslands in central Oahu.

The 30 test plots with uniform areas of 0.1 acre in the newly planted OSC Field No. 246 were divided into three basic irrigation schemes: 10 plots were scheduled to receive only ditch water for the 2-yr growth cycle, 10 plots to receive secondary effluent for the first half of the growth cycle and ditch water thereafter, and 10 plots to have only effluent irrigation applications for the full growth cycle. Commercial fertilizers were applied at planting to all plots to achieve a rapid and uniform start for the crop and were subsequently adjusted to the intended equal total (commercial plus effluent) nitrogen for all plots.

Fifty ceramic point samplers were installed in representative plots at depths of 9 to 12 in. and 18 to 21 in. that resulted in the shallower points being positioned in the tillage zone and the deeper points being positioned approximately 6 in. below the tillage zone. Thus, leachate collected by the shallower points represented liquid available to the sugarcane root zone, whereas, leachate collected from the the deeper points is assumed to be generally unavailable to the sugarcane and potentially to percolate to the groundwater table.

Sugarcane parameters were periodically monitored throughout the culture cycle. The field was hand harvested in March 1975 after 24 months of growth.

Application of sewage effluent for the first year only of a 2-yr crop cycle increased the sugar yield by about 6% compared with the control plots. However, when sewage effluent was applied for the entire 2-yr crop cycle, sugar yield was reduced by about 6% and the cane quality by about 16% even though the total cane yield increased by about 11% (Table 7).

The quality of percolate from the effluent-irrigated sugarcane cultured soil was of acceptable concentration from the standpoint of groundwater quality protection; the only possible concern was for nitrate nitrogen that sporadically exceeded the 10 mg/l limit for drinking water during the first 6 to 7 months of cane growth. However, similar levels of nitrate nitrogen occurred in the ditch water-irrigated sugarcane plots receiving commercial fertilizers at normal rates and the plots irrigated with effluent during the first year and with ditch water during the second year. Furthermore, there was no major difference in the total quantity of nitrogen produced in the percolate among the three different treatments.

Human enteric viruses have been shown to be present in the majority of effluent samples examined and, hence, can be assumed to be present in the effluent applied to the irrigated field. However, the absence of these viruses in all sugarcane and grass percolates sampled over a 2-yr period, plus other project viral studies conducted, suggest strongly that the possibility of contaminating deep underground water sources is extremely remote.

TABLE 7

Effect of Treated Effluent on Cane Yields, Cane Quality, and Sugar Yields in Oahu Sugar Company Field 246, Hawaii

Code	Treatment	Tons of Cane/Acre	Tons of Sugar/ Ton Cane (%)	Estimated Tons of Sugar /Acre
A	Ditch water for 2 years	138.1	12.2	16.8
B	Effluent first year then ditch water second year	144.6	12.3	17.8
C	Effluent for 2 years	152.9	10.3	15.8
	Statistical Summary			
	A vs. B	*	NS	NS
	A vs. C	**	**	NS
	B vs. C	**	**	*

* = Difference significant at 5% probability level.
** = Difference significant at 1% probability level.
NS = Difference is nonsignificant.

Survival of poliovirus was minimal in an open field area which was exposed to direct sunlight, high temperature, and dessication. In contrast the viability of the virus was maintained for up to 2 months in a field of mature sugarcane where the virus was protected from the physical elements.

The results of Phase I were promising in terms of increased sugar yield, an additional irrigation water source, and alleviation of a sewage effluent disposal problem; however, it is not presently considered economically feasible to construct and maintain a separate ditch water and sewage effluent field distribution system. Thus, the question arises as to the possibility of an optimum dilution of sewage effluent with ditch water for a single field distribution system so that sugar yield will not be decreased and may hopefully increase over present plantation practices.

The first study in Phase II was undertaken to determine the dilution necessary for an optimal balance of water disposal and sugar yield. Secondary objectives of the project were to determine the quantities of nitrogen leaching past the root zone and to continue monitoring of sewage effluent for the presence of human enteric viruses.

The Hawaiian sugarcane variety 59-3775 was planted in October 1976 in the 30 test plots in Oahu Sugar Company Field 246 near Mililani. Five irrigation treatments for the 2-yr cycle with six replicates in a randomized block design were: (1) ditch water, (2) 12.5%, (3) 25%, (4) 50% effluent diluted with ditch water, and (5) effluent the first year and ditch water the second year. Irrigation rounds of up to 4 in. were applied biweekly. Tensiometers in selected test plots monitored water stress conditions. Representative soil samples were collected and analyzed shortly after sugarcane planting. The fertilization program was designed to utilize the effluent nitrogen and to reduce the commercial nitrogen to be applied. Commercial fertilizer applications of N, P, and K to the test plots were completed in June 1977.

Four crop logs were made on sugarcane growth in the test plots. The physical appearance of that growth was very good; however, the relatively low K-H_2O index and the high total sugars from the crop log indicate a possible growth imbalance. Due to a very dry winter, rainfall during this period was nearly one-half of normal, whereas evaporation was more than 50% above normal.

Secondary effluent from the Mililani STP is typical of domestic sewage, although it has a higher BOD_5 than experienced during Phase I. The effluent is monitored on a routine basis at the STP and also at a storage reservoir at the test site. Soil leachates are collected during each irrigation from representative plots beneath the root zone. The concentration of nitrogen in the leachates collected beneath the root zone fluctuates with fertilizer applications; but, after fertilizer applications were completed, increases in leachate nitrate nitrogen with the higher percentage of effluent in the irrigation water were observed. The nitrate nitrogen value of the percolate collected from the plots were 0.6, 2, 5, 12, and 28 mg/l and appeared to be consistent with the applied irrigation dilutions.

Virus tests on the effluent at the STP have been positive, but tests on effluent from the field reservoir have been negative. These results indicate an apparent desirable effect of reservoir storage time, sunlight, or other biological factors in reservoir on virus inactivation. A soil sample from one of the plots receiving 100% effluent was also negative for viruses.

