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¹² ABSTRACT (PURPOSE, METHOD, RESULTS, CONCLUSIONS) <p>Groundwater is the source of 99% of the drinking water provided to consumers on Oahu, the major island in the state of Hawaii. However, virtually all approved sources of water on Oahu have been planned for use. As a result, plans for new urban development are currently being delayed for lack of approved water sources. A well to provide drinking water was dug by a private developer in an area of questionable groundwater quality. This investigation assessed the quality of the groundwater and determined whether sewage effluent, which was discharged into an unlined ditch in the vicinity of the well, had an impact on the quality of the groundwater. The quality of groundwater from a new well dug near the coastal plain on Oahu was determined by pumping out 1 022 m³ (270,000 gal) of water over 1.5 days and analyzing nine representative samples. No fecal coliforms (<1/100 ml) and only 1.6 fecal streptococcus/ 100 ml were recovered in the nine samples. Also, no human enteric virus was recovered in the four 0.38-m³ (100-gal) samples, an indication that the groundwater was not contaminated with sewage. One and three foot soil percolates collected under the ditch which transported sewage near the well were similarly analyzed and the results indicated that it would be most unlikely for sewage-borne bacteria and viruses in the effluent to percolate through the soil profile to contaminate the groundwater. The groundwater was also analyzed for eleven chemicals. The concentration of total dissolved solids (750 mg/l) was the only measurement which exceeded the MCL for drinking water, although the concentration of chloride (241 mg/l) closely approximated its MCL. Blending of this groundwater with high quality groundwater is a viable alternative of increasing the volume of potable water required for urban expansion.</p>	

AUTHORS:

Dr. Roger S. Fujioka
Professor
The School of Public Health
and
Researcher
Water Resources Research Center
University of Hawaii at Manoa
2540 Dole Street
Honolulu, HI 96822
Tel.: 808/948-8021

Dr. L. Stephen Lau
Director
Water Resources Research Center
Univeristy of Hawaii at Manoa
2540 Dole Street
Honolulu, HI 96822
Tel.: 808/948-7848

**MONITORING MAKAKILO WELL NO. 1 FOR HUMAN
ENTEROVIRUSES AND SELECTED BACTERIA INDICATORS**

Roger S. Fujioka
L. Stephen Lau

Technical Memorandum Report No. 81

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Project Completion Report
for
Monitoring of Makakilo Well No. 1 Water
for Human Enteric Viruses and Selected Bacterial Indicators
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Principal Investigator: Roger S. Fujioka

WATER RESOURCES RESEARCH CENTER
University of Hawaii at Manoa
Honolulu, Hawaii 96822

ABSTRACT

Groundwater is the source of 99% of the drinking water provided to consumers on O'ahu, the major island in the state of Hawai'i. However, virtually all approved sources of water on O'ahu have been planned for use. As a result, plans for new urban development are currently being delayed for lack of approved water sources. A well to provide drinking water was dug by a private developer in an area of questionable groundwater quality. This investigation assessed the quality of the groundwater and determined whether sewage effluent, which was discharged into an unlined ditch in the vicinity of the well, had an impact on the quality of the groundwater.

The quality of groundwater from a new well dug near the coastal plain on O'ahu was determined by pumping out 1 022 m³ (270,000 gal) of water over 1.5 days and analyzing nine representative samples. No fecal coliforms (<1/100 ml) and only 1.6 fecal streptococcus/100 ml were recovered in the nine samples. Also, no human enteric virus was recovered in the four 0.38-m³ (100-gal) samples, an indication that the groundwater was not contaminated with sewage. One and three foot soil percolates collected under the ditch which transported sewage near the well were similarly analyzed and the results indicated that it would be most unlikely for sewage-borne bacteria and viruses in the effluent to percolate through the soil profile to contaminate the groundwater. The groundwater was also analyzed for eleven chemicals. The concentration of total dissolved solids (750 mg/l) was the only measurement which exceeded the MCL for drinking water, although the concentration of chloride (241 mg/l) closely approximated its MCL. Blending of this groundwater with high quality groundwater is a viable alternative of increasing the volume of potable water required for urban expansion.

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INTRODUCTION

Preliminary Evaluation for Proposed Use of Makakilo Well No. 1

The Makakilo Well No. 1 site is located in southwestern O'ahu, Hawai'i at the Makakilo Interchange, the intersection of the H-1 Freeway and Makakilo Drive, where the 'Ewa plain abuts the foothills of the Wai'anae Range (Fig. 1). The ground elevation of the well is 43-m (141-ft) above sea level, and the static water level in the well is about 4.3 to 4.6 m (14-15 ft) above sea level. The groundwater within this area occurs as a Ghyben-Herzberg basal lens in a basaltic aquifer composed of the Waianae volcanic series and flows from northeast to southwest along a gradient of 0.4 m/km (1.3 ft)/mile (M & E Pacific 1981). Recharge sources for this aquifer have been reported to include some rainfall in the southern Wai'anae Range, some leakage from the Koolau basaltic aquifer in the Pearl Harbor basin, and considerable return flow from sugarcane irrigation (M & E Pacific 1981).

