INFILTRATION AND PERCOLATION OF SEWAGE

THROUGH OAHU SOILS IN SIMULATED CESSPOOL LYSIMETERS

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ABSTRACT

This study investigated conditions contributing to cesspool failure and followed selected parameters to measure the degree of treatment afforded sewage in cesspool disposal.

This laboratory study utilized bench scale soil lysimeters and two basic soil types: the Wahiawa Low Humic Latosol and the Lolekaa Humic Latosol. The soils were specimens from areas of potential urban development within known ground water recharge zones.

The soils were molded into an "L" shape in the lysimeters to simulate the corner of a cesspool. The lateral soil column was 11 inches wide and the bottom soil layer was ten inches deep.

A constant head of 11 inches was maintained in the pool of all lysimeters for thirty to forty days.

Pressures throughout the flow field were determined by piezometers and manometers. The side and bottom drains in the lysimeters allowed separate sampling and flow rate determinations.

The Hawaiian soils exhibited typical die-away curves of infiltration with time depending on physical, chemical, and microbial qualities of both the feed and soil. Infiltration rates ranged between 0.7 to 3.6 ft/day.

A 99% reduction of the infiltration rate was evidenced by the Wahiawa soil over the experiment-period of 30 to 40 days. Both sewage-fed lysimeters containing the Low Humic Latosol developed a pan-like layer of soil fines approximately 3 cm below the bottom of the cesspools, preventing the penetration of suspended solids after seven days. The Lolekaa soil did not show such changes.

Flow nets plotted from pressure readings of the Wahiawa Low Humic Latosol showed that clogging occured in the 8 to 10-cm zone of the side

wall and the soil base of the lysimeters containing this soil. Flow through the lysimeter was governed by infiltration, rather than percolation.

Visual observation and negative manometer readings showed that unsaturated flow conditions were always present in all of the lysimeters throughout the experimental period. Both domestic and synthetic sewage-fed lysimeters exhibited a 90% reduction in organic nitrogen and a 62 to 96% reduction in COD.

The oxidation reduction potential reading (-340 mv) indicated that anaerobic conditions existed within the cesspool: appreciable concentrations of nitrates in the effluent indicated that aerobic conditions existed in the soil mass surrounding the cesspool.

The results of this experiment indicate that unless further degradation of the effluent is effected by the soil mass, the incomplete degradation of the sewage makes it a definite hazard to ground water sources. This study presents soil-effluent inter-reaction at a one-foot depth. No conclusive evidence exists to substantiate any further degradation of the effluent by the soil at greater depths to the required U.S. Drinking Water Standards of 45 mg/l of nitrates.

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INTRODUCTION

The oceanic environments, the climatic conditions, and the geohydrology of the Hawaiian Islands combine to pose some unique situations for water supply and waste water disposal.

The ocean provides the rainfall on Oahu through the processes of evaporation and precipitation. The basaltic geological structure forms the water-permeable landmass, and the rainfall, leaching, and weathering produce water-permeable soils covering portions of the landmass. These natural processes together with cracked volcanic formations result in the enormous ground water storage in the basaltic lava mass replenishable by the natural recharge of rainfall.

In 1962, Hawaii was one of three states fortunate enough to have escaped problems of ground water contamination (1).* However, the land use projection for Oahu for the period 1960 to 1980 shows an increase in urban area from 28,000 to 58,000 acres partly at the expense of lands now used for plantation agriculture, conservation, and open spaces (2). Hence, the possibility of ground water contamination will continue as long as ground disposal of liquid wastes continues.

Geohydrology and Water Supply on Oahu

The island of Oahu was formed between 30 to 100 million years ago by the flow of basaltic lavas from rifts in the ocean floor. The merger of the Waianae and the Koolau volcanic domes created the island. A central plateau links the two domes (3). The volcanic rock formations and their residual soils have a great capacity to absorb and percolate water.

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*Number in the parentheses refers to the reference number in the bibliography.

There are three characteristic types of ground water on Oahu from which the public water supply is obtained (3). The most extensive of these, supplying 90% of the water used for public consumption, is the basal fresh water that overlies the sea water under much of the southern and northern parts of the island. This body of fresh water is often referred to as a Ghyben-Herzberg lens. Less widespread, but also important, is the ground water restrained between impermeable vertical rock formations, called dikes, in the core of the Koolau mountains. The third type, of minor significance, is the ground water supported in horizontal impermeable beds, often called "perched" water (4).

Soil Characteristics

The soils on Oahu developed from volcanic materials including lava, ash, tuff, and cinders, and are rich in iron, magnesium, and aluminum, but deficient in phosphorous (5).

Leaching and the amount of rainfall in the area influence the relative proportions of these elements in the soil profile. Soils in higher rainfall zones have lower amounts of silica and bases than those of the lower rainfall areas (5).

The Great Soil Groups found on Oahu are the Low Humic Latosols, Humic Latosols, Hydrol Humic Latosols, Humic Ferraginous Latosols, Reddish Brown Soils, Gray Hydromorphic Soils, Paddy Soils, Dark Magnesium Clays, Solonchak, Alluvial Soils, Regosols, and Lithosols (6).

THE ACTION OF THE CESSPOOL

In 1915, the state of Hawaii, then the Territory of Hawaii, enacted the Public Health Regulations which permitted the plumbing of dwellings to be connected to a cesspool, septic tank, or a combination of both (7). Subsequently, the cesspool gained wide public acceptance as a means of waste liquid disposal.

Cesspools and septic tanks are similar in many respects. Both operate in a soil medium, both handle domestic wastes, and both incur problems of clogging under normal operating conditions. The major difference between the two lies in the method of waste treatment. In the septic tank, solids are settled and held in one tank and the liquid is decanted from the tank and leached into the ground through percolation fields. In cesspools, the solids are settled and held in a pit, and the effluent is leached through the sides and bottom of the same pit.

There is presently no information available on cesspool clogging. Most of the research done in the field of soil clogging by liquid wastes is related to septic tank-operation systems. However, due to the many similarities between the two methods of liquid waste disposal, much of the research in septic tank percolation field failures can be applied to the cesspool.

When reduction of the infiltration rate of the soil system falls below its designed capacity to percolate waste liquid, cesspool failure occurs. This reduction is due to a physical change in the soil pore size and may be brought about by chemical, physical, or biological means, singularly, or in any combination of the three methods.

Chemical Factors

Chemical clogging is mostly the result of the ion-exchange phenome-

non, in particular, the exchange of sodium ion for calcium ion resulting in a deflocculation of soil aggregates (8). Where water softeners are used, chemical clogging assumes importance, but only a small proportion of percolation system failures can be attributed to deflocculation. Agriculturists agree that sodium detrimentally reduces infiltration rates when its concentration approximates 50 percent of the total cationic content of the irrigation water. The reduction in infiltration is in direct proportion to the sodium concentration. Fireman (9) has shown this effect for different soils.

Owing to the low hardness of Oahu's water supply, the use of domestic ion exchange water softening units is nil. These units are utilized only by the military and industry. Their waste water is piped into sewers for subsequent biological treatment and/or dilution by ocean outfall.

Chemical clogging, as such, may thus be discounted as a major contributing factor to cesspool clogging on Oahu.

Biological Clogging

Allison (10) established that long term decrease in permeability resulted from microbial activity.

Orlob and Butler (11, 12) in a study of the sewage spreading on California soils, found that microbial activity caused soil clogging of a greater magnitude than that of purely physical clogging by sewage solids.

Winneberger, Francis, Klein, and McGauhey (13) in soil clogging experiments under anaerobic conditions showed ferrous sulfide to be an important clogging agent. Approximately 40 percent of clogging in a soil sample was attributed to insoluble sulfides formed under anaerobic

conditions, hence, an important factor in minimizing microbial clogging would be to maintain aerobic conditions in the soil.

Winneberger, et al, (13) showed that the initial clogging of the inundated soil resulted from filtration of suspended solids, and that later, microbial growth enhanced clogging to an appreciable degree. They went on to say,

> It is impossible to evaluate precisely the contribution of each factor (suspended solids, filtration, and microbial growth) to soil clogging because solids were present in the sewage fed to all permeameters. Such a differentiation could probably be achieved by studies with synthetic sewage.

The latter statement influenced the selection and use of synthetic sewage in this investigation.

Physical Factors

The flow of water through soils in both the saturated and unsaturated condition has been and is being studied extensively.

The action of the flow of water through soils, such as the clays selected for this study, has been observed by Kozlova (14, 15) who demonstrated through the use of a microscope and motion picture camera that there was a movement of fine material in soils of uniform grain size with percolation of water. This translocation of colloids and macro particles has been studied in filter action by Eliassen (16) and, indeed, serves as the background for the removal of suspended material by filtering action (the physical removal by straining and by electostatic precipitaion). The phenomenon of increase in head loss and decrease in quantity of water filtered has been noted, also.

The action of reduction in soil infiltration of rain has been noted by Duley (17,18) with the formation of a tightly packed layer of fines

a few millimeters below the soil surface. This type of clogging becomes a permanent soil feature and the retrieval of original soil infiltration properties can only be achieved by physical rearrangement of the soil mass.

A similar change in soil structure has been observed in Oklahoma and Missouri in somewhat similar clays. An arch type open-pored soil mass has under the influence of unsaturated flow suffered soil particle structure rearrangement with a subsequent change in soil permeability and volume. *

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*Personal communications to the author.

SCOPE

This investigation was intended as a laboratory study utilizing bench size soil-filled lysimeters simulating cesspool configuration. The lysimeters were dosed continuously for 30 to 45 days with a domestic sewage, a synthetic sewage without suspended solids, and tap water. Three Oahu soils, the Lolekaa, Wahiawa, and Tantalus were initially selected for testing on the basis of urban development potential, geohydrology of the areas in which the soils occur, and the availability of analysis data on these soils (5). The three percolants and three soils were incorporated into nine combinations of soil and percolant. A comparison of controls among these nine lysimeters was expected to yield information of the relative time rate of physical and biological clogging of the various soils.

Trial infiltration runs revealed that an impractically large volume of percolant was required to maintain constant head in the lysimeters containing the Tantalus soil. Consequently, the Tantalus soil was eliminated from the investigation. The remaining six combinations of two soils and three percolants proved amenable to further testing. Investigation of these groupings continued along the lines originally delineated.

Pressure taps and sampling points were placed in the lysimeters to allow direct determination of head, calculation of percolation rates, construction of flow nets, and collection of liquid samples. Laboratory tests of the liquid samples were performed in order to study biological degradation occuring in the cesspool and in the soil surrounding the cesspool. These tests were performed in accordance with the Standard Methods by the American Public Health Association, American Water Works

Association, and the Water Pollution Control Federation, and included chemical oxygen demand (COD), oxidation reduction potential (ORP), pH, the nitrogen and nitrate content of the percolants (19).

PURPOSE

The purpose of this study is twofold:

1. To study certain controlling parameters in early cesspool failure for two soil groups, and
2. To ascertain to a limited extent the degree of biodegradation afforded sewage discharged into cesspools.

The principles of ground disposal of sewage including those revealed by Winneberger, et al, (13) will be applied and examined in the light of the distinct regional differences in soil, sewage, and practice.

METHODS AND PROCEDURES

General

Domestic sewage, Weinberger synthetic sewage (20), and tap water were used in six combinations with Lolekaa Humic Latosol and Wahiawa Low Humic Latosol. Tap water was used as a control to establish physical changes which might develop in the lysimeter due to solvent action alone, synthetic sewage was used to evaluate the effects of microbial clogging, and domestic sewage was used to determine the combined effects of microbial and physical filtering action on soil clogging. The changes observed in hydraulic factors and chemical contents of the effluent from the lysimeters were used as gauges to ascertain the effect of these changes on infiltration rates of sewage in the cesspools.

Soil

Soil was collected from pesticide and fertilizer free sites. The upper six inches of soil cover was removed, the soil loosened and pulverized, and extraneous material (weeds, roots, and branches) was removed and the sample transported to the laboratory.

The sampling site for the collection of Wahiawa soil was located one-half mile north of Kamehameha Highway in an eucalyptus grove behind the Wahiawa National Guard Armory.

The Lolekaa soil was obtained from a hill at the Haiku Plantations sub-division in Kaneohe.

Synthetic Sewage

The Weinberger synthetic sewage was prepared according to a formula by Bennett (20). (See Appendix A for Weinberger's synthetic sewage formula.) The diatomaceous earth was omitted during the mixing process

to produce a product biologically similar to sewage but with a low suspended solids content. Since diatomaceous earth is biologically inert, the biodegradability of the sewage was not affected. Tap water used in preparing synthetic sewage was obtained from the Kaimuki Low Service and Beretania Low Service artesian wells. (Water quality information for these sources may be found in Appendix B.) The sewage was seeded with normal sewage bacteria, using 1% by volume of settled domestic sewage. Although it was never allowed to age more than two days in the holding carboys, according to Bennett, the Weinberger synthetic sewage has a 5-day biochemical oxygen demand, BOD, at 20°C of approximately 210 ppm, a pH of 8.2, 6.2 ppm of soluble phosphorous, 13,7 ppm urea nitrogen, and approximately 25.3 ppm of total nitrogen. As tested, the pH of the freshly mixed synthetic sewage was 8.2, the 5-day BOD at 20°C was 134 ppm, and the total nitrogen content was 22.1 mg/l.

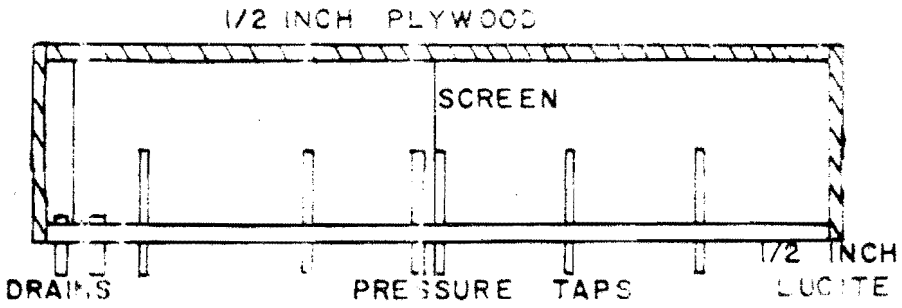
Domestic Sewage

Domestic sewage was obtained from the Pacific Palisades sewage treatment plant at Pearl City with the permission of the Division of Sewers of the City and County of Honolulu. This source was chosen because the waste entering this plant came solely from domestic sources and was free of all industrial wastes. An observation tour through the community substantiated this.