Inasmuch as irrigation of sugarcane in Hawaii is being converted to the more water efficient drip method, the Phase II drip irrigation study is concerned with what additional treatment of the secondary effluent is necessary to minimize plugging of the minute holes in the plastic tubing. The treatment will include pressurized sand filtration, screening, and disinfection, and reservoir or pond detention that would in combination reduce the suspended solids and microorganisms causing the plugging.

REUSE BY GRASSLAND (GOLF COURSE)

An important part of the Mililani pilot field study completed in 1975 was reuse by bermudagrass (*Cynodon dactylon* [L.] Pers.). This was conducted in hydraulic lysimeters at the Mililani STP using a similar methodology applied to the sugarcane study. With periodic cutting and harvesting, bermudagrass proved to be an excellent utilizer of sewage effluent applied nitrogen and thus excelled sugarcane from the standpoint of groundwater protection. Essentially no nitrogen was recovered from the percolate at the 5-ft depth below the grassed surface. Viral monitoring in percolate indicated that the sewage borne viruses are effectively retained within the first 0.6 in. of the sodded soils.

A further investigation of bermudagrass was conducted at a golf course at the Kaneohe Marine Corps Air Station, Oahu. The STP employs a single stage trickling filter, chlorination, and an aerated polishing pond. The effluent is either used for golf course irrigation or discharged into Kaneohe Bay. The effluent quality is essentially a mild to weak domestic sewage as a result of considerable (20 to 28%) infiltration of brackish groundwater. The N, P, K, concentrations of the effluent applied by sprinklers is 13, 9, 22 mg/l, respectively. The soils are the very well-drained Ewa silty clay loam and

Jaucas sand. The irrigation practice called for 0.4 in./wk for the fairways and tees and much more (2.2 in./wk) for the greens, supplementing less than 40 in. of annual rainfall. Chemical fertilizers in addition to effluent fertilizers were applied in the amounts of total N 208 lb/wk and total P 145 lb/wk. The crop growth shows no visual adverse effects attributable to the effluents. It should be noted that both sodium and chloride concentrations in the effluent are 230 and 329 mg/l, respectively, and are higher than the Mililani STP effluent which is free of infiltration by brackish groundwater.

The water table is located 7 to 10 ft below the sodded surface. The groundwater quality monitored in sampling test holes shows 86 to 98% removal of N and 100% removal of P, K, and fecal coliform. As all other studies reported here, the monitoring of air quality was another Hawaii first in research. A transect of elevated agar plates, used for total coliform count during a cycle of sprinkling, was located along the direction of prevailing trade winds. A decrease of 90% of the total coliform in the sprinkler effluent application was consistently achieved within 300 ft from the sprinkler head in an environment of moderate humidity (66 to 87% relative humidity), moderate temperature (75 to 76°F), and darkness, all possessing not especially strong bactericidal effects.

IV. EVALUATION AND PROJECTION

The potential value of water reclamation and reuse from sewage effluent by irrigation in Hawaii has been demonstrated by the Mililani STP case study. The study concluded that: (1) Mililani STP's secondary effluent, containing insignificant amounts of toxic chemicals (heavy metals and pesticides), represents a generally usable water supply for irrigation; (2) sewage effluent may be used for the first year of a 2-yr sugarcane crop cycle without decreased sugar yield, however when applied for an entire 2-yr cycle, sugar yield is reduced; and (3) the possibility of contaminating deep underground water sources is remote (Lau et al. 1975).

Although supportive of effluent irrigation, this WRRC study was not intended to answer technological questions associated with using secondary effluent in drip irrigation systems and what effect diluted effluent would have on sugar yield. Nevertheless, based on the results of the study, the Oahu Sugar Company has agreed to: (1) provide 1,000 acres of sugarcane fields for effluent irrigation, (2) accept 5 mgd of effluent, and (3) provide land for an effluent reservoir (City and County of Honolulu 1977).

In 1976 the WRRC undertook a research program to answer these technological questions. The completion of the research is expected to be sometime in 1979.

It should be noted that Oahu Sugar Company's commitment to accept the 5 mgd of effluent is not predicated on the results of the current WRRC research study. If necessary, furrow irrigation will be utilized, with effluent being used during the first year followed by Waiahole Ditch water during the second year (City and County of Honolulu 1977).

The City and County of Honolulu have adopted reclamation and reuse for Mililani waste water. The proposed engineering system would consist of an effluent pump station at the Mililani STP site, about 17,500 linear ft of effluent force main located within agricultural lands west of Mililani Town, and a 15-mil gal effluent reservoir at the junction of Poliwai and Manuwaihau gulches (Fig. 3). However, if the current studies on dilution of effluent with Waiahole Ditch water and on post-treatment by WRRC are favorable, the project would be terminated at Waiahole Ditch. This option would eliminate approximately 6,000 linear ft of force main and the effluent reservoir. Facilities for post-treatment viral inactivation and flow regulation will be provided if a need for these facilities is demonstrated by the current studies (City and County of Honolulu 1977).

Among the alternatives considered for Mililani waste water treatment and disposal were: (1) tertiary treatment and continued discharge into Kipapa Stream, (2) effluent disposal by deep well injection, (3) disposal of secondary effluent through deep ocean outfall for Honouliuli Waste Water Treatment Plant, and (4) disposal of untreated waste water to the Honouliuli waste water treatment system. None of these alternatives was judged acceptable and feasible. The selection of a reclamation-reuse alternative produces a significant savings in present worth values of up to $3.52 million (City and County of Honolulu 1976a).

Another major commitment of water reuse from sewage effluent for sugarcane irrigation was made by the Waialua Sugar Co. on Oahu in 1977. The effluent is from the following three sewage treatment plants (and their present discharge and plant capacities): Whitmore Village (0.17 and 0.2 mgd), Wahiawa (1.3 and 2.5 mgd), Schofield (1.6 and 4.1 mgd). The effluents will be diverted from their present discharge points into Wahiawa Reservoir, thus producing an additional benefit of alleviating several existing problems in the reservoir including fish kill, artificial aeration requirement at low flow, and localized eutrophication.