An assessment to use this well water for potable purposes was conducted by M & E Pacific, Inc. and J.F. Mink. As stated in that report, the water for this well should meet the Hawaii State Department of Health (1977) requirements of Chapter 49, Section 29, Public Health Regulations, for new sources of raw water to be used for municipal water systems. Based on all the available data, the M & E Pacific report concludes that Makakilo Well water is expected to be marginal in quality and to be at the upper limits of chloride and total dissolved solids requirement of the drinking water standards. However, by blending this source of water with higher quality water, both the chloride and total dissolved solids of the product water will meet the drinking water standards with regard to these two constituents of concern. Two sources have been cited as contributing to the high chloride and total dissolved solids of this aquifer water. First, this aquifer is located near the extreme downslope margin of the southern O'ahu groundwater system; therefore, normal accumulation of dissolved solids can be expected to be high. Second, a major source of water for this aquifer is the return flow from the irrigation of sugarcane, a source of recharge water known to contain high concentrations of dissolved solids (Visher and Mink 1964).

Sewage and Other Probable Sources of Groundwater Pollution

Water to be used for drinking water must be stringently analyzed for potential sources of contaminants. The report by M & E Pacific assessed several probable sources of groundwater pollution and their control measures (Table 1).

Sewage effluent as a source of contamination is of considerable concern. The Makakilo Wastewater Treatment Plant (WWTP) effluent was discharged for many years into the Oahu

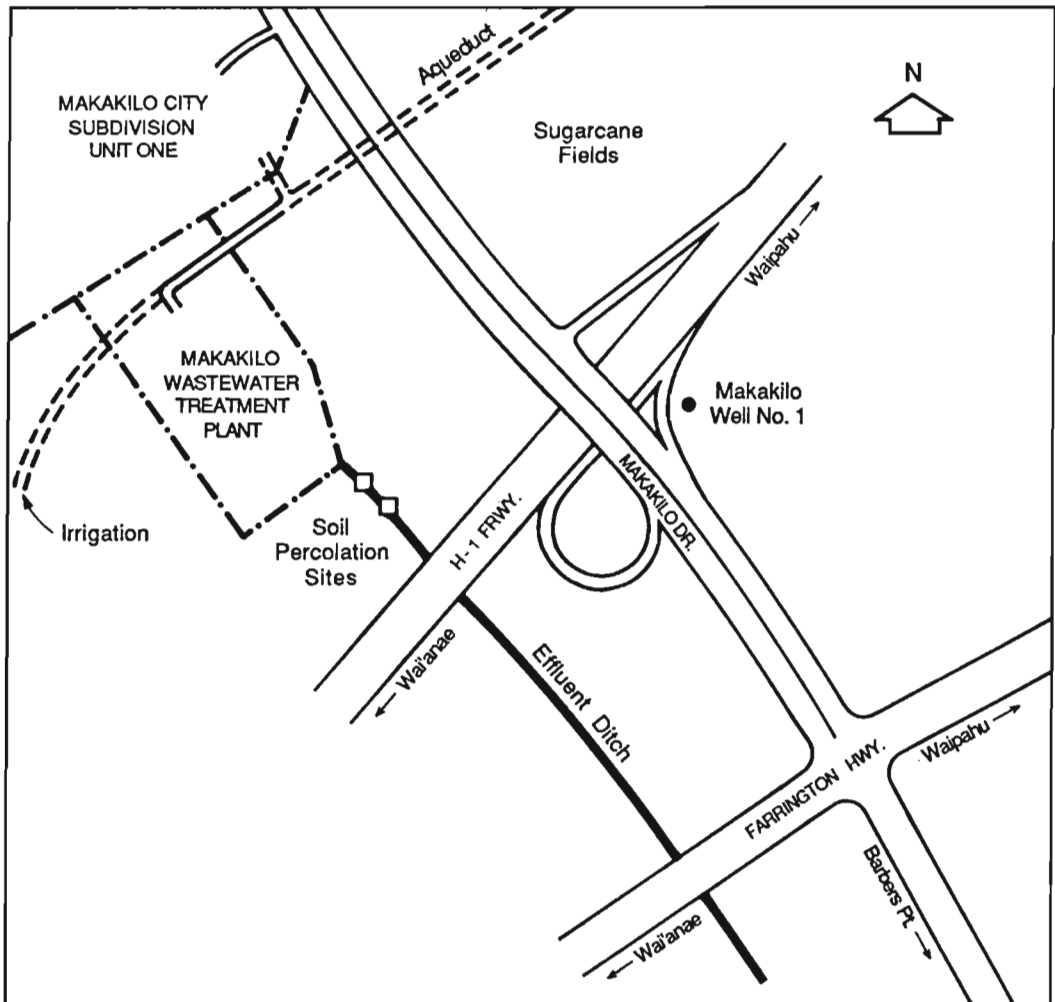


Figure 1. Makakilo Wastewater Treatment Plant, soil percolation sites, and Makakilo Well No. 1

Sugar Company's irrigation aqueduct system and mixed with ditch water to irrigate sugarcane within the Makakilo Well area. However, as of June 1981, effluent from the Makakilo WWTP was no longer added to the irrigation aqueduct system. Instead, it was first discharged into an oxidation pond in the WWTP and then continued into an unlined irrigation ditch located approximately 305 m (1000 ft) mauka of Makakilo Well. Currently, approximately 0.5 mgd (0.02 m³/s) of activated-sludge treated and chlorinated sewage effluent from Makakilo WWTP is discharged into the ditch water which flows in a direction southeast of the WWTP, under the H-1 Freeway, and to a sump located approximately 1.6 km (1 mile) from the WWTP and within the 'Ewa plain. Based on data obtained elsewhere on O'ahu, the report concludes that if the percolate from the ditch reached the well, it should be innocuous.