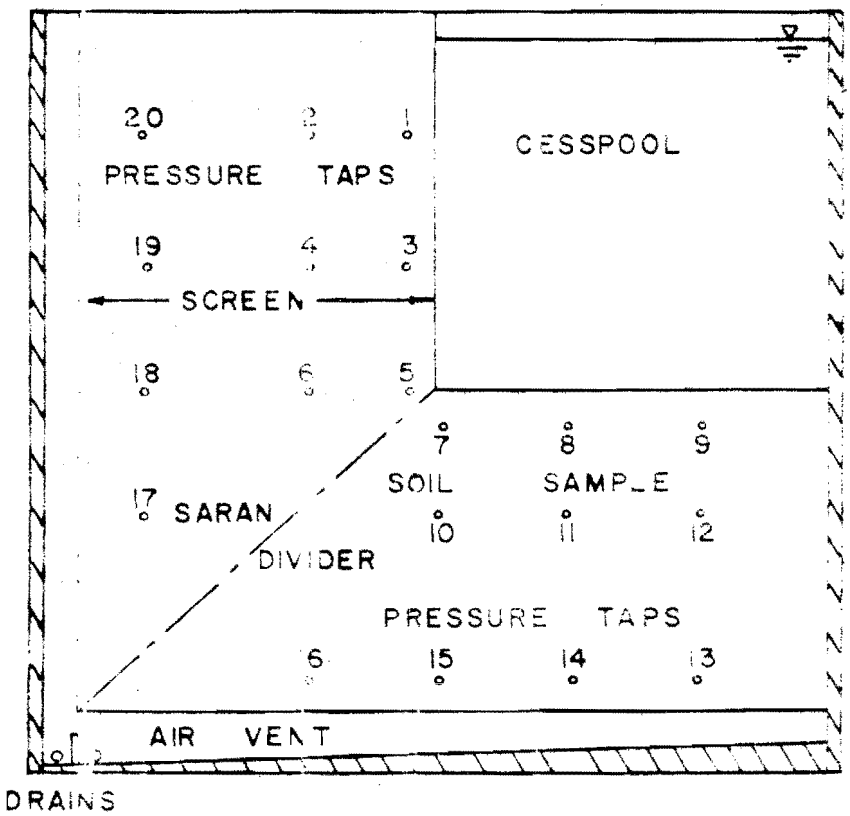
Sewage to be used during the course of the day was left at room temperature. The excess was refrigerated at 0° to 5°C. After three days, the unused sewage was discarded.

Lysimeter Boxes

The lysimeters measuring 6" x 2' x 2' were constructed of marine grade plywood with a sheet of clear 1/2 inch thick lucite plastic cover-



TOP VIEW - SOIL REMOVED



FRONT VIEW

FIGURE 1--LYSIMETER SCHEMATIC

ing one of the 2' x 2' sides of each lysimeter to allow observation of the contents (figure 1). The lysimeter rested on the 6" x 2' base with the top open and the soil packed along the bottom and one side forming an L-shaped mass. The soil was contained within screen walls of galvanized 1/2 inch wire mesh overlayed with 1/16 inch mesh Saran fiber window screen. An air vent allowed soil aeration. Two drains at the bottom of each unit allowed sampling of the percolant from the side wall and the bottom of the cesspool. A six inch plastic Saran wrap film was placed in the soil at approximately a 45° angle running from the inner corner of the "L" to the base corner to divide the soil into two hydraulically separate masses. Preliminary infiltration tests showed only negligible leakage past this partition.

Pressure taps of rigid 1/4 inch lucite tubing were passed through the plastic side of the lysimeter to the center of the soil mass. Piezometers of clear glass tubing were connected with Tygon, a flexible plastic tubing, to the two rows of pressure taps closest to the side and bottom of the cesspool. The third row of pressure taps was sealed with three inch lengths of surgical rubber tubing and pinch clamps. Head readings were taken from these pressure taps with a portable U-tube manometer.

Soil Packing

Layers of soil were placed along the bottom in approximately 2 1/2 inch lifts. (The plastic Saran film was placed in proper position at this time.) Care was taken in depositing the soil to prevent mechanical separation of the fine from the coarse material: the soil was not tamped or jarred. Only dry soil was used because wet soils markedly reduced permeability. After the lysimeters were filled with soil, tap water was slowly introduced through the bottom drains until the water level was

approximately 1 cm from the top of the unit. Care was taken to avoid excessive uplift pressures and the attendant unstable soil condition. The inundated lysimeters were drained completely. Additional soil was added to regain the pre-inundation level. The flooding, draining, and soil replenishing cycle was repeated five times.

The lysimeters were then fed with tap water from the top with the drains open. Tap water was introduced into the empty cesspools by first placing a 250 ml beaker in the pit and filling the beaker and allowing it to overflow into the cesspool. The water was run continuously for three days. Any volume of soil lost through compaction was replaced on the third day when the units were drained completely. The units were again dosed with tap water for five more days before the first infiltration rate reading was taken. This procedure assured hydraulically stable testing conditions.

Dosing

The lysimeters were simultaneously dosed with tap water, domestic sewage, and synthetic sewage. The flow of tap water was adjusted by using pinch clamps and a globe valve faucet. Flow fluctuation was negligible. The tap water-fed lysimeters maintained a constant head without difficulty.

Domestic sewage was fed through a 1/2 inch flexible Tygon tubing feed line from plastic storage bottles by a variable speed sigmamotor positive displacement pump. A 6-hour inspection schedule guarded against clogging of the intake lines to the pump by suspended matter. The entire contents of the bottles were pumped into the lysimeters within six hours. While this did not insure a uniform feeding of suspended matter to the lysimeters, it did transfer the total quantity of suspend-

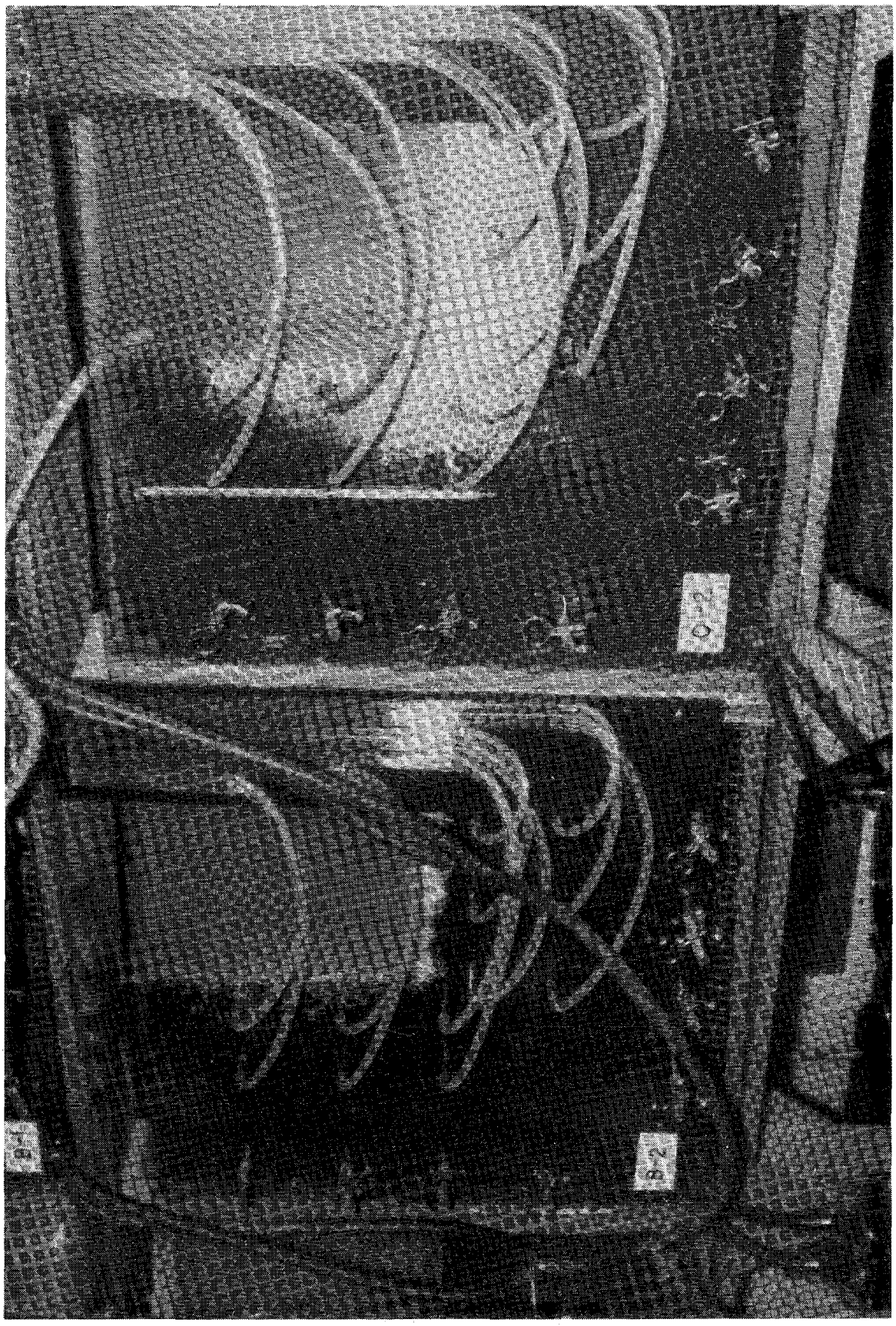


FIGURE 2--THE WAHIAWA (B-2) AND LOLEKAA (C-2) SYNTHETIC SEWAGE-FED LYSIMETERS. THE WHITE MATERIAL WAS A PRECIPITATE CAUSED BY CASTILE SOAP, ONE OF THE INGREDIENTS OF SYNTHETIC SEWAGE.

ed matter into the units within six hours. As clogging of the lysimeters progressed, and the flow rate diminished, feed was regulated by a constant head device.

Synthetic sewage was fed with a sigmamotor pump. Being relatively free of suspended solids, it exhibited high infiltration rates. Feed was supplemented with gravity flow from plastic reservoir bottles. Floc-like material, presumably microbial growth, accumulated within the feed lines to the lysimeters. This was loosened and flushed free with tap water at regular intervals.

Sampling

Flow rates and samples for chemical analysis were obtained from the bottom drains of the lysimeters. To determine flow rates, any ponding effect at the bottom of the lysimeters were eliminated. The sampling procedure for lysimeters fed with tap water consisted of collecting effluent from the drains. For the sewage-fed lysimeters, removal of microbial growth from the drains was necessary before sampling. All samples were collected in one liter medicine bottles.

It took progressively longer to obtain one liter aliquots as the infiltration rate decelerated. The slowest flowing lysimeter took seven hours to percolate about one liter. To reduce sample degradation, the collection period was shortened by one-half.

When scheduling permitted, the samples were analyzed immediately. If the laboratory facilities were occupied, samples were stored at 0° to 5°C and analyzed the following day.

For the domestic sewage, grab samplings for a six day period were averaged to obtain values for BOD, total and suspended solids, and COD. Because synthetic sewage was expected to be more consistent, only three

test samples were run.

Antiseption

After approximately seven days of continuous dosing with domestic sewage, the Lolekaa soil showed creamy white microbial growth in the bottom drains of the lysimeters. These deposits subsequently appeared in the other sewage fed units. The microbial flora was removed by flushing with 100 ml of clorox diluted to 500 ml with tap water. The clorox solution was left in the drainage system for five minutes. The drains were then rinsed three times with tap water. The clorox caused a rise in COD values for the effluents. Therefore, samples were obtained three days after the rinsing procedure.

Chemical Tests

The variables tested in this study included chemical oxygen demand, chloride content, biochemical oxygen demand, ammonia-nitrogen content, organic-nitrogen content, and nitrate content.

The chemical oxygen demand test is used extensively as a means of determining the pollution strength of liquid wastes (21). The basic premise for this test is that organic matter is oxidized to water and carbon dioxide by a strong oxidizing agent under acid conditions. It does not distinguish between biodegradable and non-biodegradable organic matter, however. Also, the biological degradation rate of organic matter is not determined. This test is useful because of the short span of only two hours required to obtain results. In comparison, the BOD test requires five days. The COD test was run with one modification: the refluxing and titrating of the samples within the same standard taper ground glass neck 500 ml Erlenmeyer flask. Normally, samples are refluxed in a round bottom ground glass neck flask then transferred to a 500

ml Erlenmeyer flask for titration. This modification appreciably reduced the time and effort required to run the test. Silver sulfate, added as a catalyst, more effectively oxidized straight chain aliphatic compounds, aromatic hydrocarbons and pyridine (22). The Mercuric Nitrate Method of determination of chloride ion concentration was used to obtain a correction factor applied to the COD results.

The Biochemical Oxygen Demand (BOD) determinations were run according to Standard Methods by the Winkler Method as modified by Alsterberg (AZIDE MODIFICATION) to measure the amount of oxygen required by bacterial organisms as they stabilized degradable organic matter under aerobic conditions. The BOD test determined the polluting strength of liquid wastes under aerobic conditions. The test was run with and without seed (natural anaerobic flora) to investigate its effect upon cesspool contents.

Kjeldahl distillation with subsequent back titration with 0.02N sulfuric acid determined ammonia and organic nitrogen ratios. Because organic nitrogen is progressively converted to ammonia by biological activity, the measure of ammonia relative to organic nitrogen in the sample gives a qualitative measure of biological degradation of nitrogenous compounds. In the Kjeldahl determination, the amines were reported to cause interference.

The Brucine Method for nitrate determination in Standard Methods was used because it is free from chloride interference which was expected in this determination due to the nature of the percolants.

Oxidation Reduction Potential and pH Measurements

Beckman Models G and 76, an Analytical Measurements Incorporated Recording pH meter, and a Photovolt Model 125 pH meter were calibrated with pH7 buffer. Regular rinse and wipe procedures were implemented to

cleanse the electrodes before and after each reading.

The ORP, oxidation reduction potential, meters were calibrated according to the method cited by Kehoe (23). The electrodes were immersed in solutions of pH4 and pH7 buffers to which a pinch of Quinhydrone was added. The meters were calibrated to read 218 mv on the pH4 buffer and 41 mv on the pH7 buffer. The platinum electrodes were cleaned by rubbing a neutral abrasive cleaner, Bon Ami, on the platinum loops of the electrodes.