For more general application in Hawaii, a set of provisional principles and guidelines has been suggested for irrigation with sewage effluent (Lau et al. 1975). While not a definitive set of requirements for projects successfully utilizing effluent in Hawaii, this set of principles and guidelines is being used in planning future projects in Hawaii unless special measures are taken to compensate for any deviations. A summary checklist is as follows:

1. Effluent Quality Requirement
   - Secondary treatment and chlorination where necessary
   - Domestic and municipal origin
   - Minimal toxic chemicals
   - Low concentration of total dissolved solids, boron, suspended solids, and grease
   - Reasonably consistent quality over time
2. Soils and Crops
   - Soils suitable for crop growth
   - Soils with high sorptive capacity and high iron oxide preferred
   - Crops with high tolerance to nitrogen (as cane variety H59-3775) and/or salinity
   - Grass, such as bermudagrass, with thickly matted root system
   - Vegetable crops that are generally eaten after cooking
3. Irrigation and Fertilization
   - Maintain a no-water stress condition: for furrow irrigated sugarcane, 1-mgd supply for 150-200 acres @ 4.2 in. per round every 2 wk for an annual rain of about 40 in.; for sprinkler irrigated grassland, 1 mgd supply for 100 acres

- o Apply no excess of irrigation water for pollution control assuming the effluent is not too saline to require leaching
- o Provide a storage or bypass facility for non-irrigation period
- o Apply commercial fertilizers to give cane a fast growth start

4. Geohydrologic Considerations of Application Site
   - o Conduct a geohydrologic survey to ascertain the potable pathway of deep percolation and to determine groundwater occurrence, circulation, quality, recharge, and discharge
   - o Select areas of minimum soil thickness of 5 ft with high adsorptive capacity
   - o Determine minimum allowable depth to water table on a case-by-case basis of geology and potable groundwater quality
5. Monitoring Factors
   - o Selective monitoring of chemical, microbiological, and viral water quality, including STP effluent, leachate at bottom of root zone, and groundwater
   - o Selective monitoring of soil in terms of chemical properties and viruses
   - o Monitoring of crop growth and yield

A large quantity of municipal secondary treated effluent of adequate water quality for irrigation is available but not yet put to use at many different locations on Oahu according to an initial survey recently completed by the WRRC (Table 8). Readily usable and available for diversion is a total of 12 mgd from 16 different treatment plants some of which are located at high elevations, thus requiring little pumping. Four additional sources may also be added with additional treatments: three STP (Sand Island, Waianae, Pearl City) are presently primary treated; three (Sand Island, Waianae, Kailua) have moderately high TDS ranging from 3400 to 5400 mg/l. The cost of additional treatments may be justified in time with increasing needs for supplemental water.

Table 8. Effluent Quantity and Quality of Municipal Sewage Treatment Plants, Oahu, Hawaii

Treatment Plant	Design Capacity (mgd)	Type of Treatment	06/77 Flow (mgd)	Cl^-	TDS	TP	TN	K	Na	B
				(mg/l)						
Ahuimanu	1.4	T.F., Pond	0.31	64[a]	336[a]	10	21	7.6[a]	33[a]	.44[a]
Halawa Corr. Facil.	0.094	T.F.	0.02	--	--	10	21	--	--	--
Kailua	7.0	T.F.	4.26	2448	5387	6.5	19	--	--	--
Kaneohe	4.3	T.F.	3.47	756	1270	6.5	15.1	--	--	--
Kukanono	0.07	E.A., Pond	0.05	--	--	10	21	--	--	--
Makakilo Heights	0.60	A.S.	0.51	143[a]	536[a]	10	21	11.2[a]	92[a]	.50[a]
Maunawili 1 (Park)	0.14	E.A., Pond	0.10	61[a]	320[a]	10	21	8.8[a]	33.6[a]	.21[a]
Maunawili 2 (EST)	0.095	E.A.	0.10	41[a]	256[a]	10	21	6.4[a]	27[a]	.18[a]
Mililani	1.8	Rapid Bloc	1.33	51.6[b]	355[b]	13.2[b]	16.7[b]	9.5[b]	59[b]	.40[b]
Nanakai	0.125	E.A.	0.05	--	--	10	21	--	--	--
Pacific Palisades	0.675	T.F.	0.49	53[a]	348[a]	16	20.3	10.4[a]	39.8[a]	.49[a]
Pearl City	7.4	P.	6.69	336	667	8.6	15.3	--	--	--
Pohakupu	0.426	T.F.	0.31	76[a]	312[a]	10	21	8.8[a]	33[a]	.50[a]
Sand Island	82.0	P.	64.8	1388	3403	6.8	8.8	--	--	--
Wahiawa	2.5	A.S.	1.30	68[a]	368[a]	8.0	8.7	9.2[a]	36[a]	.57[a]
Waianae	1.72	P.	1.01	1749	4286	7.1	16	--	--	--
Waimanalo	1.1	Rapid Bloc	0.29	69[a]	308[a]	10	21	7.6[a]	34.2[a]	.24[a]
Waipahu	3.6	Stab. Ponds	2.79	284[c]	888[c]	12	20	--	--	--
Waipio	0.35	E.A.	0.16	43[a]	296[a]	10	21	8.0[a]	34.2[a]	.63[a]
Whitmore Village	0.20	E.A.	0.17	54[a]	296[a]	10	21	8.0[a]	33.6[a]	.38[a]

NOTE: Data from City and County of Honolulu except as noted otherwise.
*T.F. = trickling filter, A.S. = activated sludge, P. = primary, Stab. = stabilization, E.A. = extended aeration.
[a]WRRC (8 Dec. 2977) samples.
[b]Date from WRRC Tech. Rep. No. 94.
[c]WRRC (7 June 1978) sample.