TABLE 1. CONTAMINANT SOURCES AND CONTROL MEASURES,
MAKAKILO WELL NO. 1, O'AHU, HAWAII

Contaminant Sources	Control Measures
Agriculture Biocides	Limit or prohibit use; if feasible, remove by absorption techniques from pumped water
Agriculture Fertilizers	Limit fertilizer use if serious increases occur in certain dissolved constituents, especially nitrate (This would impose a severe economic penalty on agriculture, and all of the water of southern Oahu would be affected, not only the Makakilo Well)
Return Irrigation	As 1 and 2 above
Pasturing	No contamination problems expected from this activity
Urban Runoff	No contamination problems expected from this activity (If contamination were identified, runoff would be diverted to caprock area of the Ewa plain)
Sewage Effluent	No contamination is anticipated but, should it occur, the effluent could be readily diverted to caprock portion of the aquifer
Sanitary Landfill	Well site too far upgradient of landfill site to be threatened, unless entire aquifer flow pattern were reversed
Seawater Intrusion	Controlled pumping from the Waianae aquifer is logical way to prevent intrusion; if it were to occur, desalination would be required to yield domestic quality water

SOURCE: M & E Pacific, Inc. (1981).

It should be noted that this area is located within a transitional zone with regard to the geomorphologic formation of the island of O'ahu (Ruhe et al. 1965; Foote et al. 1972). At the Makakilo Well site, the top soil is comprised of 0.3 to 0.6 m (1-2 ft) of the Molokai soil series a Typic Torrox of the Oxisol order which is characterized as being permeable, and consisting of kaolinitic clay plus stable iron and aluminum hydrates. The soil occurs as in-place residuum and no alluvium or other transported sediments occur at the well site. Below this top soil layer, lies a zone of 3.05 to 6.1 m (10-20 ft) of weathered rock (saprolite) which is less permeable than the top soil and the underlying unweathered, rigid and stable basalt of the Waianae series which forms the basement and where the basal groundwater occurs. However, the effluent ditch area is located within the Kapolei fan characterized by 1.5 to 4.6 m (5-15 ft) of top soil which has been transported from the mountain. This top soil is predominantly Ewa (Torroxic Haplustolls, Mollisols order; fine, kaolinitic, isohyperthermic) silty clay latosols. Beneath this top soil is the 3.05- to 7.6-m (10-25 ft) layer of marine clay characterized as gray hydromorphic followed by saprolite and the basement basaltic series of the Waianae series. The area in which sugarcane is grown also varies in geomorphology (Ruhe et al. 1965). These variations in the geomorphology make general prediction difficult and necessitate collection of field data for evaluation.

Human Enteroviruses: A Group of Sewage-Borne Pathogens of Special Concern

Over 100 different types of infectious human enteroviruses are known to be able to multiply in the alimentary tract of humans, to be shed with the fecal wastes of man, and to enter domestic sewage. These viruses are known to be more resistant than bacteria to natural environmental factors as well as to chlorination. Consequently, it is not surprising that human enteroviruses have been recovered from water samples which have been determined to be safe based on low or no recoveries of indicator bacteria. Infections by human enteroviruses are much more likely when small numbers of viruses, as compared to bacteria, are ingested by man. Notable among the diseases caused by human enteroviruses are poliomyelitis, hepatitis, and gastroenteritis.

Exhaustive virus studies were conducted over a 10-yr period by the University of Hawaii at Manoa Water Resources Research Center, on the occurrence of human enteroviruses in the Mililani sewage and effluent and on their fate when effluent was applied as irrigation water to sugarcane, grass sod, and soils (Lau et al. 1975; Fujioka and Loh 1978).

The results of these studies establish that the possibility of contaminating deep underground water sources by viruses is extremely remote. A brief summary of parts of the findings indicates the following.

1. Under the field condition of applying the Mililani effluent, viruses were effectively retained by absorption within a 1.5 m (5 ft) soil depth of Lahaina silty clay (Tropetric Haplustox, an Oxisol; clayey, kaolinitic, isohyperthermic), on which approximately 90% of irrigated sugarcane on O'ahu is grown.
2. In a number of corollary experiments with marker virus which involved application of extremely high concentration of viruses never encountered in sewage, the maximum percolation of viruses through the soil profile was not extensive: sod, 1.2 m (46 in.); bare soil, 0.9 m (36 in.); and undisturbed soil, 0.4 m (15 in.). Naturally packed soil appeared to be a better retardant of virus movement than repacked soil. The survival of virus adsorbed to irrigated soil was as short as 7 days when the soil was bare and exposed in sunlight, and as long as 61 days when the soil was protected from sunlight by a canopy of mature cane.

In studies conducted in other parts of the world, viruses have been recovered from drinking water wells which ranged in depths from 3 to 30 m (10-98 ft) (Keswick and Gerba 1980). Human enteroviruses have also been recovered in groundwater 3 m to 67 m (10-220 ft) beneath land receiving sewage effluent. These findings indicate that viruses can move through the soil stratum to contaminate groundwater. It should be noted, however, that the probability that viruses will move through the soil strata depends on a combination of many factors,

including the concentration of virus applied, the chemical composition of the suspending medium of the virus, the rate of water and virus applied, and the physical and chemical properties of the soil which affect its porosity and virus-adsorbing capacity. Therefore, the movement of viruses through given soil strata can only be predicted after the specific site in question is characterized. In this regard, sandy and organic soils are poor adsorbers of virus and thus allow extensive movement of virus, whereas soils high in clay and iron oxides—as are found in Hawai'i—are generally good virus adsorbers and thereby prevent extensive movement of viruses.