TABLE 1 -- THE RESULTS

AREAS OF TESTS	LOLEKAA HUMIC LATOSOL			WAHIAWA LOW HUMIC LATOSOL		
	TAP WATER	WEINBURGER'S SYNTHETIC SEWAGE	DOMESTIC SEWAGE	TAP WATER	WEINBURGER'S SYNTHETIC SEWAGE	DOMESTIC SEWAGE
INFILTRATION CURVE	Showed characteristic die-away curve. Log-log plot values, using the empirical formula: $\log_{10} q = \log_{10} K - n \log_{10} t$ or $q = Kt^{-n}$ q=infiltration rate K and n=constants. n=0.25 K=24.5	Typical die-away curve with time. Initial rate=58 ft/day. After 22 days, 3.6 ft/day (94% reduction) Reduction after 7 days=94%	Typical die-away curve with time. Initial rate=58 ft/day. After 9 days=1.1 ft/day (98% reduction). At the end of the test: 0.8 ft/day, 99% reduction in 30 days. Initial great reduction due to filtration of suspended solids and slow decline due to microbial action. Difficult to evaluate microbial action because of activity noted during initial infiltration stage. Microbial action also reflected in the color and odor of the effluent.	Showed characteristic die-away curve. Log-log plot values (see Lolekaa Humic Latosol, Tap Water for formula): n=0.25 K=46.8	Die-away curves present. Final rate much less than for tap water. Initial rate: 181 ft/day. After 23 days: 1.4 ft/day (a 99% reduction). Much of the reduction occured after 13 to 14 days. Initial great reduction due to suspended solids and slow decline to microbial action.	Initial rate=181 ft/day. Rate at end of testing period= 1.1 ft/day. After 7 days of testing reduction=99%. Total percentage of decrease at end of 22-day test period was 99.4% based on the initial flow rate. Initial reduction was due to filtration from suspended solids and clogging of the soil-sewage interface. Greatest increase in percentage of clogging resulted from clogging by filtration and some microbial action. This constitute the second phase. Third phase characteristic slow long term clogging, caused by microbial growth in the soil mass. Slow decline due to microbial action which followed in the 15 to 50-day period.
FLOW POTENTIAL	Fluctuating and negative head readings, and visual observations showed that unsaturated conditions existed. The equipotential lines were uniformly spread out initially, but as dosing continued, grew closer together near the sides and bottom of the cesspool. Formation of a layer of fines was <u>not present</u> for this soil group.			General reaction same as that for Lolekaa Humic Latosol. High head loss region present at approximately 2.5 cm below the soil surface at the pit bottom; related to a layer of fines which had migrated to this depth from the surface. Condition present in all lysimeters containing this soil group. Clogging occurred less than 10 cm from the pit floor. Change rate always a 99% reduction.		
pH	Reading=7.9 to 8.0	Initial reading at the pit=7.7 After 23 days=7.0 to 7.1. Foul odors present, but did not undergo acid fermentation followed by alkaline recovery.	Readings: After 12 days=6.7 After 26 days=6.5 After 43 days=6.9 Action similar to anaerobic breakdown in a sewage digester. Classic acid fermentation followed by alkaline recovery.	Readings=7.9 to 8.0	Initial reading in the pit=7.7 approximately. After 23 days decreased to 7.0-7.1. Indicates microbial degradation was established with difficulty.	pH of Hawaiian domestic sewage=7.2 to 8.2. After 12 days=6.7 After 25 days=5.9 After 43 days=6.9 Indicated normal anaerobic progression and breakdown.
OXIDATION REDUCTION POTENTIAL	No reaction	Within 18 days ORP values were in excess of -200 mv and continued to drop until a maximum value of -340 was reached. Developed a very disagreeable odor, but effluent did not show appreciable color.	Sewage actively anaerobic in a short time. Reading range =-340 mv to -390 mv. Reading was consistently lower than -300 mv during period of observation. True anaerobiasis in the pit. Disagreeable odor developed. Also, a black area manifested itself in the soil layers at this time.	No reaction	Anaerobic conditions slow to develop due to lack of active microbial flora. In 18 days ORP dropped to anaerobic conditions with values of -340 to -380 mv. Strong disagreeable odor persisted from the first day on. Effluent did not show appreciable color.	ORP remained at +40 to +100 mv for nearly two weeks. After 15 days it dropped to a negative value (pH reflected similar changes at this time). Condition due to lack of seed in sewage, or soil, or both. ORP reading was similar to synthetic sewage reading.
CHEMICAL OXYGEN DEMAND	No reaction	No pronounced peak. Values close for both side and bottom effluents. Greatest difference was 20 mg/l. Values for both side and bottom rose from 40 to 50 mg/l in two days. After 21 days value=125 mg/l. Indicated the cesspool became progressively less efficient in the removal of solubles.	After 7 days a creamy microbial growth appeared in the bottom drains. Peak reached in 20 days: reading=310 mg/l. After 42 days range=80 to 130 mg/l for bottom effluent. For the side, peak COD at 21 days=140 mg/l. After 42 days remained 50 to 80 mg/l. COD for sides less than the bottom. Maximum dif-	No reaction	Initial value=80 mg/l, a soluble COD. Progression continuous without serious changes in character of the waste. Reductions: 56.4% in the pit. 87.5% through the side. 96.2% through the bottom.	Values similar to Lolekaa soil dosed with domestic sewage. Peak in 20 days, (may indicate breakdown of compounds readily oxidized by diromate). After 4 days COD of effluent=80 mg/l. After 42 days, range was 80 to 110 mg/l for the bottom. The side effluent showed a peak at 20 days=140 mg/l. On 26th day=50 mg/l.

TABLE 1 -- THE RESULTS (CONT'D)

AREAS OF TESTS	LOLEKAA HUMIC LATOSOL			WAHIAWA LOW HUMIC LATOSOL		
	TAP WATER	WEINBURGER'S SYNTHETIC SEWAGE	DOMESTIC SEWAGE	TAP WATER	WEINBURGER'S DOMESTIC SEWAGE	DOMESTIC SEWAGE
CHEMICAL OXYGEN DEMAND (cont'd)			ference=30 mg/l at equilibrium. Indicated that soil became progressively efficient in the removal of chemically oxidizable substances.			The range remained 40 to 70 mg/l (less than the bottom). Maximum difference between the side and bottom effluent =300 mg/l after 26 days. The difference was reduced to 30 mg/l at the end of the observation period at equilibrium. Soil became progressively more efficient in removal of chemically oxidizable substances.
BIOCHEMICAL OXYGEN DEMAND	No reaction	Confirmed COD test; BOD of bottom percolant was less than that of the side. Indicated bottom was slightly more efficient in the reduction of the BOD than the side. Samples were seeded, and subsequent rise in BOD noted. Reading 110 to 220 mg/l indicated effluent was capable of supporting biological activity.	Anaerobiasis was more complete at the bottom of the cesspool than at the side, particularly when the lysimeter was permitted free drainage. Samples were seeded --followed by subsequent BOD rise. Reading=110 to 220 mg/l. Indicated that the effluent was capable of supporting biological activity.	No reaction	Soil action was merely straining. No evidence of change in the effluent. Indicated that BOD removal was due to biological action. (BOD reading was the same as for domestic sewage.) When samples were seeded the BOD rose. Reading=110 to 220 mg/l. Indicated that the effluent was capable of supporting biological activity.	Average raw feed BOD reading=270 mg/l. Initial reading showed 0 over a 2 week period. Rose with seeding. Range in value=approximately 110 to 220 mg/l. Side reading was lower than for the bottom. Indicated that the side was more efficient in the reduction of BOD. Effluent still capable of supporting biological activity.
NITROGEN	No reaction	No reaction	Ammonia nitrogen in raw sewage=12.2 mg/l. Side effluent reached peak in 14 days at 19 mg/l. After 43 days=0.5 mg/l. Organic nitrogen content in raw sewage=24.3 mg/l. Values in both side and bottom effluent remained nearly the same. Initial values=8.0 mg/l for the pit. After passage through side and bottom (after 43 days) value=1 to 3 mg/l respectively. This indicated a conversion of total organic nitrogen to ammonia in passage through 1 ft. of a cesspool lysimeter. Amount of ammonia nitrogen higher in the bottom effluent than in the side effluent. High was 33 mg/l after 18 days. Decreased to 19 mg/l after 47 days. Organic nitrogen high on 17th day: value=19 mg/l. Decreased to 1 mg/l in 47 days for the bottom. Side value =2 mg/l on the 15th day, increasing to 2.5 mg/l on the 47th day. Indicated a normal progression of biodegradation.	No reaction	Normal conversion of protein to nitrate or nitrite was being accomplished. Changes are not as marked in comparison to domestic sewage as might have been expected. Protein was converted to ammonia to nitrite and to nitrate.	The amount of ammonia nitrogen percolating through the sides was lower than through the bottom. Ammonia nitrogen content of raw sewage=12.2 mg/l. Bottom value rose to 34 mg/l after 19 days. Decreased to 22 mg/l after 43 days. Organic nitrogen content of raw sewage was 24.3 mg/l. Values for both side and bottom were nearly the same. Initial reading=8.0 mg/l for pit, decreased to 1 and 3 mg/l for side and bottom after 43 days. (Indicated conversion of total organic nitrogen to ammonia in passage through 1 ft. of soil.) Biodegradation progressed as expected. Side effluent showed higher production of ammonia nitrogen, thus, higher degree of degradation indicated. Test showed 90% reduction in organic nitrogen content, and 62 to 96% reduction of COD of the liquid waste as it was acted upon by microorganisms.
NITRATES	Value=1 mg/l. (Equivalent to that of water) No change	No nitrate formation.	Higher concentrations of nitrates in the side than in the bottom ef-	Value=1 mg/l. (Equivalent to that of water) no change	No nitrate formation.	Higher concentration in the side than in the bottom: range for side=37

TABLE 1 -- THE RESULTS (CONT'D)

AREAS OF TESTS	LOLEKAA HUMIC LATOSOL			WAHIAWA LOW HUMIC LATOSOL		
	TAP WATER	WEINBURGER'S SYNTHETIC SEWAGE	DOMESTIC SEWAGE	TAP WATER	WEINBURGER'S SYNTHETIC SEWAGE	DOMESTIC SEWAGE
NITRATES (cont'd)			fluent. Values: for side=13 mg/l bottom=2.7 to 6.0 mg/l. Brucine Method used.			to 53 mg/l;for bottom=12 to 14 mg/l. Decreasing nitrogen trend and increasing nitrate value indicated that degradation was proceeding to effect sewage stabilization. Brucine Method used.
BIOLOGICAL ACTIVITY	No reaction	Disagreeable odors from 1st to final day of tests. Light yellow effluent from the side, darker effluent from the bottom. Soil mass did not darken until after 35 days of dosing.	No obnoxious odors for 14 days. On 17th day musty odor with faint hints of mercaptans and skatoles was produced. Darkest colored effluent of all units with darker color effluent at the bottom than at the side. Red growth appeared after 11 days--could not be removed with clorox. Black ferrous sulfide patches appeared after 3 days in the bottom sediment. Liquid turned black in 7 days. Soil mass darkened after 2 weeks. Extensive colored deposits present.	No reaction	Soil mass darkened after 33 days of dosing. Disagreeable odors from 1st to last day of investigation. No darkening of the soil mass for 30 days. Appeared after 33 days of dosing.	Red growth appeared after 11 days. Similar to the Lolekaa domestic sewage fed unit. After 3 days black patches (ferrous sulfide) appeared in the bottom sediment. Liquid turned black in 7 days. Soil mass darkened after 2 weeks. Penetration of dark colored deposits was not so extensive. No odor for 14 days. After 17 days musty odor developed with hints of mercaptans and skatoles. Effluent light orange --bottom darker than sides.
CONTAMINATION POSSIBILITY	No reaction	Rising trends indicate that both sewage fed units would produce effluents with higher concentration of nitrates than the U.S. Drinking Water Standards of 45 mg/l.	The color, odor, and turbidity indicated that the effluent was capable of supporting microbial growth--a definite hazard to ground water supply.	No reaction	See notation under Lolekaa soil Group. Identical conditions existed in this soil group also.	See note under Lolekaa - Domestic Sewage.
HYDRAULIC CONSIDERATIONS	No reaction	Extensive penetration of solids which caused the bottom sediment to be broken up by the formation of gas. Flow rate from the bottom at times was higher than from the sides. Soil appeared to be drying out at 6 to 8 inches from the pit at the sides and 2 to 3 inches from the floor of the pit.		No reaction	Developed a pan-like layer of fines approximately 2.5 cm below the floor of the cesspool pit. This layer restricted the passage of suspended solids into the soil. Restriction appeared to prevent the gas formation within the soil to disrupt the bottom sediment. Bacterial action was limited to the sediment on the floor of the pit without penetration. The physical obstruction caused a lower rate of flow from the bottom than from the sides. As flow diminished, the soil appeared to dry out at a distance of 6 to 8 inches from the sides and 2 to 3 inches below the floor of the pit. This soil is notoriously poor for cesspools, although good results are offered in field infiltration flow rate tests.	

TABLE 2 -- NITRATE CONTENT

(mg/l N)

	WAHIAWA--SIDE		LOLEKAA--SIDE		WAHIAWA--BOTTOM		LOLEKAA--BOTTOM	
	8/4/65	8/6/65	8/4/65	8/6/65	8/4/65	8/6/65	8/4/65	8/6/65
SYNTHETIC SEWAGE	0.0	-	0.0	-	0.0	-	0.0	-
DOMESTIC SEWAGE	37.0	53.0	13.0	13.0	12.0	13.7	2.7	5.8
TAP WATER	-	0.8	-	0.8	-	0.8	-	0.9

TABLE 3 -- COD REDUCTION

	COD (mg/l)		REDUCTION (mg/l)		% REDUCTION	
	WAHIAWA	LOLEKAA	WAHIAWA	LOLEKAA	WAHIAWA	LOLEKAA
			SYNTHETIC SEWAGE			
SEWAGE	335	335				
PIT	146	150	185	185	56.4	55.2
SIDE	42	128	293	207	87.5	61.8
BOTTOM	13	126	322	209	96.2	62.4
			DOMESTIC SEWAGE			
SEWAGE	557	557				
PIT	407	379	150	178	27.0	31.9
SIDE	42	131	515	426	92.5	76.4
BOTTOM	71	81	486	476	87.3	85.5

TABLE 4 -- NITROGEN REDUCTION

	AMMONIA-N (mg/l)		% CHANGE		ORGANIC-N (mg/l)		% REDUCTION		TOTAL	
	WAHIAWA	LOLEKAA	WAHIAWA	LOLEKAA	WAHIAWA	LOLEKAA	WAHIAWA	LOLEKAA	WAHIAWA	LOLEKAA
					SYNTHETIC SEWAGE					
SEWAGE	0.47	0.47			21.61	21.61			22.08	22.08
PIT	19.70	19.70	+394	+394	5.40	5.50	75.00	74.50	25.10	25.20
EFFLUENT--SIDE	21.70	15.80	+434	+316	1.70	3.00	92.00	86.20	23.40	18.80
EFFLUENT--BOTTOM	21.00	19.70	+420	+394	1.90	2.60	91.00	88.00	22.90	22.30
					DOMESTIC SEWAGE					
SEWAGE	12.20	12.20			12.10	12.10			24.30	24.30
PIT	23.70	22.40	+194	+184	8.00	7.70	37.30	[illegible].30	31.70	30.10
EFFLUENT--SIDE	0.40	1.60	- 97	- 87	1.10	0.80	91.00	93.40	1.50	2.40
EFFLUENT--BOTTOM	20.80	19.50	+170	+160	2.30	2.40	81.00	80.00	23.10	21.90