Likewise, the military installations on Oahu presently produce about 10 mgd from 10 different sources (App. C). Except for the already mentioned Kaneohe MCAS and Schofield Barracks there is an additional 6 mgd effluent, most of which is secondary treated and all of which should be evaluated for possible reuse for irrigation.

Other candidate crops and application sites are worthy of consideration for Hawaii. Pasture grass, such as paragrass or californiagrass (*Brachiaria mutica* [Forsk.] Stapf) used as green-chopped forage; tropical fruits, papaya, and banana; macadamia nut trees (*Macadamia integrifolia* Maiden and Betche); and commercial vanda orchid production should be considered and tested. Geographic sites, such as the Ewa Plain, North Shore district (Waimea Bay to Kualoa Point), Waialua District (Kaena Point to Waimea Bay) and Waimanalo on Oahu possess considerable potential for effluent irrigation. It should be parenthetically noted that the estimated cost for the planned North Shore and Waialua Outfall is respectively $26 million and $30 million (City and County of Honolulu 1976*b*). It seems that reclamation and reuse should be thoroughly considered before huge expenditures are committed for such sparsely populated areas.

In summary, water reuse from sewage effluent by irrigation of sugarcane and bermudagrass golf courses has been established as an acceptable and feasible measure for water conservation and waste water management in Hawaii. Other crops are worthy of consideration. Although the economic impact and legal aspects have yet to be addressed, the scientific aspects are reasonably understood and the technological aspects are being investigated. The forecast favors immediate implementation of reclamation and reuse of effluent for irrigation in Hawaii.

SOURCE: Board of Water Supply 1971.

FIGURE 4. GENERAL HYDROLOGIC AND GEOLOGIC CHARACTERISTICS OF OAHU

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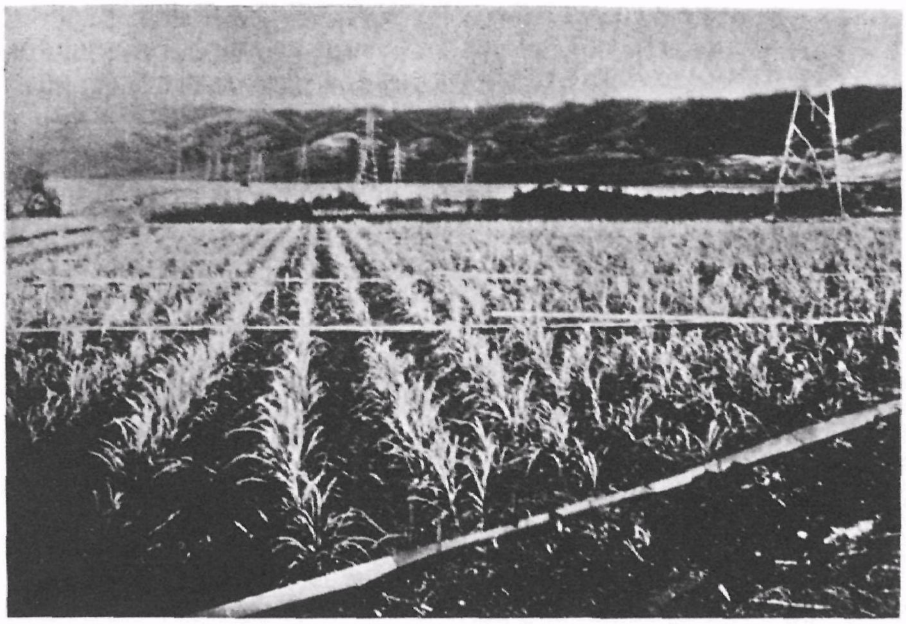
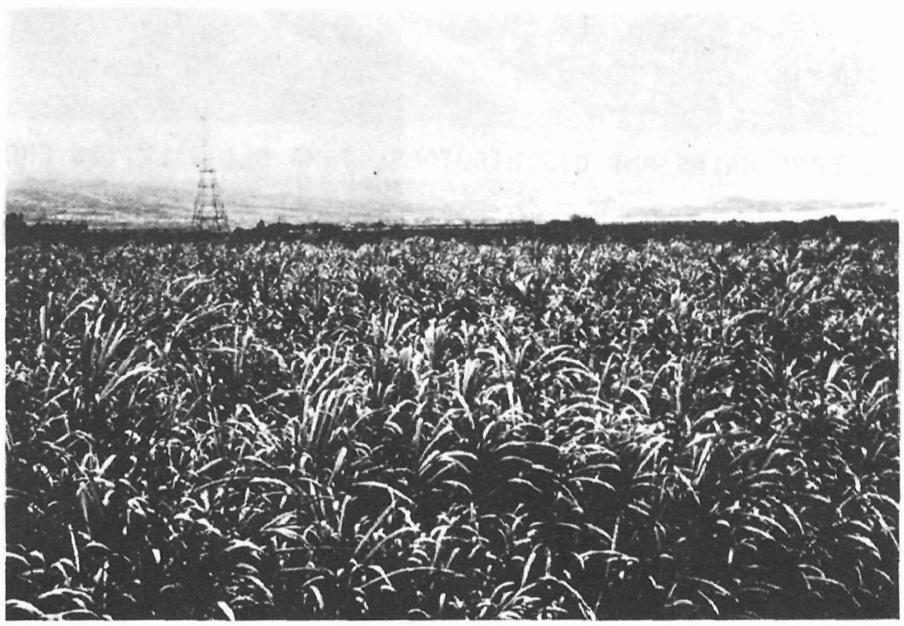


Photograph No. 1. NEWLY PLANTED PROJECT SUGARCANE IN OAHU SUGAR COMPANY FIELD NO. 246



Photograph No. 2. MATURE PROJECT SUGARCANE ON OAHU SUGAR COMPANY FIELD NO. 246. CANE GROWTH ABOUT 25 MONTHS JUST BEFORE HARVEST.