GOALS AND DESIGN

Our primary goal was to determine the microbiological quality of water samples obtained from Makakilo Well No. 1 and to assess the probability that human enteroviruses in the sewage effluent discharged by the Makakilo WWTP into an unlined ditch may be contaminating the underground water source for the Makakilo Well.

This study was divided into three phases to assess three specific objectives:

Phase I. To determine the concentrations and frequencies of human enteroviruses present in the treated effluent from the Makakilo WWTP.

Phase II. To determine the extent by which sewage-borne components (human enteroviruses, indicator bacteria) can be expected to percolate through the soil strata under the effluent ditch.

Phase III. To analyze water samples obtained from Makakilo Well No. 1 for microbiological (human enteroviruses, indicator bacteria) parameters used in the assessment of water quality.

METHODOLOGY

Sampling Methods

Sewage effluents were obtained by the grab method from the chlorine contact chamber and the oxidation pond located within the grounds of Makakilo WWTP and from the effluent ditch located approximately 46 m (150 ft) from the oxidation pond.

For percolate sampling, the flow of the effluent in the ditch was temporarily stopped by blocking the overflow pipe from the oxidation pond. Two PVC pipes (31.75 mm [1.25 in.] diameter) were laid at 0.3-m (1-ft) depths and two other pipes laid under 0.9 m (3 ft) of soil on 23 and 24 November 1981. Portions of the sampling pipes were drilled with 8-mm holes and

then wrapped with a permeable 12 μ porosity PVC membrane (Porvic, Atlas Minerals & Chemicals Division). This membrane prevented particulate matter from entering the pipe but allowed sewage-borne indicator bacteria, viruses, as well as water and chemical components of the water to enter the pipes. One end of the pipe was completely sealed while a tubing was attached to the other end of the pipe. Two of the pipes were laid approximately 0.3 m below the soil surface and within the relatively loosely packed top soil zone. The other two pipes were laid approximately 0.9 m below the soil surface and within the densely packed anaerobic, clay zone. The soil covering the pipes was manually repacked as well as possible and the effluent was then allowed to flow over these sampling sites. To collect percolate samples, a vacuum was applied to the tubing and the percolate was collected in sterile bottles. The time sequence to obtain soil percolates was to pump the pipes for 2 hr followed by a 1 hr rest period and a final 1 hr of pumping. By pooling the percolate from the two pipes at each of the site, a total of 0.011 to 0.015 m³ (3-4 gal) of water was thus obtained from the 0.3-m pipes while 0.004 to 0.011 m³ (1-3 gal) of water were obtained from the 0.9-m pipes. The pooled samples were analyzed for chemical, physical, and virus analyses.

To assess the variability of the soil-percolate quality, samples collected during the first 2 hr of pumping and during the last hour of pumping from each of the pipes were individually analyzed for fecal coliform (FC) and fecal streptococcus (FS). But because the concentrations of FC and FS from these individual analyses did not vary significantly, the quality of the soil percolates was concluded as being reasonably consistent throughout the entire pumping sequence. Consequently, the FC and FS counts from all the samples obtained from the 0.3 m (1 ft) or from the 0.9 m (3 ft) deep pipes were averaged and presented as a single figure.

Water from Makakilo Well No. 1 was obtained by contracting the services of Roscoe-Moss Company. To assess the quality of the aquifer water, it is necessary to ensure that the well water for analysis is indeed aquifer water and not stagnant water in the casing. A large volume of water is also needed for virus assay in the case of a very diluted solution. Thus, water was pumped out of the well at a high 0.0025 m³/s (400 gpm) and sustained rate and the water sampled over a period of many hours. During the first day of pumping (12 January 1982), a total of 674.9 m³ (178,300 gal) of water was pumped out over an 8.5-hr period and six samples were collected at 0900, 1000, 1200, 1400, 1600, and 1700 hr for physical, chemical, and bacteriological analyses. At approximately 1030, 1300, and 1630 hr, 0.38 m³ (100 gal) water samples were collected for human enteroviruses analysis. During the second day of pumping (13 January 1982), a total of 352.8 m³ (93,200 gal) of water was pumped over a 3-hr period and samples for routine water quality analysis were collected at 0915, 1115, and 1200 hr. At 1030 hr a single 0.38-m³ sample was collected for virus analysis.

Analysis of Water for Human Enteroviruses

The University of Hawaii at Manoa Water Resources Research Center and the Department of Microbiology collaborated in 1972 to form the Environmental Virus Laboratory. The laboratory can isolate and identify human enteroviruses from raw and treated sewage, from streams receiving sewage effluent, as well as from effluent-irrigated soil and soil percolates, and from estuarine and coastal waters. Nearly all of the reported major methods to concentrate viruses from water have been evaluated and used by the laboratory. The laboratory has developed the only environmental viral information source of Hawaii; methodologies for concentration, isolation, and identification of human enteroviruses from relatively large volumes of water and wastewater samples; and provides experienced personnel to collect, identify, and evaluate data. Methodologies for the growth, enumeration, and identification of animal viruses and for the growth, maintenance, and preservation of all kinds of animal cell cultures have also been established in the laboratory.

