TRAVEL OF ABS AND AMMONIA NITROGEN WITH

PERCOLATING WATER THROUGH SATURATED OAHU SOILS

by

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ABSTRACT

A laboratory study was undertaken to determine the ability of four Oahu soils, Lolekaa, Lahaina, Manana, and Wahiawa, to remove ammonia, ABS, and coliforms from water percolating continuously through saturated soils. The soils utilized were chosen on the basis of their wide occurrence on the island in areas where percolating water may enter directly and in quantity into the ground water body that principally provides the island's domestic water supply. All four soils had a high clay content and low pH.

Laboratory tests were conducted with 10-ml burettes and subject to continuous saturated flow. Each contaminant was applied in solution one at a time to a fresh soil sample. Tap water was used for ABS and ammonia nitrogen while sewage was used to study coliform removal.

All soils were effective in the removal of ammonia and ABS. One-hundred percent breakthrough for ammonia occurred after a throughput volume of 345 to 470 times the gross soil sample volume. For ABS it was 15 to 53 times the gross soil sample volume. The total exchange capacity for ammonia ranged from 29.3 to 50.1 micro-grams of ammonia per gram of soil. The total adsorptive capacity for ABS ranged from 8.6 to 36.4 micro-grams of ABS per gram of soil. The applied concentration of ammonia was approximately 7.1 mg/l as found in a primary clarifier effluent and that of ABS was approximately 5.5 mg/l as found in a final clarifier effluent.

The results of coliform removal from percolating liquids were not conclusive because of small soil samples and the loading procedures. Preliminary tests verified some of the general principles developed
elsewhere for effective coliform removal by ground disposal of sewage. The final clarifier effluent from a trickling filter was passed continuously through a 30" column of Wahiawa soil and an initial coliform reduction of about 90% was effected.
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INTRODUCTION

The island of Oahu was created by basaltic lavas flowing from rifts in the ocean floor. In general the island is a double volcano, the weathered Waianae and the younger Koolau, linked by a central plateau (1). The lava mass was formed in layers; structural voids resulting from solidification and cooling allow percolation of water through the lava rock.

An average rainfall of 75 to 300 inches is received over the Koolau range. Between forty and fifty percent of this rain infiltrates the overlying soil and percolates through the lava. Some of this percolating water may be entrapped and stored at high elevations by water-tight dike complexes. The major portion of the percolating water, however, eventually enters the basal water table and has formed an enormous ground water body through geologic time. This huge basal water body in southern Oahu has been the prime source of water supply for Oahu for over half a century, and in 1959 supplied over 42% of the total water used on the island and close to 100% of the public water supply (2).

For the protection of the basal water and preservation of ground water recharge areas, 123,000 acres of land in the heavy rainfall areas of the Waianae and Koolau ranges have been designated as Forest Reserve with entry and use regulations (3). Sugar cane and pineapple cultivation account for another 34,900 and 22,050 acres of Oahu's land, respectively (4). These three classifications account for 46.5% of the island's area. Most of the land in these classifications is located where there is no impervious strata and percolating waters can enter directly into the ground water lens. Land use areas for Oahu are depicted in Figure 1.
The largest source of recharge water is from rainfall but some return flows from irrigation and cesspool seepage would follow similar available percolation passages.

The centuries old practice of ground disposal of waste water can generally improve its qualities. But such waste disposal systems must take cognizance of the hydraulic and constituent loadings of the liquids, soil properties, and biological activity in the soils for most efficient operation. Since, in general, soils themselves have only a limited capacity and capability for removing pollutants from percolating waters, some degree of pre-treatment is necessary prior to ground application of waste waters.

Many urban areas on Oahu utilize only the cesspool for disposal of domestic waste waters. It is estimated that over 38,000 cesspools are distributed over the island with more being constructed each year. The possibility exists that contamination from these cesspools may enter the basal water body. Other possible contaminants include pesticides, herbicides and fertilizers (including phosphates and ammonia-nitrogen) from return irrigation water.