Photographs by P.C. Ekern

PLATE 3. PVC MAINS AND DISTRIBUTORS, 7-MO OLD DILUTION CROP

VI. APPENDICES

APPENDIX TABLE A.1

Quality Constituents of Percolate in Effluent

Irrigated (E) Sugarcane in Lysimeters

DATE	pH	TDS	COND. @ 25°C µmhos/cm	TOTAL HARD-NESS	NITROGEN as N: NH_3-N	NITROGEN as N: NO_2+ NO_3	NITROGEN as N: TOTAL	PO_4-P	Ca	Mg	Na	K	Cl	SO_4	SiO_2
		mg/ℓ		mg/ℓ											
(1973) JUN 14	7.4	—	350	158	0.25	21.00	21.25	—	—	—	41	8.0	70	--	—
JLY 2	—	374	440	187	--	6.59	--	0.033	—	—	33	1.7	86	14	14
JLY 10	7.2	--	470	254	--	12.04	12.04	0.048	20	50	31	2.0	83	10	17
JLY 12	7.4	453	420	259	--	4.22	--	0.024	33	43	29	2.0	91	10	—
JLY 24	7.4	538	580	269	1.39	7.31	8.70	0.047	44	39	34	1.5	83	14	11
JLY 25	7.1	—	—	326	0.12	9.56	9.68	0.08	72	36	32	1.8	93	12	16
JLY 26	7.4	722	---	302	0.09	8.46	8.55	0.05	61	36	31	1.5	122	8	15
JLY 31	7.3	650	460	300	0.04	7.16	7.20	0.06	42	48	46	3.8	112	11	15
AUG 3	7.1	730	510	275	0.09	15.56	15.65	0.03	72	23	30	1.5	112	9	13
AUG 6	7.1	610	500	315	0.09	14.80	14.89	--	68	35	30	1.5	130	9	14
AUG 7	7.6	642	490	245	--	7.72	—	0.04	33	40	29	2.2	120	8	14
AUG 8	7.1	802	530	345	0.17	7.92	8.09	0.05	79	36	29	1.5	139	8	14
AUG 13	7.0	630	—	275	0.41	10.72	11.13	0.09	42	41	26	2.2	—	8	14
AUG 14	--	726	412	330	0.63	—	--	0.04	—	—	—	—	132	8	11
AUG 22	7.3	716	550	320	0.12	21.48	21.60	—	54	45	26	2.0	155	—	16
AUG 23	7.3	762	540	315	0.12	8.83	8.95	—	50	46	26	2.0	155	—	17
SEP 5	7.6	746	580	385	0.53	21.20	21.73	0.05	60	57	37	2.0	118	13	17
SEP 12	7.2	652	620	380	0.33	18.58	18.91	0.03	84	41	34	1.2	100	14	12
OCT 4	7.6	806	545	430	0.75	25.18	25.93	0.03	92	49	37	1.4	95	13	6
OCT 11	6.8	610	740	384	ND	20.99	20.99	0.03	55	60	36	1.8	103	13	9
OCT 15	7.6	522	580	380	0.30	26.29	26.59	0.05	54	60	44	1.4	95	13	9
OCT 17	6.8	598	600	378	0.55	27.81	28.36	0.03	54	59	44	2.1	85	11	6
OCT 18	7.7	680	—	328	ND	19.07	19.07	0.01	55	47	35	1.5	115	12	8
OCT 19	7.5	748	560	380	0.35	20.71	21.06	0.03	54	60	36	2.1	110	12	2
OCT 25	7.7	760	560	350	ND	21.31	21.31	0.01	53	53	38	2.1	95	12	8
NOV 7	6.8	558	555	320	ND	18.41	18.41	0.02	60	42	47	1.5	75	10	12
NOV 9	7.1	578	640	348	ND	26.25	26.25	0.02	51	54	57	2.3	98	13	14
NOV 12	7.3	676	640	344	ND	17.84	17.84	0.13	60	47	34	1.5	108	12	13
NOV 14	7.2	654	720	356	ND	26.25	26.25	0.08	50	56	39	1.4	100	12	13
NOV 16	7.2	590	580	364	ND	19.99	19.99	0.11	55	55	36	1.5	108	11	9
NOV 19	7.6	666	600	364	ND	13.50	13.50	0.03	55	55	39	1.8	103	12	13
DEC 3	7.4	--	---	—	ND	18.90	18.90	0.26	--	—	—	—	150	14	77
DEC 6	7.4	666	660	328	ND	14.99	14.99	0.12	76	34	40	2.0	113	13	18
DEC 21	7.3	580	620	312	ND	23.48	23.48	0.13	68	35	56	1.3	74	10	16
DEC 24	7.2	614	640	312	ND	7.82	7.82	0.13	76	30	48	1.5	92	12	11
DEC 28	7.9	550	610	312	0.90	20.38	21.28	ND	75	30	44	1.5	98	11	9
DEC 31	7.8	520	660	332	1.06	21.00	22.06	ND	75	35	47	1.3	92	10	7
(1974) JAN 2	7.5	560	660	352	0.89	23.10	23.99	ND	80	37	45	1.1	78	9	16
JAN 3	7.6	534	650	336	1.26	21.27	22.53	ND	78	34	44	1.3	86	10	14
JAN 4	7.4	530	680	332	1.22	18.23	19.45	ND	89	27	43	1.3	94	8	14