One to four gallons of sewage effluent or soil percolates were concentrated by the AlCl_3 -Gel Precipitation method and the precipitate reconcentrated using the beef extract reconcentration method (Loh, Fujioka, and Lau 1979). One-hundred gallons of Makakilo Well water was concentrated onto a single 0.25 m (10 in.) long cartridge type filter comprised of either a wound fiberglass (Commercial Filters Division) or pleated, epoxy-fiberglass (Filterite Corp.) in the presence of either MgCl_2 or AlCl_3 to enhance adsorption of viruses to these filters (Loh, Fujioka, and Lau 1979). These filters were then eluted with 0.001 to 0.002 m^3 (1-2 l) of 1 to 3% beef extract and the eluate concentrated by acid precipitation. To assess the presence of virus, the concentrated samples were added to cultures of continuous African green monkey kidney cells (BGM) and incubated at 36°C for 5 to 15 days. Evidence of virus present in the sample was obtained when the cells demonstrated cytopathology from the multiplication of virus in the cells. Samples which did not demonstrate evidence of virus replication after the initial inoculation were passed to fresh cell cultures of BGM and again observed for cytopathology before the sample was considered negative for virus. For this study the viruses isolated were not identified. However, based on past experience since 1972, we can conclude that the system recovers many of the 100 or so human enteroviruses and false positives are virtually nonexistent.

Standard Analyses of Water Samples for Chemical, Physical, and Biological Parameters

Procedures in *Standard Methods* (APHA, AWWA, and WPCF 1975) were used for the following analyses: (1) total residue or total solids (dehydration at 103-105°C), (2) orthophosphate

(ascorbic acid method), (3) chloride as Cl (mercuric nitrate method), (4) total Kjeldahl nitrogen or TKN (Macro Kjeldahl method), (5) ammonia nitrogen or $\text{NH}_3\text{-N}$ (titrimetric method), (6) nitrate nitrogen as $\text{NO}_3^- + \text{NO}_2^-$ (cadmium reduction), (7) sulfate as SO_4 (turbidimetric method), (8) bicarbonate as HCO_3^- (alkalinity method), and (9) fecal coliform as FC or fecal streptococcus as FS (membrane filtration method). Conductivity and pH were determined using specific meters, while silica as SiO_2 was determined by the molybdate blue method of Rainwater and Thatcher (1960). Hach kits were used to determine total chlorine and turbidity. Sodium (Na), calcium (Ca), magnesium (Mg), and potassium (K) were analyzed using flame photometry by laboratory personnel of the Division of Wastewater Management, City and County of Honolulu.

RESULTS

Virological Assessment of Effluent from Makakilo WWTP, Phase I

The primary objective of Phase I was to verify the assumption that infectious human enteroviruses are present in the treated and chlorinated sewage effluent discharged from the Makakilo WWTP into an effluent ditch. Three samples of chlorinated sewage effluent obtained on three separate days were analyzed for human enteroviruses and for residual chlorine and indicator bacteria. Two effluent samples were obtained as the effluent left the chlorine contact chamber of the WWTP while the third sample was taken from the effluent ditch.

All three samples were positive for human enteroviruses at concentrations ranging from 1.2 to 16.5 PFU/l (Table 2). Residual chlorine concentrations of 0.5 mg/l and FC and FS counts of 132 and 66 per 100 ml were determined in one of the samples obtained from the chlorine contact chamber, while a chlorine residual of 0.2 mg/l was revealed in the sample obtained from the ditch. These results indicate that effluent from the Makakilo WWTP was adequately chlorinated, resulting in reduced concentrations of indicator bacteria. However, infectious human enteroviruses survived the chlorination and were present in the effluent.

Assessment of Percolating Potential of Sewage-Borne Bacteria and Viruses Through Soil Strata, Phase II

The primary objective of Phase II was to determine whether the sewage-borne pathogens (bacteria and viruses) in the effluent stream can be expected to percolate through the soil strata below the effluent ditch. The percolate samples were visibly clear, did not contain soil particles, and did not foam or have a strong putrefying odor. To assist in assessing the retentive capacity of the soil strata, effluent and percolate samples were also analyzed for total

TABLE 2. MONITORING WATER FROM MAKAKILO WELL NO. 1, O'AHU, HAWAII, 1985-1986

SAMPLING SITE	DATE	COLONY FORMING UNITS PER 100 ml						HUMAN ENTERIC VIRUSES	pH	SALINITY (ppt)	CONDUCTIVITY (μ mhos/cm)	TURBIDITY (NTU)
		Total Bacteria	Coliform Total	Coliform Fecal	Fecal Strep.	Enterococcus	<i>C. perfringens</i>					
BWS Pipe (Kalaeloa Blvd.)	05/21/85	23	<1	<1	20	1	<1	Neg.	7.0	N.A.*	626	1.00
Well Head	01/07/86	383	<1	<1	<1	<1	<1	Neg.	7.6	0.5	748	N.A.
Well Head	06/24/86	222	<1	<1	1	<1	<1	Neg.	7.6	0.5	935	0.26
Well Head	12/03/86	204,800	<1	<1	<1	<1	<1	Neg.	7.4	1.0	1029	N.A.