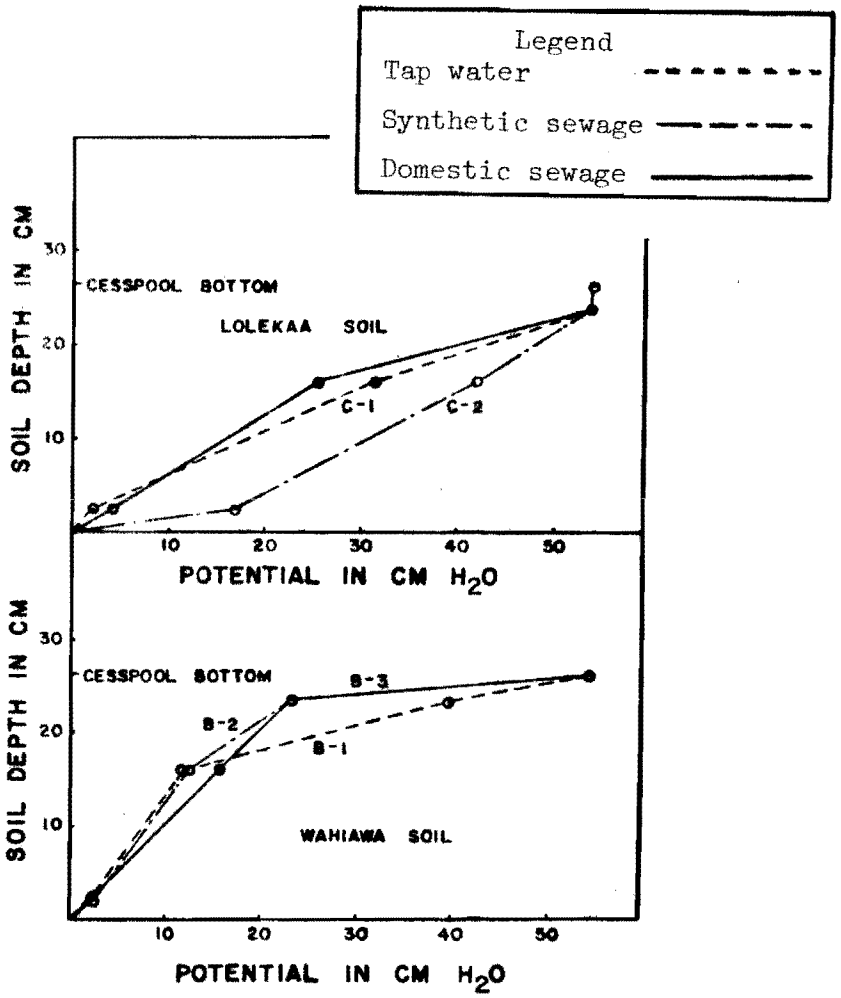
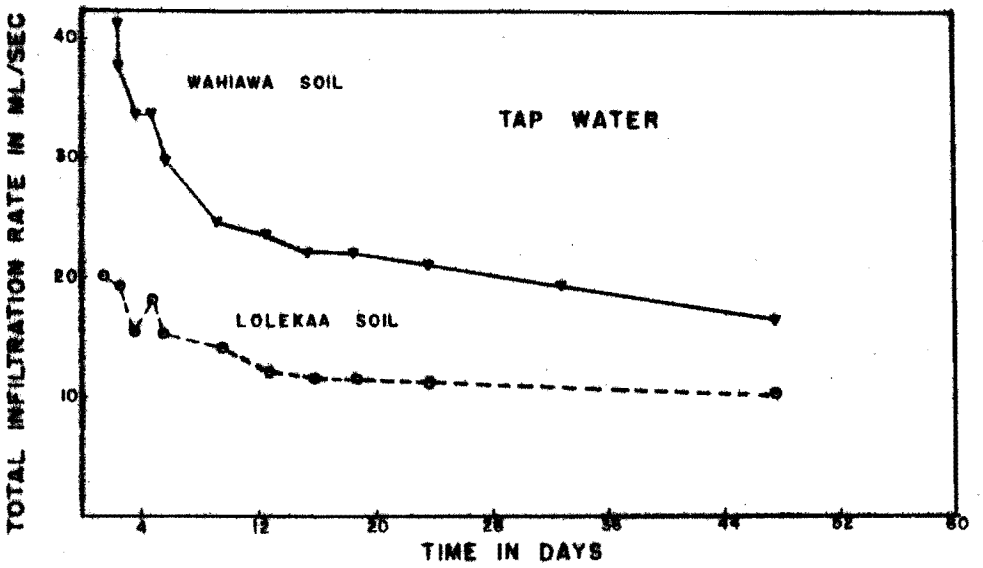
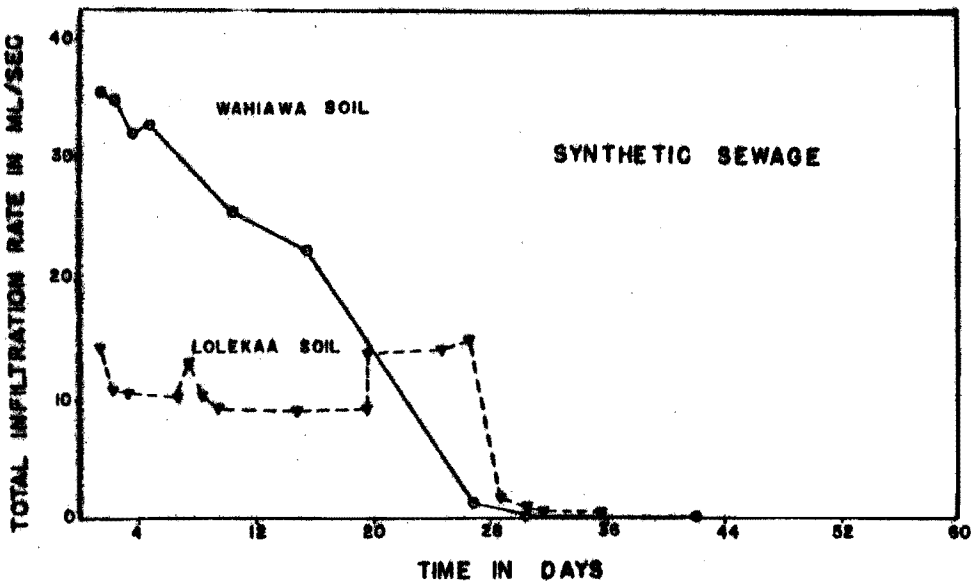


FIGURE 3--DEPTH VS POTENTIAL CURVES





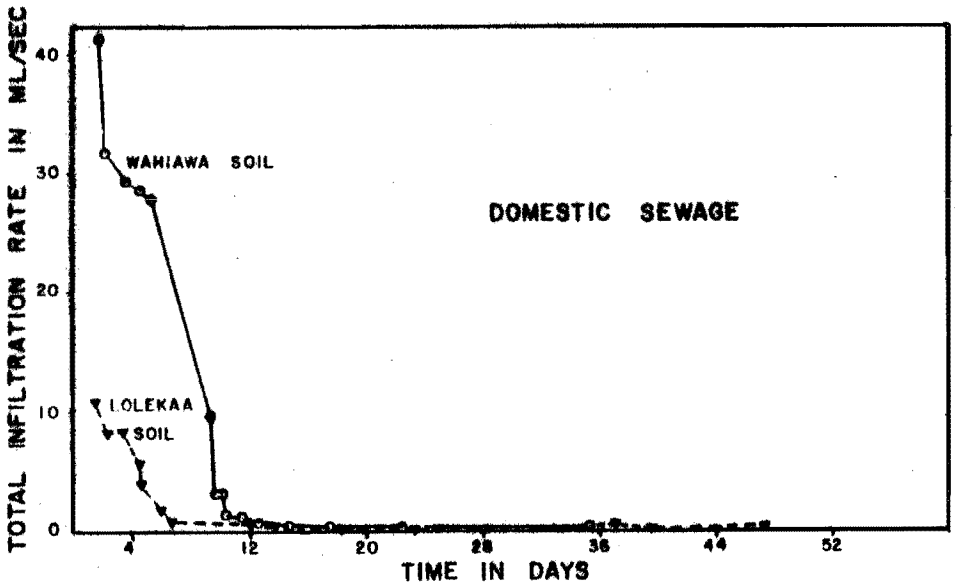


FIGURE 4--TOTAL INFILTRATION CAPACITY CURVES

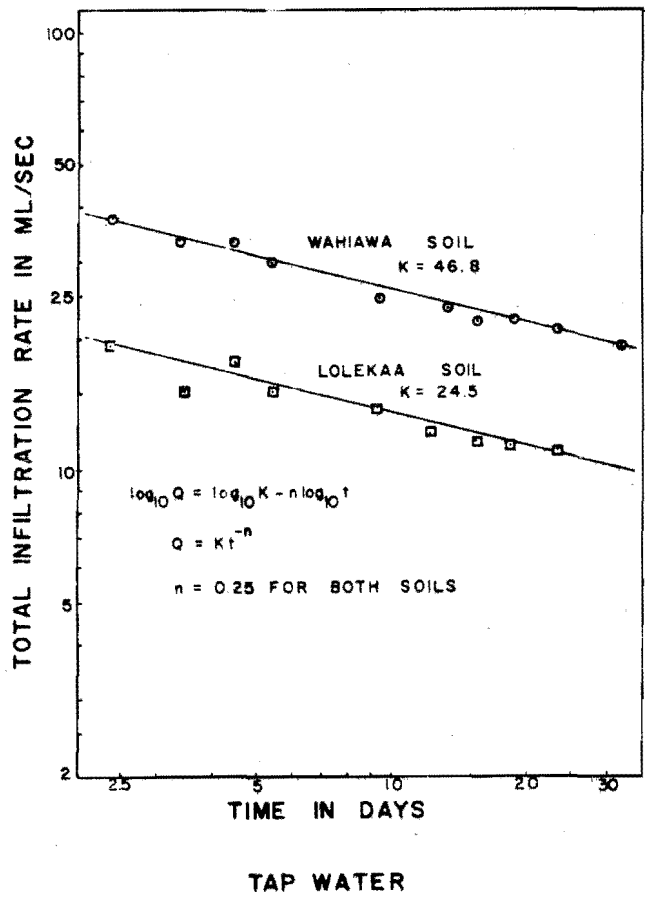
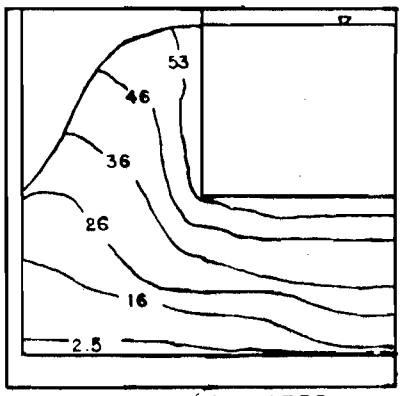
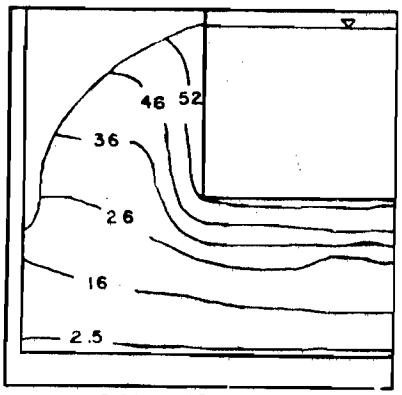


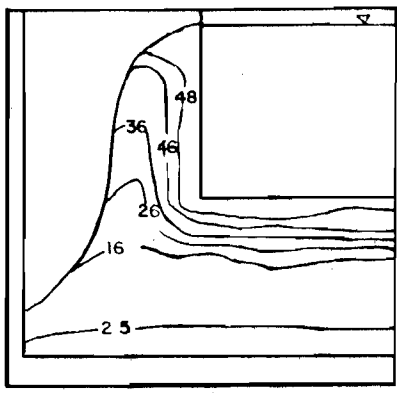
FIGURE 5--INFILTRATION CAPACITY CURVES



3 DAYS TAP WATER



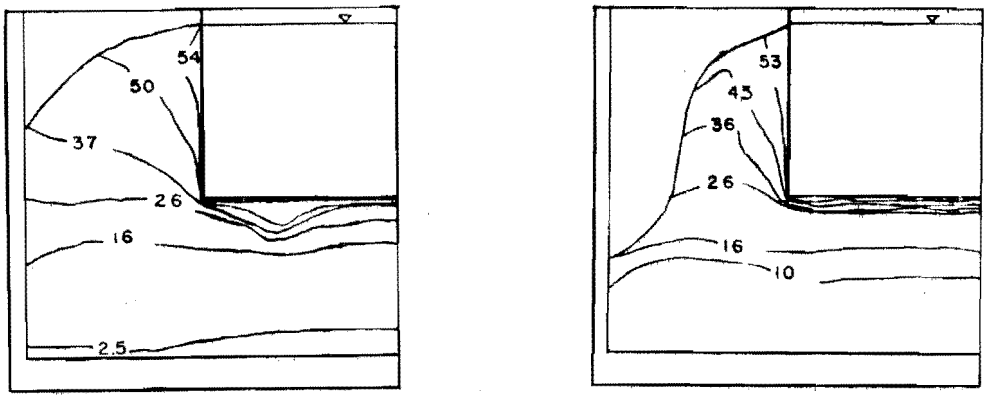
1 DAY SEWAGE



C-2 22 DAYS SEWAGE

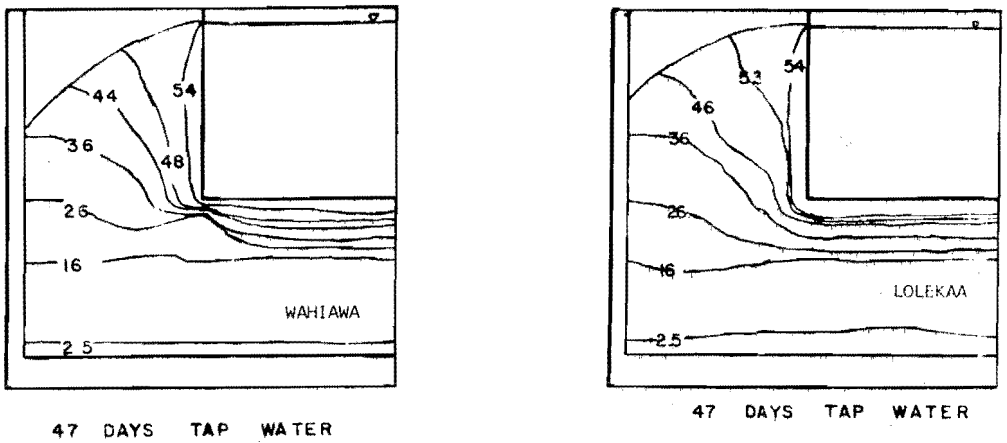
IN THE FLOW NETS PLOTTED ABOVE, THE LOLEKAA SOIL DOSED WITH SYNTHETIC SEWAGE, EXHIBIT A GENERAL PATTERN OF CONVERGENCE AT BOTH THE SIDE AND BOTTOM OF THE PIT EVEN THOUGH THIS SOIL GROUP DID NOT FORM A LAYER OF FINES. THE EQUIPOTENTIAL LINES ARE CLEARLY DEFINED.