Appendix Table A.1.—Continued

DATE	pH	TDS mg/ℓ	COND. @ 25°C μmhos/cm	TOTAL HARD-NESS	NITROGEN as N: NH_3-N	NO_2+ NO_3	TOTAL	PO_4-P	Ca	Mg	Na	K	Cl	SO_4	SiO_2
				mg/ℓ											
(1974)															
JAN 7	7.5	--	800	304	1.30	16.56	17.86	ND	86	22	40	1.3	88	9	16
JAN 11	7.6	500	840	320	1.26	21.11	22.37	ND	88	24	44	1.3	82	9	7
JAN 14	7.4	450	820	304	0.76	13.68	14.44	ND	84	23	45	1.1	76	8	9
JAN 16	7.3	330	800	296	0.79	10.88	11.67	ND	79	24	41	1.1	74	9	8
JAN 21	7.6	392	780	312	0.86	7.98	8.84	ND	91	21	41	1.1	76	9	11
JAN 22	7.7	436	750	300	0.77	10.26	11.03	ND	85	21	44	1.5	74	10	4
JAN 31	7.7	450	710	280	0.08	8.26	8.34	ND	63	30	44	1.1	58	11	9
FEB 4	7.2	402	720	256	0.27	7.85	8.12	ND	48	33	48	0.5	58	9	7
FEB 11	7.7	--	680	256	0.11	3.91	4.02	ND	60	26	47	1.1	60	10	6
FEB 27	7.2	--	630	244	0.52	1.14	1.66	ND	69	17	45	0.9	44	9	11
MAR 8	7.7	--	700	264	ND	0.99	0.99	ND	74	19	39	0.9	70	9	7
MAR 14	7.6	--	680	252	ND	0.50	0.50	ND	74	16	42	0.8	56	8	9
MAR 20	7.5	410	690	260	0.55	0.51	1.06	ND	74	18	41	0.9	58	9	13
MAR 21	7.6	428	670	264	0.79	0.57	1.36	ND	76	18	38	1.6	64	9	13
APR 5	7.0	380	680	272	0.64	0.13	0.77	0.01	76	20	46	0.9	40	9	10
APR 11	7.4	394	670	280	ND	0.46	0.46	ND	78	21	46	1.0	52	9	9
APR 22	7.4	426	710	280	ND	0.25	0.25	0.01	79	20	47	1.0	42	10	7
APR 25	7.6	400	650	284	ND	0.37	0.37	ND	79	21	44	1.0	—	—	9
MAY 9	7.3	360	580	224	—	0.77	—	0.004	63	16	43	1.0	—	--	—
MAY 10	7.5	400	680	280	0.24	0.29	0.53	0.016	72	24	50	1.3	38	12	13
MAY 20	7.2	416	700	288	0.12	0.35	0.47	0.010	67	29	47	1.3	44	12	13
JUN 3	7.2	380	670	272	0.11	1.92	2.03	ND	62	28	48	1.3	40	11	11
JUN 15	6.9	--	—	—	—	1.56	--	—	—	—	—	—	—	42	—
JUN 20	7.4	388	690	240	0.05	1.45	1.50	ND	62	21	52	1.3	—	11	15
JUN 26	7.1	354	600	236	ND	—	ND	ND	26	42	52	1.3	--	--	9
JLY 2	6.7	446	660	248	0.10	2.64	2.74	0.023	62	23	56	1.1	—	10	13
JLY 15	6.9	384	—	272	0.17	1.52	1.69	0.026	62	28	56	1.1	--	—	14
JLY 18	--	—	--	—	—	0.72	—	—	—	—	—	—	--	12	—
AUG 4	--	—	580	240	ND	0.93	0.93	0.003	94	1.2	47	1.2	16	13	—
AUG 14	—	—	—	260	0.31	0.98	1.29	0.002	86	10.9	54	1.2	—	12	—
AUG 15	—	—	580	260	ND	0.44	0.44	0.003	82	13.4	55	1.2	53	13	—
AUG 16	--	—	680	290	ND	0.24	0.24	0.002	98	10.9	49	1.2	6	13	—
AUG 30	--	—	650	282	0.33	0.45	0.78	0.006	98	9.0	58	1.2	16	12	—
SEP 9	—	—	690	244	0.07	0.24	0.31	0.036	90	4.6	50	1.3	55	12	—
SEP 10	--	—	680	256	ND	0.90	0.90	0.007	90	7.5	56	1.3	60	10	--
SEP 20	—	—	600	260	ND	1.00	1.00	0.006	91	7.9	39	2.2	58	10	—
SEP 23	—	—	650	254	ND	0.14	0.14	0.019	92	5.8	55	1.1	59	10	—
OCT 4	--	—	680	248	0.07	0.63	0.70	ND	92	4.4	60	1.5	84	9	—
OCT 29	--	—	660	254	0.16	0.56	0.72	ND	92	5.9	48	1.7	51	10	—
NOV 11	--	—	660	204	—	4.40	—	0.040	60	13.1	56	1.3	—	10	—
NOV 27	—	—	620	236	ND	1.00	1.00	—	74	12.6	55	1.0	70	10	--

Appendix Table A.1—Continued

DATE	pH	TDS mg/ℓ	COND. @ 25°C µmhos/cm	TOTAL HARDNESS	NITROGEN as N NH_3-N	NO_2+NO_3	TOTAL	PO_4-P	Ca	Mg	Na	K	Cl	SO_4	SiO_2
				mg/ℓ											
(1975)															
JAN 14	—	—	—	182	—	—	—	—	60	7.8	63	1.4	65	—	—
JAN 14	—	—	—	180	—	—	—	—	59	7.9	63	2.8	67	—	—
JAN 15	—	—	—	170	—	—	—	—	50	10.9	54	1.0	70	—	—
FEB 5	—	—	—	128	—	—	—	0.010	43	5.0	38	0.9	31	—	—
FEB 7	—	—	—	180	—	—	—	ND	67	3.0	50	0.9	52	—	—
FEB 11	—	—	—	164	—	—	—	ND	62	2.2	51	0.9	61	—	—