*N.A. = Not assayed.

chlorine, pH, conductivity, total residue, orthophosphate, chloride, nitrogen series, FC and FS and the results summarized in Table 3. In the effluent from the Makakilo WWTP, the high total residual chlorine of 0.75 to 0.78 mg/l as well as the low FC (65/100 ml) and FS (67/100 ml) counts confirm that the chlorination process was efficiently operating. In the oxidation pond water, one can expect some reduction in chlorine, whereas concentrations of indicator bacteria may increase as a result of regrowth. These expectations were indeed observed as shown in Table 3. The results tabulated in Table 3 also indicate that the quality of the effluent in the ditch closely resembles the quality of the effluent in the oxidation pond. This comes as no surprise since the ditch was located only 45.7 m (150 ft) from the oxidation pond and the transit time of the effluent from the oxidation pond to the ditch was very short.

As of 18 December 1981, the oxidation pond was phased out and effluent from the contact chamber of Makakilo WWTP was piped directly to the ditch. This action was reflected by the higher concentrations of chlorine residuals and lower concentrations of FC and FS in the samples obtained on 21 December 1981 and 27 January 1982.

The high concentrations of FC and FS present in the effluent was substantially removed as the effluent infiltrated the soil surface and percolated through 0.3 m (1 ft) and then 0.9 m (3 ft) of soil strata. This result is completely expected and is consistent with the Mililani project results. The principal mechanisms causing the decrease are the ability of soil to absorb and filter the microorganisms and their natural die-off.

It is important to note that the consistent and drastic reduction with time of concentrations of FC and FS in the percolate at the 0.9-m (3-ft) depth was observed over a period of one and a half month. This reduction pattern over time at the 0.3-m (1 ft) depth was not consistent. These results indicate that a 0.9 m soil depth is necessary in order to achieve consistent retention of indicator bacteria.

Viruses were recovered from one of the three percolate samples collected at the 0.3-m depth of soil over a 2-wk period. A similar result was obtained for the percolates at the 0.9-m depth. However, it is important to note that viruses were absent in the percolate collected at both depths in the last of the three samples. These results demonstrate the effectiveness of the additional depth of soil for reducing viruses during percolation. They also appear to show that a period of time is required for a once disturbed soil to compact and attain its effectiveness in the removal of viruses.

Because no percolate was collected from soil depths deeper than 0.9 m, no definitive conclusion can be made as to the maximum penetrating depth of viruses. However, it is reasonable to conclude that indicator bacteria and viruses may reach deeper but not much deeper than 0.9 m and that the concentration will decrease as the depth of soil increases.

TABLE 3. WATER QUALITY ANALYSIS OF MAKAKILO EFFLUENT AND SOIL PERCOLATES

SAMPLE SOURCE	DATE	TOTAL CHLORINE (mg/l)	pH	CONDUCTIVITY (µmhos/cm)	TOTAL RESIDUE	ORTHO-PHOSPHATE	CHLORIDE	SiO ₂ (mg/l)	NITROGEN			FECAL COLI. (100 ml)	FECAL STREP.	HUMAN ENTERIC VIRUSES†
									TKN	NH ₃	NO ₃ +NO ₂			
Effluent from Chlorine Contact Chamber	12/08/81		7.6	1000	576.0	5.50	150	60	N.A.	N.A.	N.A.	2	62	N.A.
	12/14/81		7.5	1100	601.3	7.50	150	61	29.8	N.A.	0.05	64	66	N.A.
	12/21/81	0.8	N.A.*	1025	540.0	4.90	150	59	22.0	18.4	0.06	32	8	N.A.
	01/27/82	0.8	N.A.	N.A.	528.0	2.59	140	55	14.9	12.8	0.18	63	47	N.A.
Effluent from Oxidation Pond	12/08/81	<0.1	7.1	1050	592.0	8.40	100	61	N.A.	N.A.	N.A.	120,000	1,300	N.A.
	12/14/81	<0.1	7.3	1125	590.7	10.00	170	64	29.1	N.A.	0.05	5,400	2,200	N.A.
Effluent in Stream	12/08/81	0.2	7.1	1000	618.7	9.30	210	61	N.A.	N.A.	N.A.	190,000	42,000	N.A.
	12/14/81	0.2	7.5	1100	601.3	10.50	200	64	28.4	N.A.	0.02	10,900	7,400	N.A.
	12/21/81	0.7	7.5	1000	566.7	5.00	150	60	22.0	18.7	0.07	585	2,870	N.A.
	01/27/82	0.7	N.A.	N.A.	509.3	4.40	150	56	19.0	13.1	0.10	60	730	N.A.
1 ft Soil Layer Percolate	12/08/81	<0.1	7.5	1125	714.7	3.60	150	48	N.A.	N.A.	N.A.	15,800	4,480	Pos.
	12/14/81	<0.1	7.4	1400	661.3	4.10	140	47	16.5	N.A.	0.42	308	7,983	Neg.
	12/21/81	0.2	7.3	1200	650.7	2.90	155	47	15.1	13.0	1.08	3,400	1,800	Neg.
	01/27/82	<0.1	N.A.	N.A.	448.0	3.44	150	42	11.3	9.2	0.18	43	64	N.A.
3 ft Soil Layer Percolate	12/08/81	<0.1	7.4	1175	658.7	0.90	160	48	N.A.	N.A.	N.A.	4,630	559	Neg.
	12/14/81	<0.1	7.7	1475	849.3	1.10	200	35	14.7	N.A.	0.65	430	500	Pos.
	12/21/81	<0.1	7.5	1575	848.0	0.40	215	33	11.3	8.7	0.26	220	106	Neg.
	01/27/82	<0.1	N.A.	N.A.	634.7	1.55	155	32	6.5	5.1	0.11	158	101	N.A.