FIGURE 6--FLOW NETS OF LOLEKAA SOIL WITH SYNTHETIC SEWAGE



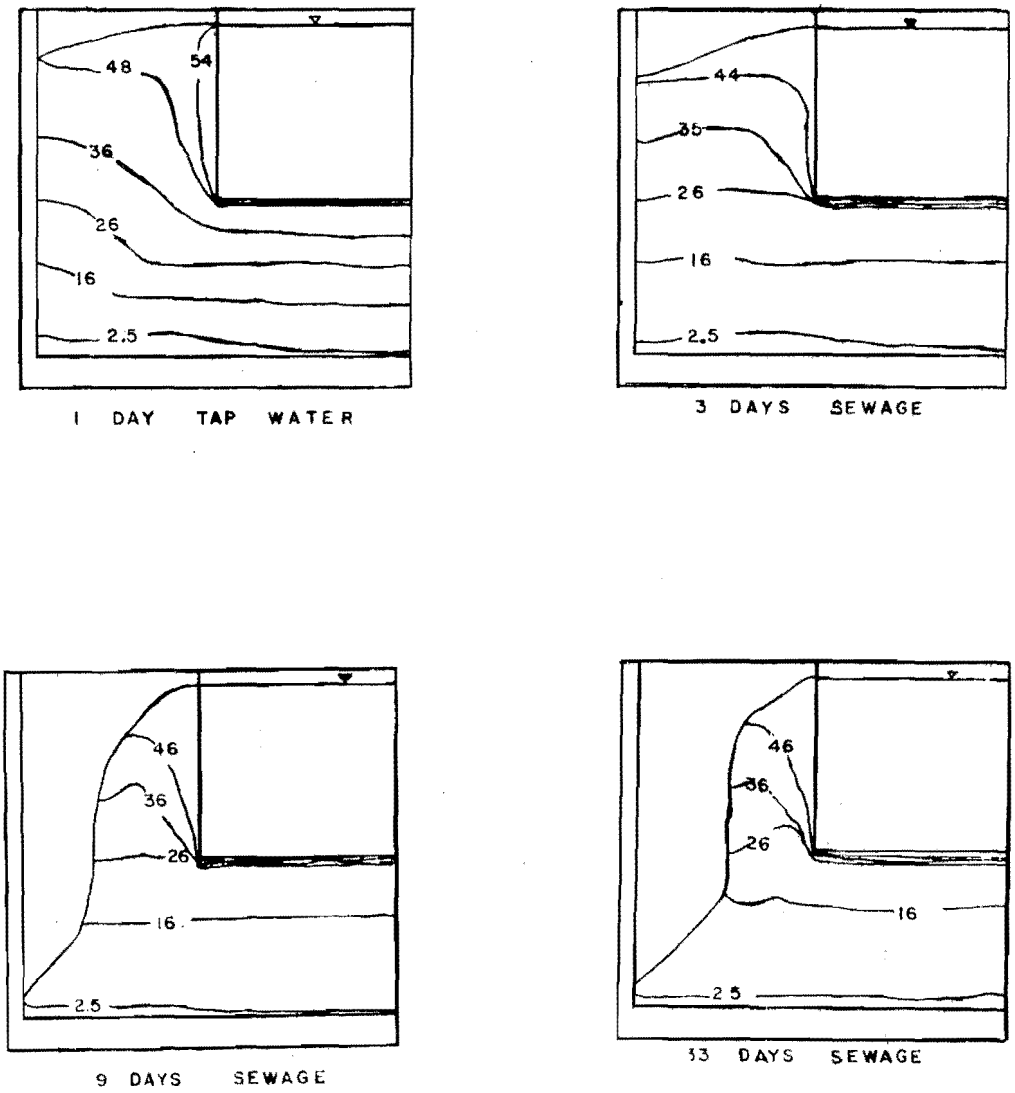
THE WAHIAWA SOIL DOSED WITH SYNTHETIC SEWAGE DEVELOPED A LAYER OF FINES ABOUT 2.5 CM FROM THE PIT FLOOR. NOTE THE EXTREME CONVERGENCE OF THE EQUIPOTENTIAL LINES BELOW THE PIT FLOOR AFTER 16 DAYS OF DOSING.

FIGURE 7--FLOW NETS OF WAHIAWA SOIL WITH SYNTHETIC SEWAGE



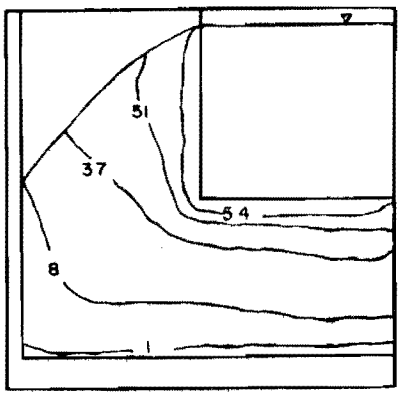
TAP WATER WHICH MEASURED PHYSICAL CLOGGING MAINTAINED DISTINGUISHABLE EQUIPOTENTIAL LINES FROM THE FIRST DAY OF TESTING TO THE LAST. NOTE THAT EVEN IN THE WAHIAWA SOIL-FILLED LYSIMETER THE LINES ARE SEPARATE AND CLEAR.

FIGURE 8--FLOW NETS OF WAHIAWA AND LOLEKAA SOIL WITH TAP WATER

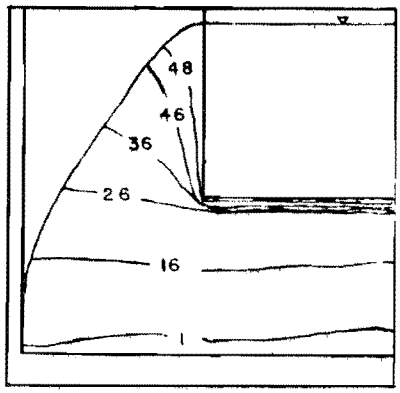


THE CONTRAST OF DEGREE OF CONVERGENCE OF THE FLOW NET IS SHARPLY ILLUSTRATED IN THESE SEQUENTIAL GRAPHS. NOTE THE EVENLY SPREAD LINES IN THE TAP WATER-DOSED READING IN CONTRAST TO THE READING AFTER ONLY THREE DAYS OF SEWAGE DOSING. THE UNSATURATED CONDITION OF THE WAHIAWA SOIL IS READILY EVIDENT IN THE SUBSEQUENT FLOW NET PLOTS.

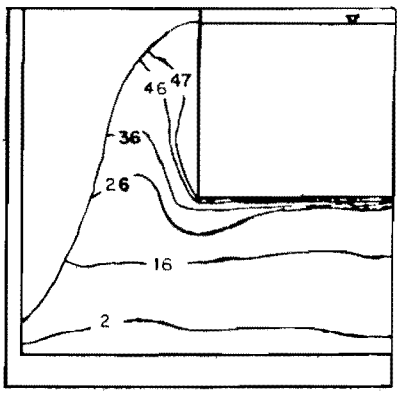
FIGURE 9--FLOW NETS OF WAHIAWA SOIL WITH DOMESTIC SEWAGE



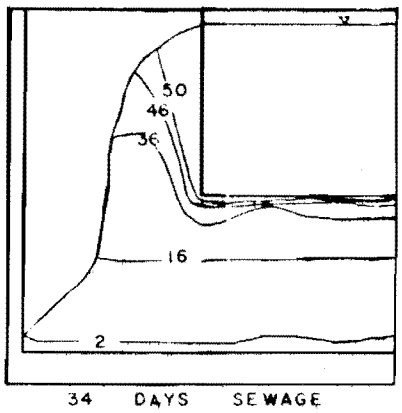
1 DAY TAP WATER



1 DAY SEWAGE



10 DAYS SEWAGE



34 DAYS SEWAGE

THIS SOIL ALSO EXHIBITED MARKED CONVERGENCE OF THE EQUIPOTENTIAL FLOW PATTERNS. ALTHOUGH A SHARP CONVERGENCE IS PRESENT IN AFTER ONE DAY OF DOMESTIC SEWAGE DOSING, THE CONDITION IMPROVED AFTER 34 DAYS OF SEWAGE DOSING.

FIGURE 10--FLOW NETS OF LOLEKAA SOIL WITH DOMESTIC SEWAGE

DISCUSSION AND CONCLUSIONS

The Equipment

The soil lysimeters constructed to simulate a corner of a cesspool performed according to design. All of the vital features of the lysimeters withstood the stresses imposed and their hydraulic properties were readily observable.

The lysimeters were simple to operate and maintain, requiring only a periodic removal of microbial growth from the bottoms and drains of the units. All extremes of flows through the test soils were handled by the drains with the exception of the Tantalus soil which had an appreciably higher infiltration rate.

The Results

FLOW STUDIES

This investigation of the flow of sewage through typical Hawaiian clay soils shows through flow net studies that clogging of the soil occurs rather close to the exposed soil surface, a depth of approximately 10 cm. Hawaiian soils show a dramatic 99% decrease in infiltration rate with soil clogging. However, in comparison with the flow rate of tap water through unclogged California soils, the rate of infiltration for clogged Hawaiian soils is seven times higher than that for unclogged California soils of the same type.

It was found that the infiltration curve for tap water fed into a simulated cesspool lysimeters containing Wahiawa Low Humic Latosol and Lolekaa Humic Latosol when plotted against time could be represented by an empirical equation of the form:

$$q = Kt^{-n}$$

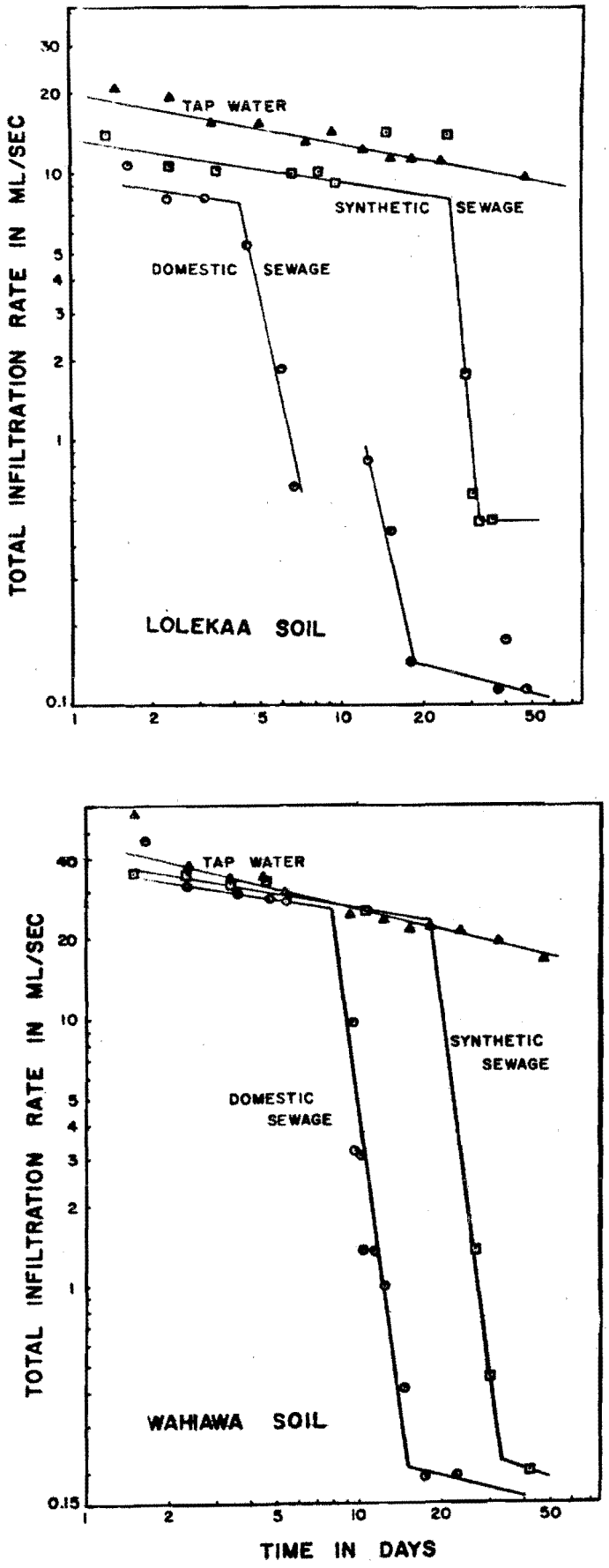


FIGURE 11--INFILTRATION CURVES

successful operation of cesspools depend largely on the continued permeability of the pit bottom.

The simulated cesspool lysimeter containing Lolekaa soil showed extensive solids penetration and the bottom sediment was broken up by gas formation. The flow rate through the cesspool bottom was at times higher than through the sides.

DEVELOPMENT OF FERROUS SULFIDE

The development of ferrous sulfide was noted within three days in domestic sewage-fed lysimeters; first, in the bottom sediment, and then in the liquid of the pit within seven days, and after two weeks in the soil immediately beside the layer of organic matter which had accumulated on the sides and bottom of the pit.

The synthetic sewage-fed units showed the same effects but within 33 days.

The Wahiawa soil demonstrated less extensive penetration by the dark colored deposits. This appears to be in accord with the development of the pan-like resistant layer beneath the cesspool bottom with continued inundation.

A relationship was observed between the color of the cesspool effluent and the occurrance of the ferrous sulfide and its deposit in the soil layers.

ACTION OF THE CESSPOOL

Within the cesspool contents true anaerobiasis was observed (negative ORP, the pH changes of the anaerobic environment, gas formation, and the formation of ferrous sulfide).