APPENDIX TABLE B.1

Quality Constituents of Percolate in Ditch Water

Irrigated (D) Sugarcane in Lysimeter

DATE	pH	TDS mg/ℓ	COND. @ 25°C µmhos/cm	TOTAL HARD-NESS	NITROGEN as N: NH_3-N	NO_2+ NO_3	TOTAL	PO_4-P	Ca	Mg	Na	K	Cl	SO_4	SiO_2
				mg/ℓ											
(1973)															
JUN 15	7.5	--	340	62	0.10	17.92	18.02	—	—	--	34	2.3	84	—	—
JLY 2	--	—	450	101	—	6.56	--	0.041	—	—	33	1.7	98	6	13
JLY 10	7.6	406	480	226	—	9.30	--	0.048	21	42	24	2.0	86	—	18
JLY 12	7.3	387	420	206	--	5.22	—	0.026	15	41	24	2.3	98	10	15
JLY 24	7.7	394	500	187	0.53	7.63	8.16	0.051	29	28	31	1.8	98	21	13
SEP 5	7.1	808	510	390	0.26	37.09	37.35	0.13	54	62	34	3.0	110	26	15
SEP 19	7.2	—	--	500	0.32	56.35	56.67	0.10	110	54	38	2.7	130	27	21
OCT 4	7.1	966	655	480	1.20	48.96	50.16	0.05	--	--	43	3.4	115	24	—
OCT 11	7.3	1046	700	528	ND	44.49	44.49	0.02	60	92	47	3.6	123	19	5
OCT 15	7.2	1060	940	640	0.95	59.71	60.66	0.08	97	97	50	4.4	143	23	55
OCT 17	6.8	958	800	610	ND	57.06	57.06	0.05	102	86	44	2.4	135	13	9
OCT 18	7.1	316	740	568	ND	36.58	36.58	0.03	60	102	41	2.3	138	12	25
OCT 19	7.5	862	580	490	0.56	31.91	32.47	0.05	70	77	35	1.4	123	11	ND
OCT 25	7.8	754	640	420	ND	9.19	9.19	0.01	54	69	35	1.0	113	12	1
NOV 7	7.3	714	580	392	ND	19.89	19.89	0.02	60	59	21	0.9	100	10	1
NOV 9	7.4	696	565	388	ND	17.84	17.84	0.03	60	58	27	0.9	113	10	9
NOV 12	7.6	550	640	380	ND	11.03	11.03	0.18	52	61	27	1.8	113	12	10
NOV 14	7.7	606	645	356	ND	8.64	8.64	0.13	76	41	—	—	108	11	10
NOV 16	7.7	552	620	336	ND	7.46	7.46	0.13	55	48	27	0.9	105	15	4
NOV 19	8.0	576	—	276	ND	5.00	5.00	0.20	—	—	--	--	108	13	5
DEC 3	7.4	428	490	308	ND	1.37	1.37	0.16	79	27	36	1.3	95	11	1
DEC 6	7.6	410	480	288	ND	0.68	0.68	0.14	84	19	33	1.0	98	10	6
DEC 21	7.4	348	410	292	ND	1.56	1.56	0.12	84	20	28	1.0	--	12	1
DEC 24	7.5	414	420	292	ND	0.56	0.56	0.10	73	27	30	1.0	—	9	1
DEC 28	7.6	70	385	288	0.99	0.11	1.10	ND	85	18	32	0.7	82	8	ND
DEC 31	7.8	342	440	296	0.99	0.12	1.11	ND	75	26	27	1.1	76	7	ND
(1974)															
JAN 2	7.7	330	410	288	0.87	0.24	1.11	ND	78	23	24	0.5	66	7	8
JAN 3	7.4	394	495	288	0.83	0.09	0.92	ND	79	22	24	0.5	68	17	9
JAN 4	7.5	250	480	280	0.83	0.04	0.87	ND	80	20	23	0.5	62	6	17
JAN 7	7.4	360	630	272	0.75	0.03	0.78	0.33	72	22	24	0.5	68	6	17
JAN 11	7.6	280	630	288	0.71	0.02	0.73	0.15	73	26	24	0.5	68	7	2
JAN 14	7.4	314	630	260	0.81	0.02	0.83	ND	75	18	24	0.5	60	6	2
JAN 16	7.3	318	580	248	0.64	0.01	0.65	ND	79	12	22	0.4	50	6	1
JAN 21	7.2	224	590	248	0.62	0.01	0.63	ND	83	10	23	0.4	56	7	1
JAN 22	7.6	282	560	240	0.47	0.02	0.49	ND	69	16	22	0.4	46	7	1
JAN 31	7.9	250	550	244	0.46	0.04	0.50	ND	73	15	23	0.5	50	8	ND
FEB 4	7.1	--	535	236	0.40	0.02	0.42	ND	56	23	19	0.5	38	6	ND
FEB 11	7.5	—	520	240	0.23	0.02	0.25	ND	58	23	23	0.5	40	8	ND
FEB 27	7.4	--	550	260	0.59	0.02	0.61	--	70	21	21	0.7	38	9	ND