*N.A. = Not assayed.

†Present in 2- to 4-gal samples.

Based on the results presented for the top 0.9 m (3 ft) of soil and on the knowledge that the soil strata are comprised of a top layer of 1.5 to 4.6 m (5-15 ft) of Ewa type soil, followed by 3.05 (10 ft) to 4.6 m of marine clay, and a final saprolite layer before the aquifer is reached, the possibility is extremely remote that viable bacteria and viruses present in the Makakilo effluent can percolate through the undisturbed soil strata to contaminate the underlying source of water. This conclusion is further based on previous studies regarding the movement of virus through soil conducted in Hawaii and elsewhere. Human enteroviruses are known to be effectively adsorbed by soil with high clay (Bitton 1975; Murray and Laband 1979), high silica (Lo and Sproul 1977), high iron oxide (Gerba et al. 1981), and low organic and pH (Sobsey et al. 1980) content. These soil characteristics typify Hawaiian soil and, as a result, maximum movement of viruses to only 1.17 m (46 in.) of Lahaina type soil was determined in the previous WRRRC Mililani study. The Ewa type soil and the marine clay found in the soil stratum in this site is expected to adsorb virus in a similar manner and to effectively retard the movement of viruses.

Microbiological Quality Assessment of Water from Makakilo Well No. 1, Phase III

The objective of Phase III was to assess the microbiological quality of water obtained from Makakilo Well No. 1. Samples from this well were clear, free of odor, and at temperatures ranging from 23.4 to 25.0°C. Over the 1.5 days of sampling, 9 samples were collected and analyzed for various chemical, physical, and biological parameters. Summarized in Table 4, the results show that the values for the various parameters are uniformly consistent from samples 1 through 9, thus indicating the the aquifer water quality is homogenous surrounding the well. To assess whether sewage was a significant source of groundwater pollution, well water samples were analyzed for the presence of FC and FS bacteria as well as human enteroviruses. As shown in Table 4, no FC was recovered in any of the 9 samples (200 ml/sample). It should be noted that the drinking water quality standards are based on the more ubiquitous total coliform counts rather than the more restrictive fecal coliform level counts. Therefore, the FC counts obtained for this study constitute a more stringent test for fecal contamination than the bacteriological standards because FC is more specifically related to the presence of fecal contamination than total coliform. Consequently, the absence of FC in all 9 well samples is strongly indicative that the well is not contaminated with sewage.

In addition to FC, the well water samples were also analyzed for FS and human enteroviruses. It has been widely accepted that these two microorganisms provide positive

TABLE 4. WATER QUALITY ANALYSIS OF MAKAKILO WELL NO. 1, O'AHU, HAWAII

SAMPLE NO.	HOUR	GAL PUMPED ($\times 10^3$)	TUR-BIDITY (NTU)	TOTAL RES. (mg/l)	SPEC. COND. (μ mhos/cm)	Cl ⁻	SiO ₂	SO ₄	Ortho-PO ₄	HCO ₃ (mg/l)	NITROGEN			CFU (100 ml)		HUMAN ENTERIC VIRUSES	
											TKN	NH ₃	NO ₂ +NO ₃	FC	FS		
<u>12 January 1982</u>																	
1	0900	8.4	0.48	582.7	N.A.*	240	54	38	0.09	104	<1.0	<1.0	2.5	0	74†	N.A.	
2	1000	24.4	0.33	780.0	1075	240	55	34	0.08	108	<1.0	<1.0	2.7	0	55†	Neg.	
3	1200	44.3	0.33	806.7	1075	240	55	43	0.09	106	<1.0	<1.0	2.7	0	121†	N.A.	
4	1400	33.9	0.38	800.0	1075	230	54	35	0.09	104	<1.0	<1.0	2.6	0	51†	Neg.	
5	1600	47.1	0.30	661.3	1075	240	57	35	0.09	106	<1.0	<1.0	2.8	0	5†	N.A.	
6	1700	20.2	0.28	789.3	N.A.	240	57	38	0.08	106	<1.0	<1.0	2.6	0	17†	Neg.	
<u>13 January 1982</u>																	
7	0915	23.2	0.40	709.3	1090	250	55	34	0.08	106	<1.0	<1.0	2.9	0	24†	N.A.	
8	1115	37.5	0.25	725.3	1090	240	55	36	0.09	104	<1.0	<1.0	2.9	0	1†	Neg.	
9	1200	32.5	0.23	752.0	1100	250	59	37	0.09	106	<1.0	<1.0	2.7	0	1†	N.A.	
TOTAL AVERAGE			0.33	734.1	1083	241	56	37	0.09	106	<1.0	<1.0	2.7	0	39†	(1.6)‡	

*N.A. = Not assayed.

†Atypical colonies.

‡Calculated number of FS.

evidence for absence or presence of fecal contamination. For the FS analysis, the colonies observed were atypical in appearance but could not be considered as non-fecal streptococci. Therefore, all atypical colonies were counted and the average counts for the 9 well samples were 39 CFU/100 ml. To confirm whether these atypical colonies were FS, 25 randomly selected colonies were inoculated into Enterococcosel broth. Only 1 of 25 colonies were confirmed as true fecal streptococcus, an indication that only 4% of the counts were FS, resulting in a calculated concentration of only 1.6 CFU of FS in 100 ml of well water. Finally, the four 100-gal samples of well water which were assayed for human enteroviruses were determined to be negative. Taken together, these results indicate that water from Makakilo Well No. 1 is not contaminated by sewage effluent.