Within the soil mass surrounding the cesspool, the comparative results of changes in the ammonia and organic nitrogen content of the sew-

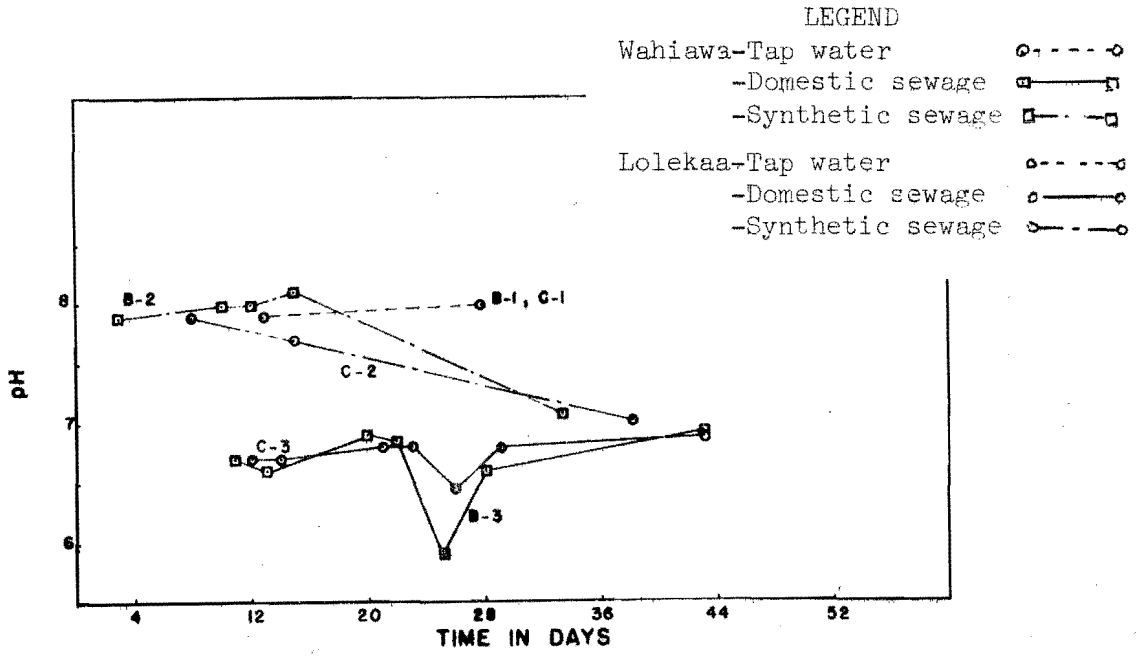


FIGURE 12--$_{P}$H CURVES FOR ALL UNITS

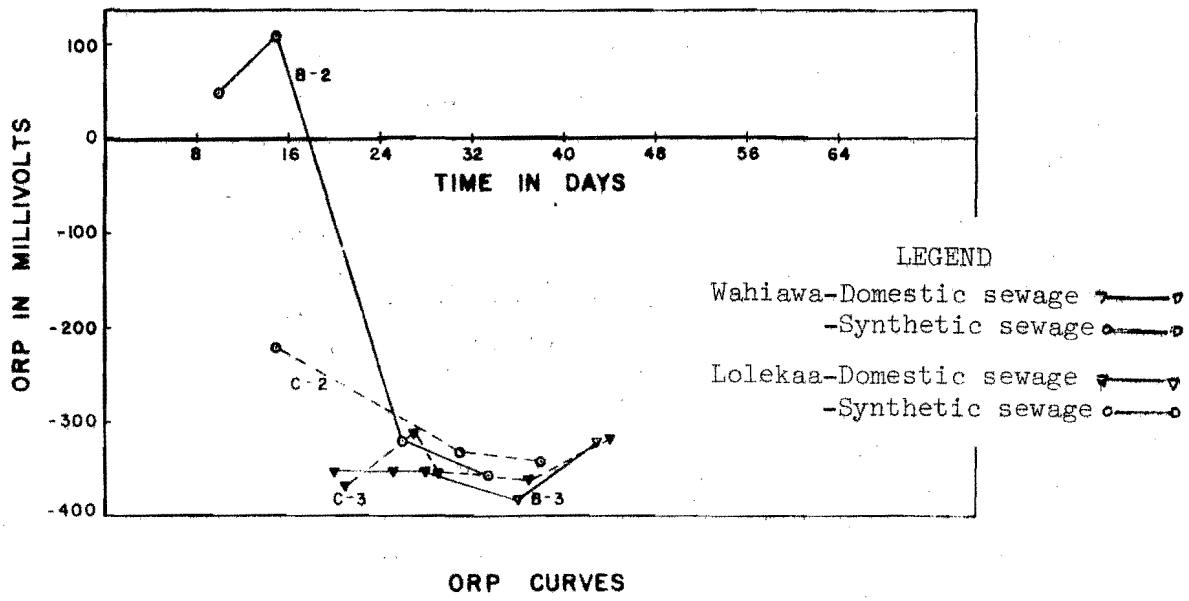


FIGURE 13--ORP CURVES

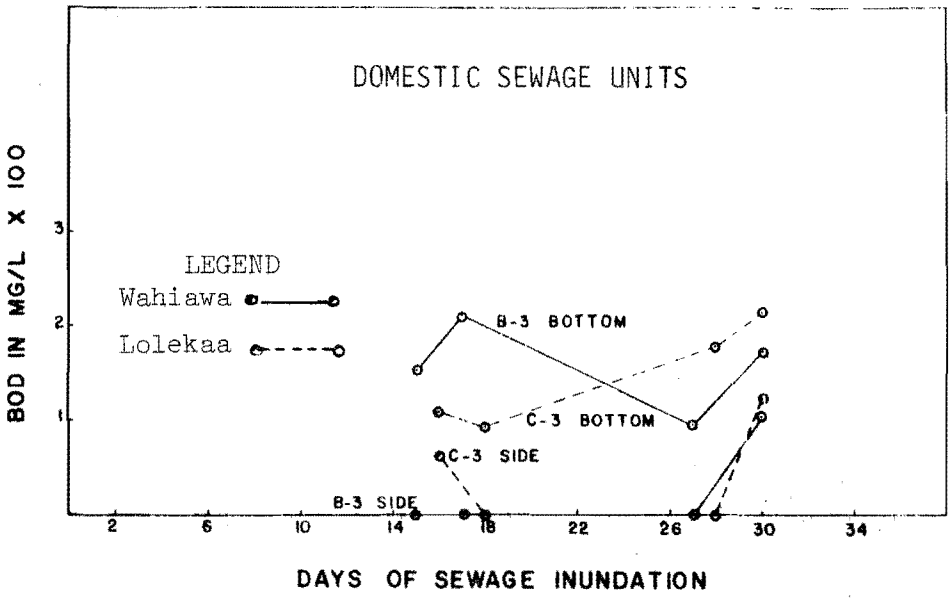


FIGURE 14--5-DAY BOD CURVES

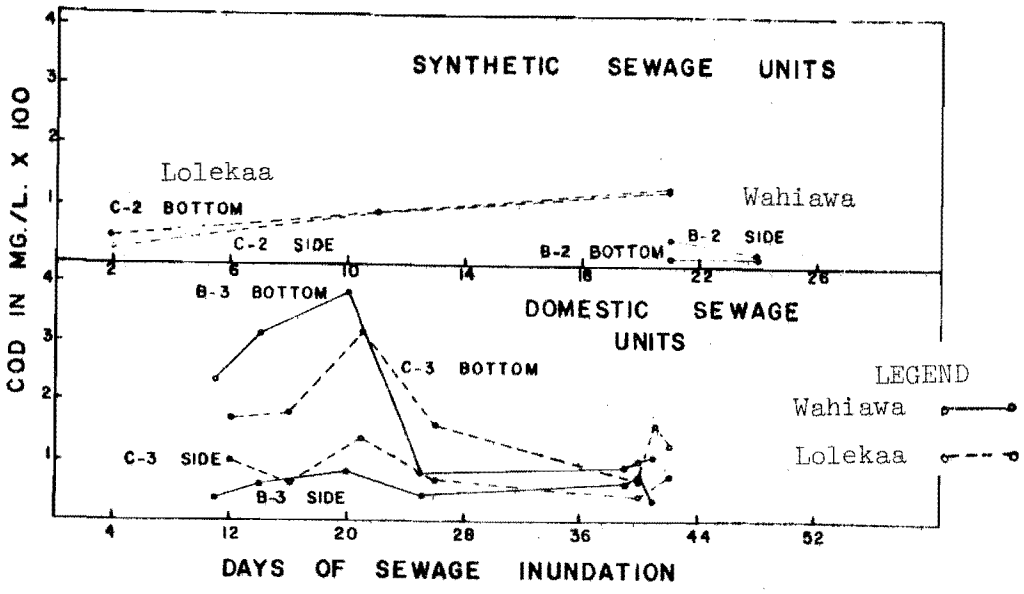


FIGURE 15--COD CURVES

where q is the flow rate, K is a constant, t is the time and n is a constant.

This equation was used by Willocks and others (24) in field infiltration tests of Oahu soils and by Hewlett and Hubbert (25) on model studies on a sloping soil mass during drainage. The results of this investigation with tap water flowing through a two dimensional flow lysimeter agreed quite closely with the empirical equation.

The log-log plot of the lysimeters dosed with sewage demonstrated that the infiltration rate changes significantly with time and could be separated into three distinct parts (Figure 11). The first segment of the curve denotes a normal reduction of infiltration by physical changes within the soul mass. The second, and steepest, segment of the curve indicates clogging by filtration and microbial action. The third portion of the curve shows the effect of long term clogging pres meably caused by microbial action.

The Wahiawa soil developed a pan-like layer of fines approximately 2.5 cm below the bottom soil surface of the cesspool. This layer restricted the passage of suspended solids in the liquid media from penetrating deeply into the soil. The restriction of solids penetration appears to prevent gas formation within the soil with its subsequent disruption of the bottom sediment and limits bacterial action to the sediment on the cesspool floor. The infiltration rate was, thus, much lower for the bottom of the lysimeter than for the side wall.

These results correlate with the field observation in the installation and operation of cesspools in Wahiawa soil which offers good field test results for infiltration, but on long term operation as in the case of cesspools, it clogs and fails. The leaching of liquid waste and the

age feed, the cesspool liquor, and the effluent for those domestic sewage-fed units demonstrated clearly that aerobiasis predominates within the soil mass. The conversion of organic nitrogen and ammonia to nitrates and the evidence of this in the side wall flow indicated some stabilization of the waste flowing through the cesspool; the levels of nitrates produced were well above the limits for potable drinking water as set by the U.S. Public Health Service.

The odorous, black, offensive cesspool liquor indicated clearly that the action of the bacteria in the cesspool liquid storage area was anaerobic. The pH changes showed the progression of anaerobiasis, the BOD and COD changes indicated that the side walls, experiencing a degree of aerobiasis, were more efficient in reducing BOD and COD (as measurements of organic matter present) than the bottom of the cesspool which showed anaerobiasis to a greater degree.

SUMMARY

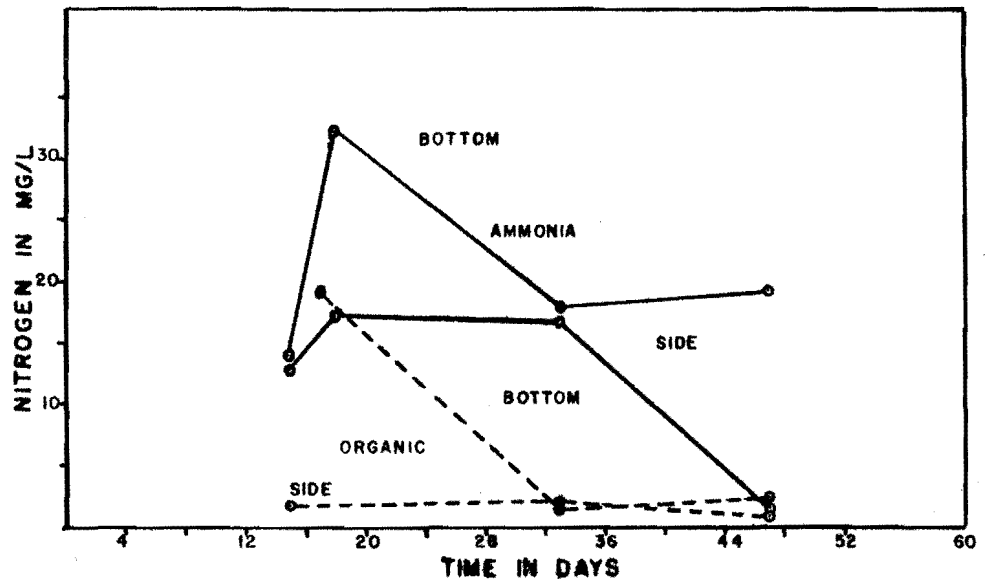
The pH readings for the two domestic sewage-fed units reflected the three stages of anaerobic digestion:

1. Acid fermentation
2. Acid regression
3. Alkaline fermentation.

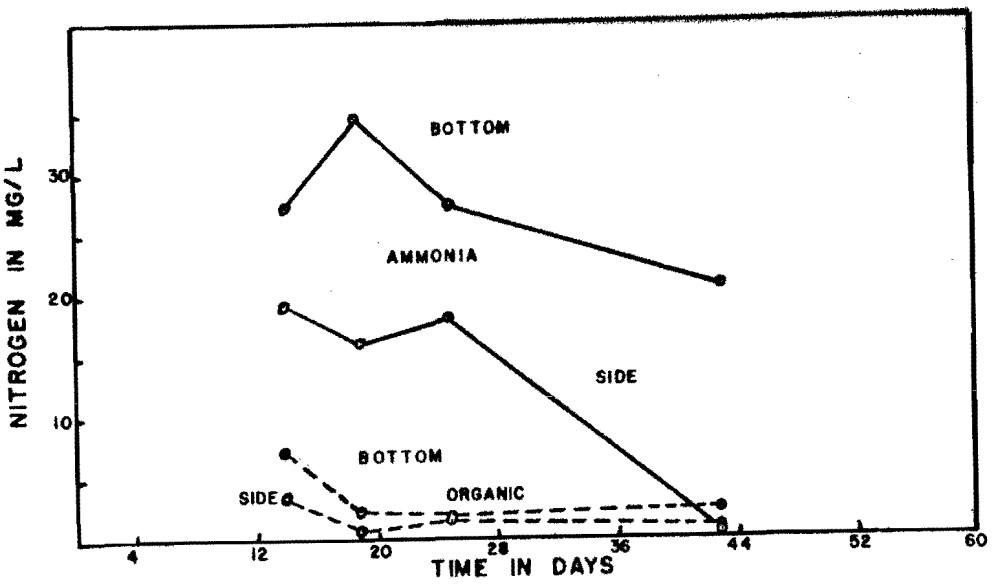
The time required for the cesspool to go through the three stages was extremely short; approximately 24 days as compared to 220 days for a sludge digester which also exhibits the same stages of anaerobiasis.

Odors developed in both units after approximately 17 days of sewage dosing. This corresponds to the start of the lowering of pH signifying the beginning of the acid fermentation stage. The domestic sewage-fed lysimeters showed a coincidental high in ammonia nitrogen concentration around the sixteenth day of inundation which supports the belief that the acid fermentation stage starts then.