Appendix Table B.1.—Continued

DATE	pH	TDS mg/ℓ	COND. @ 25°C µmhos/cm	TOTAL HARD-NESS	NITROGEN as N NH_3-N	NO_2+ NO_3	TOTAL	PO_4-P	Ca	Mg	Na	K	Cl	SO_4	SiO_2
				mg/ℓ											
(1974)															
MAR 8	7.8	—	530	244	ND	0.02	0.02	ND	68	18	20	0.4	38	8	ND
MAR 14	7.6	--	540	240	ND	0.01	0.01	ND	69	16	20	0.4	34	7	52
MAR 20	7.7	336	480	240	0.40	0.01	0.41	ND	70	16	21	0.4	--	9	6
MAR 21	7.7	312	500	240	0.32	0.01	0.33	ND	70	16	18	0.4	--	7	ND
APR 5	7.2	324	540	256	0.14	0.60	0.74	0.01	71	19	15	0.5	34	8	1
APR 11	7.4	322	550	256	ND	0.03	0.03	0.01	74	17	15	0.5	34	7	1
APR 22	8.1	314	520	252	ND	0.02	0.02	ND	70	19	18	0.6	28	8	1
APR 25	7.9	312	500	244	ND	0.02	0.02	ND	64	20	18	0.6	--	—	2
MAY 9	6.9	176	290	120	—	0.01	—	0.023	27	13	12	2.7	—	—	2
MAY 10	7.3	230	315	176	0.15	ND	0.15	0.016	40	19	13	1.5	26	10	3
MAY 20	7.2	266	432	200	0.06	ND	0.06	0.016	46	10	18	1.3	26	10	1
MAY 25	7.4	230	440	208	0.16	0.02	0.18	0.016	46	11	18	1.3	24	—	2
JUN 3	7.7	308	530	256	0.02	0.03	0.05	0.016	60	26	19	0.9	32	9	1
JUN 20	7.6	310	540	248	0.18	0.07	0.25	0.016	60	24	19	0.9	—	10	1
JUN 26	6.8	312	530	264	ND	ND	ND	0.016	62	27	19	0.9	—	—	3
JLY 2	6.6	370	550	272	0.14	0.03	0.17	0.023	60	30	19	0.8	—	11	2
JLY 10	6.7	360	520	268	0.16	0.04	0.20	0.020	58	30	17	1.1	—	11	3
JLY 18	—	—	—	—	—	0.03	—	—	—	—	—	—	—	11	—
AUG 2	7.8	—	460	258	0.11	0.06	0.17	0.019	98	3.2	18	1.0	26	10	—
AUG 14	—	—	440	234	ND	0.02	0.02	0.012	90	2.2	17	1.0	25	10	—
AUG 15	—	—	440	244	ND	0.02	0.02	0.007	86	7.0	17	1.0	21	10	—
AUG 16	—	—	450	240	ND	0.01	0.01	0.010	90	3.6	16	1.0	24	10	—
AUG 30	—	—	490	268	1.30	0.06	1.36	0.027	98	5.6	20	1.0	24	10	—
SEP 4	—	—	540	272	0.08	0.05	0.13	0.106	100	5.3	20	2.1	25	10	—
SEP 9	—	—	540	270	0.05	0.14	0.19	0.058	97	6.7	20	1.8	24	9	—
SEP 10	—	—	520	268	ND	0.15	0.15	0.008	100	4.4	21	0.7	23	10	—
SEP 20	—	—	560	270	ND	0.02	0.02	0.014	100	4.9	19	0.9	28	9	—
SEP 23	—	—	520	244	ND	0.01	0.01	0.007	96	1.0	20	0.6	28	7	—
OCT 4	—	—	550	264	0.16	0.26	0.42	0.001	96	5.9	16	1.3	27	8	—
OCT 29	—	—	500	266	0.16	0.10	0.26	ND	98	5.1	17	2.5	24	10	—
NOV 11	—	—	600	268	ND	0.04	0.04	0.022	80	16.5	17	0.8	25	10	—
NOV 27	—	—	510	256	ND	0.02	0.02	—	78	14.8	22	1.0	24	9	—
(1975)															
JAN 14	—	—	—	210	—	—	—	—	62	13.4	17	1.8	35	—	—
JAN 14	—	—	—	220	—	—	—	—	64	14.6	18	1.8	34	--	—
JAN 15	—	—	—	230	—	—	—	—	66	15.8	17	1.3	33	—	—
FEB 7	—	—	—	120	—	—	—	—	48	—	12	4.7	30	—	—
FEB 11	--	--	--	188	—	—	—	--	67	5.0	15	2.0	30	--	—

APPENDIX TABLE C.1
Effluent Quantity and Quality of Military Installation

Sewage Treatment Plants, Oahu, Hawaii

	Type	Flow (mgd)	T-P (mg/l)	T-N (mg/l)
Aliamanu	T.F.	0.24	10	21
Ft. Kam	A.S.	4.1	* 5	*12
Capehart Hsg., Iroquois Pt.	P.	0.53	*10.8	*28.8
Capehart Hsg., Manana	T.F.	0.1	10	21
Barbers Pt. NAS	P.	1.5	* 9.6	*27
Lualualei NRS	Stab. Pond	0.2	10	21
Wahiawa NCS	T.F.	0.29	10	21
Schofield	T.F.	3.2	*18.9	*21.1
Helemano	T.F.	0.5	10	21
Kaneohe MCAS	T.F.	1.0	10	27
Total		11.66 mgd		

*Tetra Tech, In. 1975 and WQPO 1969-1970 Work Area 2A 1971.
T.F. = trickling filter, A.S. = Activated sludge, P. = primary, Stab. = stabilization.

APPENDIX TABLE D.1

Conversion Factors

English Unit	Abbr.	Multiplier	Abbr.	SI Unit
acre	acre	4047	m^2	square meter
degree Fahrenheit	°F	+459.67 - 1.8	K	kelvin
foot (feet)	ft	0.304 8	m	meter
inch	in.	0.025 4	m	meter
million gallon	mil gal	2785	m^3	cubic meter
million gallons per day	mgd	0.043 81	m^3	cubic meter per second
pound	lb	0.404 7	kg	kilogram

Abbreviations

BOD_5	biochemical oxygen demand (5-day)
Ca	calcium
$CaCO_3$	calcium carbonate
cm	centimeter
α chlordane	alpha chlordane
γ chlordane	gamma chlordane
Cl^-	chloride
DDD	dichlorodiphenyldichloroethane
DDE	dichlorodiphenylethane
DDT	dichlorodiphenyltrichloroethane
effl.	effluent
ft	foot (feet)
hr	hour
in.	inch
K	potassium
Mg	magnesium
MBAS	methylene blue active substances

Abbreviations—Continued

μmhos/cm	micromhos per centimeter
μg/ℓ	microgram per liter
ml, mℓ	milliliter
mV	millivolt
mg/l, mg/ℓ	milligram per liter
mgd	million gallons per day
N	nitrogen
Na^+	sodium
$NO_2^- + NO_3^-$ N	nitrite plus nitrate nitrogen
PCB	polychlorinated biphenyl
PCP	pentachlorophenol
pH	hydrogen-ion concentration
PO_4-P	orthophosphate phosphorus
Res.	reservoir
SiO_2	silica
$SO_4^=$	sulphate
STP	sewage treatment plant
TDS	total dissolved solids

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