It had been previously concluded that return irrigation water was the major source for the well water and it has been previously determined that return irrigation water can be expected to add certain constituents to the basal underground water (M & E Pacific 1981). As a means of evaluating the contribution of return irrigation water to the well water, the chemical quality of uncontaminated basal groundwater obtained from O'ahu and cited by Visser and Mink (1964) as well as the corresponding values obtained from the well water are summarized in Table 5. The results show that well water from Makakilo Well No. 1 has a substantially higher concentration of virtually all the parameters measured when compared with uncontaminated basal water. Visser and Mink (1964) concluded that increased levels of dissolved solids, chloride, nitrate, silica, and bicarbonate can be expected when basal waters receive return irrigation water. However, the measured concentrations of the 14 constituents of Makakilo Well water (Table 5) did not exceed the maximum permissible levels for drinking water as established by the U.S. Environmental Protection Agency (1974).

SUMMARY

A microbiological assessment was made to determine if human enteroviruses in the sewage effluent discharged by Makakilo WWTP into an unlined ditch would contaminate the underground water source for the Makakilo Well No. 1.

The treated and chlorinated sewage effluent from Makakilo WWTP was discharged from the plant into an unlined ditch, the closest point of which is located approximately 213 m (700 ft) from Makakilo Well No. 1. The elevation of the general area concerned varies in the range of 30.5 to 48.8 m (100-160 ft) above sea level and the static water level in the well is approximately 4.3 to 4.6 m (14-15 ft) above sea level. The soil strata are comprised of a top layer of 1.5 (5 ft) to 4.6 m of Ewa silty clay followed by 3 to 7.6 m (10-25 ft) of marine clay

TABLE 5. CHEMICAL QUALITY OF TYPICAL UNCONTAMINATED BASAL GROUNDWATER FROM O'AHU COMPARED WITH WATER FROM MAKAKILO WELL NO. 1

Constituent	Uncontaminated Basal Groundwater*	Makakilo Well No. 1 Water
SiO ₂ (mg/l)	36.00	57.00
Ca (mg/l)	8.00	36.00
Mg (mg/l)	6.00	36.00
Na (mg/l)	20.00	116.00
K (mg/l)	2.00	7.30
HCO ₃ (mg/l)	65.00	106.00
SO ₄ (mg/l)	5.50	38.00
Cl ⁻ (mg/l)	22.00	241.00
PO ₄ (mg/l)	0.20	0.08 [†]
F (mg/l)	0.07	N.A. [‡]
NO ₃ N (mg/l)	0.25	2.50
Dissolved Solids (mg/l) [§]	165.00	750.00
Spec. Conductivity (µmhos)	205.00	1100.00
pH	7.90	7.40

*Data from Visher and Mink (1964).

[†]Only orthophosphate levels determined.

[‡]N.A. = Not assayed.

[§]Calculated.

and saprolite that overlie the basement basaltic series of the Waianae series where the basal water occurs.

The sampling methodology for the assessment included sampling (1) the effluent, (2) the percolate at various depths below the unlined ditch by special implanted samplers, and (3) the aquifer water itself by pumping over 1 022 m³ (270,000 gal) of water from the well. The samples were analyzed for fecal coliforms, fecal streptococci, human enteroviruses, and auxiliary physical and chemical water quality parameters.

A summary of the key results are as follows.

1. Viruses and bacterial indicators (FC and FS) survived the treatment and chlorination and were present in the effluent although the effluent was adequately chlorinated. Discontinuing the use of the oxidation pond resulted in lower concentrations of indicator bacteria in the effluent flowing in the ditch.
2. Bacterial indicators in the effluent were substantially removed as the effluent percolated through 0.3 m (1 ft) and then 0.9 m (3 ft) of soil strata. With time and presumably natural packing of the disturbed soil strata, substantially less bacteria were recovered from the 0.9 m soil percolates. Viruses were recovered in one of the three percolate

samples at both depths but only from the early samples. The results suggest that indicator bacteria and viruses may percolate deeper than the top 0.9 m (3 ft) of disturbed soil but would probably be effectively retained by 1.8 m (6 ft) of intact soil. However, underlying the shallow top soil is a much greater depth of soil whose physical properties are known to effectively adsorb viruses. Thus, the possibility is extremely remote for viable bacteria and viruses present in the Makakilo effluent to percolate through the undisturbed soil strata and to contaminate the underlying groundwater.

3. The basal groundwater pumped from Makakilo Well No. 1 was not contaminated with fecal matter. This was evidenced by the absence of viruses in multiple large volume (100 gal) samples. The conclusion is further supported by the total absence of fecal coliforms and only negligible fecal streptococci in these samples.

CONCLUSIONS

On the basis of the microbiological assessment, it is concluded that the possibility of viable bacteria and viruses present in the Makakilo effluent to percolate through the undisturbed soil strata and to contaminate the underlying underground source for Makakilo Well No. 1 is extremely remote. The following two conclusions are drawn from the results of this study.

1. The basal groundwater pumped from Makakilo Well No. 1 was not contaminated with fecal matter.
2. The possibility of viable bacteria and viruses present in the Makakilo effluent to percolate through the undisturbed soil strata and to contaminate the underlying underground source of water for Makakilo Well No. 1 is extremely remote.

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