The COD values for the same two units plotted on the same time scale as the pH showed an increase in COD with a corresponding decrease in pH. The cesspool was anaerobic as shown by the ORP measurements in the -340 mv range. It is safe to postulate, then, that the principle organisms present in the cesspool were the acid producing and methane producing strains. The effective pH range of the methane bacteria is 6.4 to 7.2. The acid formers are mostly facultative organisms and can exist over a much wider pH range. Since the enzymetic system of the methane bacteria is much more pH sensitive than the acid formers, the methane bacteria was inhibited as the pH of the cesspool dropped due to the action of the more prolific acid formers. Without the methane bacteria to carry oxidation to the final end products of CO_2 and CH_4, the

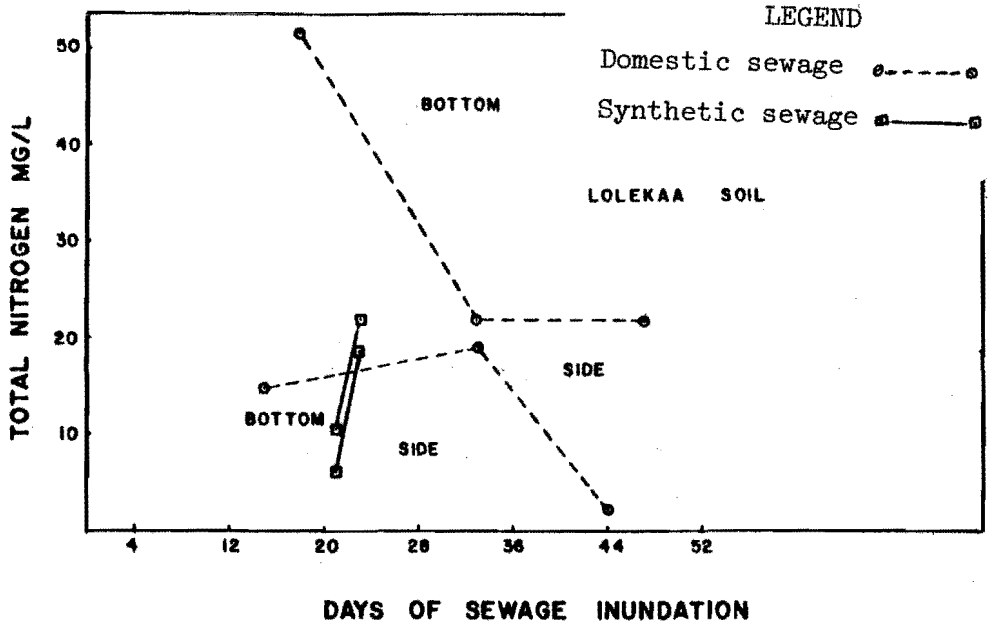


LOLEKAA SOIL/DOMESTIC SEWAGE



WAHIAWA SOIL/DOMESTIC SEWAGE

FIGURE 16--NITROGEN CURVES



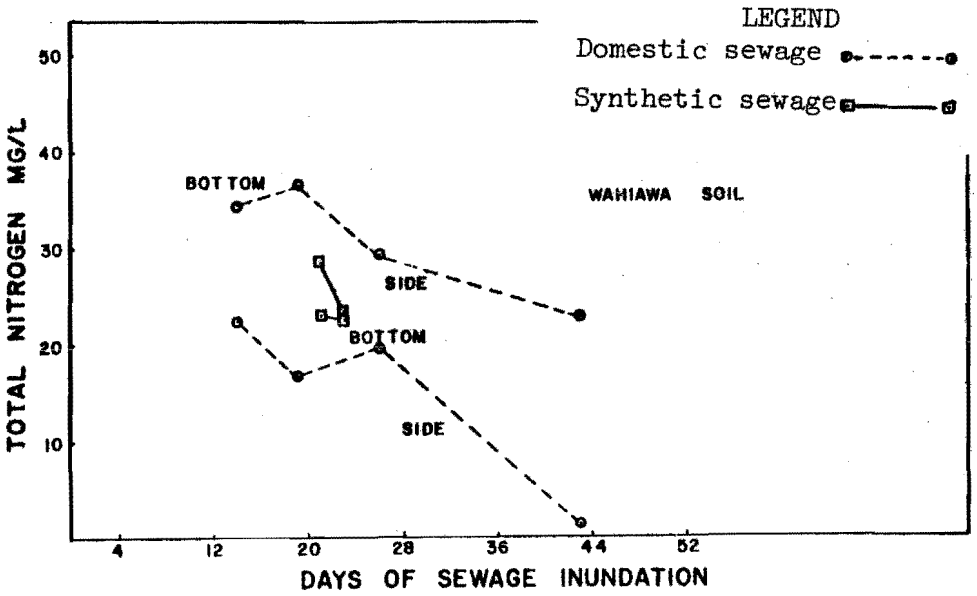


FIGURE 17--TOTAL NITROGEN CURVES

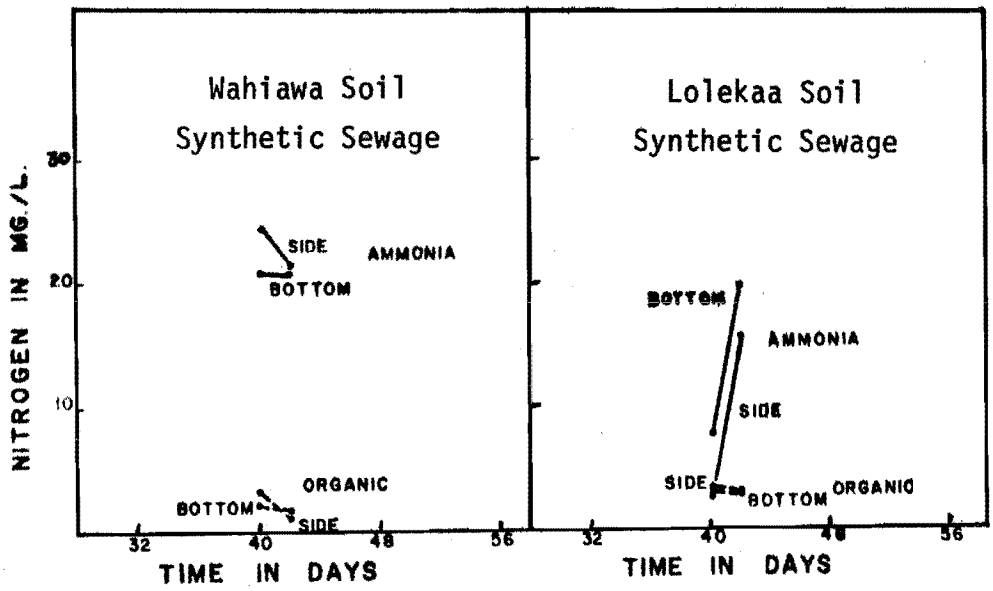


FIGURE 18--NITROGEN CURVES

amount of volatile solids in the cesspool increased, thus, causing a rise in COD. With an increase in pH, the COD values decreased. It appears, therefore, that the composition of the cesspool leachate is dependant on pH; that with pH values below 6.5 there is a trend to increase in the COD.

The phenomena of pH variation was not noted with the synthetic sewage-fed units. It is probable that the microbial flora and fauna found in the domestic sewage-fed units were not established in the synthetic sewage.

Anaerobic decomposition is in general less efficient than aerobic oxidation due to differences in the metabolic system of the respective types of organisms. Anaerobic organisms require from 20 to 30 times more food substrate than an equal number of aerobic organisms. Due to the inefficiency of the anaerobes in degradation, the effluent of the lysimeters exerted COD, BOD, and contained Ammonia. Nitrogen ammonia is not converted to nitrates by microorganisms under anaerobic conditions.

This study conclusively established the aerobic nature of the soil mass surrounding the cesspool. There was practically no increase in ammonia nitrogen as the liquid waste percolated through the soils. Also, the presence of nitrates on the order of 3 to 53 mg/l in the effluent of domestic sewage-fed lysimeters further indicated aerobiasis within the soil.

Lastly, the mobile field of flow patterns existing around the simulated cesspools were defined for the first time.

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APPENDIX A: COMPOSITION OF THE WEINBERGER SYNTHETIC SEWAGE

CONSTITUENT	CONCENTRATION mg/l CAMBRIDGE TAP WATER	CONSTITUENT	CONCENTRATION mg/l CAMBRIDGE TAP WATER
NUTRIENT BROTH	100	POTASSIUM CHLORIDE	7
UREA	30	CALCIUM CHLORIDE	7
CASTILE SOAP	50	MAGNESIUM SULFATE	5
SOLUBLE STARCH	100	ALUMINUM SULFATE (18 H_2O)	5
DIATOMACEOUS EARTH	25	DISODIUM HYDROGEN PHOSPHATE	25
SODIUM CHLORIDE	30	SODIUM BICARBONATE	168

APPENDIX B: HONOLULU WATER ANALYSIS

	KAIMUKI LOW SERVICE	BERETANIA LOW SERVICE
YEAR	1963	1963
DATE COLLECTED	OCT. 11	OCT. 11
LABORATORY NUMBER	85420	85422
REGIONAL HEAD, FEET	25.21	24.30
SPECIFIC CONDUCTANCE, MICROMHOS @ 25°C	381	310
$_pH$ VALUE	8.15	8.15
TURBIDITY	0	0
COLOR	0.1	0.1
	IN EQUIVALENTS PER MILLION	
CALCIUM	0.394	0.404
MAGNESIUM	.790	.724
SODIUM	2.194	1.607
POTASSIUM	.061	.084
BICARBONATE	1.196	1.262
SULFATE	.248	.158
CHLORIDE*	1.969	1.360
NITRATE	.026	.039
TOTALS	6.878	5.638

* HEXAVALENT ONLY.

*** INCLUDES FLOURIDE AND PHOSPHATE AS PO_4.

	KAIMUKI LOW SERVICE	BERETANIA LOW SERVICE
	IN PARTS PER MILLION	
DISSOLVED OXYGEN	8.55	9.20
FREE CARBON DIOXIDE	0	0
SILICA	36.00	40.00
CALCIUM	7.90	8.10
MAGNESIUM	9.60	8.80
SODIUM	50.40	36.90
POTASSIUM	2.40	3.30
BICARBONATE	73.00	77.00
SULFATE	11.90	7.60
CHLORIDE	69.50	48.00
FLOURIDE	0.05	0.05
NITRATE	1.60	2.40
PHOSPHATE	0.20	0.10
IRON)	.02	.02
MANGANESE)	.02	.02
COPPER)	.02	.02
LEAD) ..... LESS THAN	.02	.02
ARSENIC)	.02	.02
SELENIUM)	.01	.01
CHROMIUM***)	.02	.02
TOTAL DISSOLVED SOLIDS	263.00	232.00
ALKALINITY	60.00	63.00
TOTAL HARDNESS	59.00	56.00

APPENDIX C: WAHIAWA SOIL SERIES

THE WAHIAWA SERIES COMPRISES ALFIC HAPLOXEROX, MEMBERS OF A CLAYEY, OXIDIC, HYPERNESIC FAMILY. TYPICALLY, THE SOILS ARE DARK REDDISH BROWN WITH A GRANULAR A HORIZON OVER A FRIABLE, BUT COMPACT B HORIZON WITH A STRONG STRUCTURE. MANAGANESE IS COMMON THROUGHOUT THE SOLUM GIVING A PURPLISH CAST WHEN MOIST.

TYPIFYING PROFILE: WAHIAWA SILTY CLAY* - PINEAPPLE

AP1	0-6"	VERY DUSKY-RED (2.5YR 2/2) SILTY CLAY, DUSKY RED (2.5YR 3/2) DRY; MODERATE MEDIUM,FINE, AND VERY FINE GRANULAR STRUCTURE; VERY HARD, FRIABLE, STICKY AND PLASTIC; ABUNDANT ROOTS; MANY MEDIUM, FINE AND VERY FINE INTERSTITIAL PORES; MANY BLACK CONRETIONS (1/8 - 1/4" DIAMETER); COMPACT IN PLACE; VIOLENT EFFERESCENCE WITH HYDROGEN PEROXIDE; MEDIUM ACID ($_pH$ 5.6); ABRUPT SMOOTH BOUNDARY. TWO TO SIX INCHES THICK.
AP2	6-12"	DUSKY-RED (2.5YR 3/2) MOIST AND DRY SILTY CLAY; COMMON DARK REDDISH-BROWN (2.5YR 3/4) MATERIAL FORM THE B HORIZON MIXED BY CULTIVATION; MODERATE COARSE SUBANGULAR BLOCKY STRUCTURE; HARD, FIRM, STICKY AND PLASTIC; COMPACT IN PLACE; ABUNDANT ROOTS; FEW FINE AND VERY FINE TUBULAR PORES; MANY BLACK CONCRETIONS; VIOLENT EFFERVESCENCE WITH HYDROGEN PEROXIDE; MEDIUM ACID ($_pH$ 5.8); ABRUPT WAVY BOUNDARY; 5 TO 8 INCHES THICK.
B21	12-16"	DARK REDDISH-BROWN (2.5YR 2/4) SILTY CLAY, DARK REDDISH BROWN (2.5YR 3/4) DRY; WEAK COARSE SUBANGULAR BREAKING TO MODERATE FINE AND VERY FINE SUBANGULAR BLOCKY STRUCTURE; HARD, FIRM, STICKY AND PLASTIC; PLENTIFUL ROOTS; COMMON FINE AND VERY FINE, FEW COARSE TUBULAR PORES; MANY BLACK CONCRETIONS; STRONG EFFERVESCENCE WITH HYDROGEN PEROXIDE; MEDIUM ACID ($_pH$ 5.6).
B22	16-33"	DARK REDDISH-BROWN (2.5YR 2/4) SILTY CLAY, DARK REDDISH BROWN (2.5YR 3/4) DRY; WEAK COARSE SUBANGULAR BLOCKY BREAKING TO MODERATE AND STRONG SUBANGULAR BLOCKY STRUCTURE; HARD FRIABLE, STICKY AND PLASTIC; VERY FEW ROOTS; COMMON FINE AND VERY FINE TUBULAR PORES; NEARLY CONTINUOUS PRESSURE CUTANS; MANY FINE DISTINCT BLACK STAINS; FEW BLACK CONCRETIONS; STRONG EFFERVESCENCE WITH HYDROGEN PEROXIDE; SLIGHTLY ACID ($_pH$ 6.5); DIFFUSE WAVY BOUNDARY. FOURTEEN TO 20 INCHES THICK.
B23	33-45"	DARK REDDISH-BROWN (2.5YR 2/4) SILTY CLAY, DARK REDDISH BROWN (2.5YR 3/4) DRY; WEAK COARSE SUBANGULAR BLOCKY BREAKING TO MODERATE AND STRONG VERY FINE SUBANGULAR BLOCKY STRUCTURE; HARD, FRIABLE, STICKY AND PLASTIC; NO ROOTS,COMMON AND VERY FINE TUBULAR PORES; NEARLY CONTINUOUS PRESSURE CUTANS; MANY FINE, DISTINCT BLACK STAINS; FEW BLACK CONCRETIONS; MODERATE EFFERVESCENCE WITH HYDROGEN PEROXIDE; NEUTRAL ($_pH$ 7.1); DIFFUSE WAVY BOUNDARY. TEN TO 14 INCHES THICK.
B3	45-60"+	DARK REDDISH-BROWN (2.5YR 2/4) SILTY CLAY, DARK REDDISH BROWN (2.5YR 3/4) DRY; MODERATE AND STRONG VERY FINE SUBANGULAR BLOCKY STRUCTURE; HARD, FRIABLE, STICKY AND PLASTIC; NO ROOTS; COMMON FINE AND VERY FINE TUBULAR PORES; FEW FINE BLACK STAINS; VERY FEW BLACK CONCRETIONS; THIN PATCHY CLAY FILMS; CONTINUOUS PRESSURE CUTANS; MANY DISTINCT SLICKENSIDES UP TO 2 INCHES LONG; SLIGHT EFFERVESCENCE WITH HYDROGEN PEROXIDE; NEUTRAL ($_pH$ 6.9).

TYPE LOCATION: HONOLULU COUNTY, HAWAII. DOLE CORPORATION. KAMEHAMEHA HIGHWAY TO THE ENTRANCE ROAD TO MILILANI CEMETARY. EAST 0.7 MILE THEN 400' NORTH IN FIELD #4101 BLOCK 30. PHOT NUMBER DACE-1-25.

RANGE IN CHARACTERISTICS: THE A HORIZON HAS DRY AND MOIST VALUES OF 2 OR 3 AND CHROMAS OF 2 TO 4 WHEN DRY OR MOIST. THE B HORIZON RANGES IN HUE FROM 2.5YR TO 10R WITH DRY AND MOIST VALUES OF 2 OR 3, CHROMAS OF 3 TO 6 WHEN DRY, AND 3 TO 5 WHEN MOIST. MANGANESE CONCRETIONS OCCUR ON THE SURFACE AND TO DEPTHS OF 4 TO MORE THAN 5 FEET. DEPTH TO HIGHLY WEATHERED BASALT VARIES FROM 5 TO MORE THAN 10 FEET, BUT A FEW BOULDER CORES MAY OCCUR IN THE LOWER SOLUM.

COMPETING SERIES AND THEIR DIFFERENTIAE: THESE ARE THE KUNIA, LAHAINA, LEILEHUA, AND MANANA SERIES. THE KUNIA SOILS HAVE HUES OF 5YR IN THE A HORIZON, AND WEAK PATCHY PRESSURE CUTANS IN THE B_2 HORIZON. THE LAHAINA SOILS HAVE WEAK STRUCTURE IN THE A HORIZON; LOW CONCENTRATIONS OF MANGANESE BELOW 25 INCHES. LEILEHUA SOILS HAVE ARGILLIC HORIZONS, LOW CONCENTRATIONS OF MANGANESE, AND ARE VERY STRONGLY TO EXTREMELY ACID. MANANA SOILS HAVE A THIN PAN-LIKE SHEET IN THE UPPER B. THEY ALSO HAVE ARGILLIC HORIZONS.

SETTING: WAHIAWA SOILS ARE ON LONG, SMOOTH RELATIVELY UNDISSECTED MEDIAL UPLANDS AT ELEVATIONS OF 500 TO 1200 FEET. SLOPES ARE NORMALLY 1 TO 8 PERCENT, BUT RANGE FROM 0 TO 25 PERCENT. THE SOILS DEVELOPED IN WHAT IS PRESUMED TO BE ALLUVIUM FROM OLIVINE BASALT OF THE KOOLAU MOUNTAINS. ANNUAL RAINFALL IS 40 TO 60 INCHES. MEAN ANNUAL SOIL TEMPERATURE IS ABOUT 71°F, AVERAGE JANUARY TEMPERATURE IS 69°F; AVERAGE JULY TEMPERATURE IS 76°F.

PRINCIPAL ASSOCIATED SOILS: WAHIAWA SOILS ARE IN THE SAME GENERAL AREA AS THE KUNIA, LAHAINA, LEILEHUA, AND MANANA SERIES.

DRAINAGE AND PERMEABILITY: WELL DRAINED WITH SLOW RUNOFF AND MODERATELY RAPID PERMEABILITY.

USE AND VEGETATION: USED PRIMARILY FOR IRRIGATED SUGARCANE AND PINEAPPLE WITH SMALL AREAS OF PASTURE. NATURAL VEGETATION CONSISTS OF GUAVA (PSIDIUM GUAYAVA) KOA HAOLE (LEUCAENA GLAUCA), LANTANA (LANTANA CAMARA), JOEE (STACHYTARPHETA CYANNENSIS), JAPANESE TEA (CASSIA LESCHENAULTIANA), BERMUDA GRASS (CYNODON DACTYLON) AND HONOHONO (COMMELINA DIFFUSA).

DISTRIBUTION AND EXTENT: ON THE MEDIAL UPLANDS BETWEEN THE WAIANAE AND KOOLAU RANGES. THEY COMPRISE 22,264 ACRES.

SERIES ESTABLISHED: HONOLULU COUNTY, HAWAII. SOIL SURVEY, TERRITORY OF HAWAII, 1955. NAME TAKEN FROM THE TOWN OF WAHIAWA.

REMARKS: THE WAHIAWA SERIES WAS FORMERLY CLASSIFIED AS A LOW HUMIC LATOSOL

EUH-LDG

NATIONAL COOPERATIVE SOIL SURVEY, USA
5/9/65

APPENDIX D: LOLEKAA SOIL SERIES

THE LOLEKAA SERIES COMPRISES HUMOIC TROPOHUMULTS, MEMBERS OF A CLAYEY, OXIDIC, HYPERMESIC FAMILY. TYPICALLY, THESE SOILS HAVE DARK BROWN A HORIZONS WITH STRONG FINE AND VERY FINE SUBANGULAR BLOCKY STRUCTURE. THE UPPER B2 HORIZONS ARE DARK BROWN, HAVE STRONG SUBANGULAR BLOCKY AND CONTINUOUS CLAY FILMS ON SURFACES AND IN PORES.

TYPIFYING PROFILE: LOLEKAA SILTY CLAY* - PASTURE

AP 0-10" DARK-BROWN (10YR 3/3) SILTY CLAY, DARK YELLOWISH BROWN (10YR 3/4); STRONG VERY FINE AND FINE SUBANGULAR BLOCKY STRUCTURE; VERY HARD, FRIABLE, STICKY AND PLASTIC; ABUNDANT FINE AND MEDIUM ROOTS; MANY VERY FINE AND FINE INTERSTITIAL AND TUBULAR PORES; MANY VERY FINE HARD EARTHY LUMPS; STRONGLY ACID ($_{p}$H 5.1); ABRUPT SMOOTH BOUNDARY. EIGHT TO 10 INCHES THICK.

B1 10-15" DARK-BROWN (10YR 3/3) SILTY CLAY, DARK YELLOWISH BROWN (10YR 3/4) DRY; MODERATE VERY FINE AND FINE SUBANGULAR BLOCKY STRUCTURE; HARD FRIABLE, STICKY AND PLASTIC; PLENTIFUL FINE ROOTS; MANY VERY FINE, FINE AND MEDIUM TUBULAR PORES; CONTINUOUS THIN COATINGS ON PED FACES; EVIDENCE OF MUCH WORM ACTIVITY; MANY HARD EARTHY LUMPS; COMMON SOFT STRONGLY WEATHERED GRAVELS; DISTINCTLY YELLOWER THAN MATRIX AND SMEARY; VERY STRONGLY ACID ($_{p}$H 4.6); CLEAR SMOOTH BOUNDARY. FOUR TO 6 INCHES THICK.

B21T 15-22" DARK-BROWN (10YR 3/3) WILTY CLAY, DARK BROWN (10YR 4/3) DRY; STRONG VERY FINE, FINE AND MEDIUM BLOCKY AND SUBANGULAR BLOCKY STRUCTURE; HARD, FRIABLE, STICKY AND PLASTIC; FEW FINE ROOTS; MANY VERY FINE, FINE AND MEDIUM TUBULAR PORES; CONTINUOUS THICK CLAY FILMS IN ROOT CHANNELS; MANY HARD EARTHY LUMPS; COMPACT IN PLACE; VERY STRONGLY ACID ($_{p}$H 4.6); CLEAR SMOOTH BOUNDARY. FOUR TO 10 INCHES THICK.

B22T 23-33" DARK-BROWN (10YR 3/3) SILTY CLAY, DARK BROWN (10YR 4/3) DRY; STRONG MEDIUM SUBANGULAR BLOCKY AND STRONG VERY FINE AND FINE ANGULAR BLOCKY STRUCTURE; HARD, FRIABLE, STICKY AND PLASTIC; FEW FINE ROOTS; COMMON VERY FINE AND FINE TUBULAR PORES; CONTINUOUS THICK CLAY FILMS ON PED FACES AND DARK-BROWN (7.5YR 4/4 MOIST) CONTINUOUS THICK CLAY FILMS IN ROOT CHANNELS; MANY HARD EARTHY LUMPS; VERY COMPACT IN PLACE; VERY FEW HIGHLY WEATHERED ROCK FRAGMENTS; EXTREMELY ACID ($_{p}$H 4.3); CLEAR WAVY BOUNDARY. NINE TO 18 INCHES THICK.

B23T 33-42" DARK-BROWN (10YR 3/3) SILTY CLAY, DARK BROWN (10YR 4/3) DRY; STRONG VERY FINE AND FINE BLOCKY AND SUBANGULAR BLOCKY STRUCTURE; HARD, FRIABLE, STICKY AND PLASTIC, FEW FINE ROOTS; MANY FINE AND VERY FINE TUBULAR PORES; REDDISH-BROWN (5YR 4/4 MOIST) CONTINUOUS THIN CLAY FILM ON PED FACES AND DARK-BROWN (7.5YR 4/4 MOIST) CONTINUOUS THICK CLAY FILMS IN ROOT CHANNELS; COMPACT IN PLACE; FEW ROCK FRAGMENTS; EXTREMELY ACID ($_{p}$H 4.3); CLEAR SMOOTH BOUNDARY. THIRTEEN TO 15 INCHES THICK.

B24T 42-55" DARK YELLOWISH-BROWN (10YR 4/4) LOAM, YELLOWISH BROWN (10YR 5/4) MOIST; MODERATE TO WEAK VERY FINE AND FINE SUBANGULAR BLOCKY STRUCTURE; HARD, FRIABLE, SLIGHTLY STICKY AND SLIGHTLY PASTIC; FEW VERY FINE ROOTS; MANY VERY FINE AND FINE TUBULAR PORES; REDDISH BROWN (5YR 4/4 MOIST) CONTINUOUS THIN CLAY FILM ON PED FACES AND DARK-BROWN (7.5YR 4/4 MOIST) CONTINUOUS THICK CLAY FILMS IN ROOT CHANNELS; COMPACK IN PLACE; FEW ROCK FRAGMENTS; EXTREMELY ACID ($_{p}$H 4.3); CLEAR SMOOTH BOUNDARY. THIRTEEN TO 15 INCHES THICK.

B3T 55-65" DARK YELLOWISH-BROWN (10YR 3/4) LOAM, YELLOWISH BROWN (10YR 5/4) MOIST; MODERATE TO WEAK VERY FINE AND FINE SUBANGULAR BLOCKY STRUCTURE; HARD, FRIABLE, SLIGHTLY STICKY AND SLIGHTLY PLASTIC; FEW VERY FINE ROOTS; MANY VERY FINE AND FINE TUBULAR PORES; REDDISH BROWN (5YR 4/4 MOIST); THIN CONTINUOUS CLAY FILMS ON PED FACES AND IN PORES; 20 TO 25 PERCENT WEATHERED ROCK FRAGMENTS THAT ARE LESS WEATHERED THAN ABOVE; EXTREMELY ACID ($_{p}$H 4.3).

TYPE LOCATION: HONOLULU COUNTY, HAWAII. NEAR STATE HOSPITAL AT KANEOHE. ON FEDERAL HIGHWAY NUMBER 83. TURN WEST ON KEAAHALA ROAD TOWARD HOSPITAL, PROCEED ABOUT 2400 FEET TO HOSPITAL BOUNDARY, THEN NORTHWEST 600 FEET ACROSS KEAAHALA STREAM TO THE IMPROVED PASTURE. PHOTOGRAPH NUMBER DACE-3-42.

RANGE OF CHARACTERISTICS: DOMINANT TYPE IS SILTY CLAY, BUT SMALL AREAS OF HEAVY SILTY CLAY LOAM MAY BE INCLUDED. TEXTURE OF THE B3T HORIZONS RANGE FROM LOAM TO SILTY CLAY. MOIST VALUES AND CHROMAS OF THE A HORIZON RANGE FROM 2 TO 4. MOIST VALUES OF THE B HORIZON RANGE FROM 3 TO 4 AND MOIST CHROMAS RANGE FROM 3 TO 6. HIGHLY WEATHERED, SOFT GRAVEL AND STONES VARY FROM NONE TO MANY THROUGHOUT THE SOLUM. REACTION VARIES FROM STRONGLY TO EXTREMELY ACID. DEPTH TO HIGHLY WEATHERED GRAVEL AND STONES VARIES FROM 40 TO MORE THAN 60 INCHES.

COMPETING SERIES AND THEIR DIFFERENTIAE: THESE ARE THE KANEOHE, POHAKUPU, AND WAIKANE SCRIES. THE KANEOHE SOILS HAVE 5YR AND REDDER HUES THROUGHOUT THE SOLUM. THE POHAKUPU SOILS DO NOT HAVE AN ARGILLIC HORIZON, ARE SLIGHTLY ACID THROUGHOUT AND HAVE BLACK STAINS IN THE B HORIZON THAT EFFERVESCE WITH HYDROGEN PEROXIDE. WAIKANE SOILS HAVE 7.5YR AND REDDER HUES IN THE B HORIZON.

SETTING: LOLEKAA SOILS OCCUR ON NEARLY LEVEL TO GENTLY SLOPING TERRACES AND MODERATELY SLOPING TO VERY STEEP ALLUVIAL FANS AT ELEVATIONS OF NEAR SEA LEVEL TO 500 FEET. ANNUAL RAINFALL IS 70 TO 90 INCHES. AVERAGE JANUARY TEMPERATURE IS ABOUT 70°F; AVERAGE JULY TEMPERATURE IS ABOUT 76°F. THE MEAN ANNUAL SOIL TEMPERATURE IS ABOUT 71°F. THE REGOLITH IS ALLUVIUM AND COLLUVIUM FROM BASIC IGNEOUS ROCK.

PRINCIPAL ASSOCIATED SOILS: THESE ARE THE ALAEOA,HANALEI, KANEOHE, AND WAIKANE SERIES.

DRAINAGE AND PERMEABILITY: WELL DRAINED. MODERATELY RAPID PERMEABILITY. RUNOFF IS SLOW TO MEDIUM.

USE AND VEGETATION: USED PRIMARILY FOR PASTURE. SMALL AREAS ARE USED FOR TRUCK CROPS AND ORCHARDS. VEGETATION IS CALIFORNIA GRASS (PANICUM PURPURASCENS), HILO GRASS (PASPALUM CONJUGATUM), RICE GRASS (PASPALUM ORBICULARE), GUAVA (PSIDIUM GUAYAVA), CHRISTMAS BERRY (SCHINUS TEREBINTHIFOLIUS) AND KOA HAOLE (LEUCAENA GLAUCA).

DISTRIBUTION AND EXTENT: WINDWARD OAHU BETWEEN THE TOWNS OF WAIMANALO AND KAHUKU BELOW THE KOOLAU RANGE AND SMALL VALLEYS AND ALLUVIAL FANS NEAR HONOLULU, OAHU

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