The routine water analyses of the Honolulu Board of Water Supply have not detected such contamination as yet in the basal water source. Hawaii has not had a single reported health incident attributable to contaminated drinking water. In a 1960 survey by the American Water Works Association, Hawaii was one of only three states that could report so favorably (5). To maintain a contamination-free basal water supply and its present apparent quality, particularly in view of increasing population, increasing water use, and new chemical products, domestic and
FIGURE 1. MAP OF OAHU SHOWING LAND USES AND SOIL SAMPLE SITES

LEGEND

- LOLEKAA
- LAHAINA
- WAHLAWA
- MANANA
industrial, a study was performed to determine the reactions of certain Oahu soils to some significant ground water pollutants.

Laboratory investigations were performed to develop basic information, for continuous saturated flow, on the capacity and manner of Oahu soils common to the basal water recharge area to retain and remove ABS and ammonia nitrogen, two significant pollutants, from percolating waters. Some additional information on the possible removal of coliform bacteria, a microbiological water quality indicator, was obtained. This information may provide guidelines for planning comprehensive research in pollution effects of ground water recharge in Hawaii.
SCOPE

Soils

Three of the soils selected for the study are silty clays: the Lolekaa Humic Latosol, the Lahaina Low Humic Latosol and the Wahiawa Low Humic Latosol. The fourth soil is Manana Humic Ferruginous Latosol, a silty clay loam. These soils have been mapped by the U. S. Soil Conservation Service. (The soil descriptions are listed in the Appendix.) Soil properties pertinent to ground water pollution were developed as part of the study.

The Wahiawa and Lahaina soils occur throughout the central Oahu plateau where extensive pineapple and sugar cane cultivation is carried out. The Manana soil found on the lower slopes of the Koolau range, in areas of higher rainfall than the sites of the Wahiawa and Lahaina soils, are used for grazing or pineapple. The Lolekaa soil occurs in the vicinity of the surface reservoirs in Nuuanu Valley and on terraces in the Kaneohe district of Oahu. This soil is used for pasture or truck crops. All four soils are found where no impermeable strata exists to prevent percolating water from entering the basal water body.

Pollutants

Ammonia nitrogen (NH$_3$-N) occurs in water through four different sources: 1) Breakdown of organic nitrogen as contained in animal wastes and decomposing plant and animal protein (6,7,8), 2) fertilizers, 3) waste water from gas and coke manufacture and 4) magmatic water. The last two sources are rare and easily identified.

Ammonia nitrogen in ground water indicates that sewage or decay products are leaking through the soil or that fertilizer is being used excessively. Its presence in ground water is particularly significant.
since it is subject to capture by soil, plants and bacteria.

Tertiary alkyl benzene sulfonate, or ABS, is the synthetic detergent most resistant to biological degradation. ABS was the most important surface active agent in use in the United States (9) until 1965 when it was completely replaced by the biodegradable detergent, LAS. Synthetic detergents have largely replaced soap in dishwashing, laundering and other heavy duty washing. Since ABS is readily analyzed in trace amounts it can be used as an indicator of sewage pollution.

Synthetic detergent contamination can result in off-taste, frothing or foaming, and discoloration of water (10). Studies have shown that man and animals can tolerate relatively high concentrations of ABS in food or drinking water without ill effect.

Coliform bacteria are nonpathogenic organisms of the family\textit{Enterobacteriaceae} which includes the genera \textit{Escherichia} and \textit{Aerobacter}. The \textit{Aerobacter} and certain of the \textit{Escherichia} can grow in soils so that the presence of coliforms is not always indicative of fecal pollution. However, since \textit{E. coli} is entirely of fecal origin and can easily be detected, it has gained wide acceptance as an indicator organism of bacterial contamination from human wastes (11).
UNDERGROUND TRAVEL OF POLLUTANTS

The population growth of the United States and increased water consumption and need for waste water disposal has focused critical attention to the problem of underground travel of bacterial and chemical pollutants. The principal agencies and institutions studying soil-water systems have been the University of California at Berkeley, the California Institute of Technology, the U.S. Geological Survey, the Robert A. Taft Sanitary Engineering Center (Federal Water Pollution Control Administration, formerly U.S. Public Health Service) and the University of Illinois. A critical review of the literature on the underground travel of pollutants is documented herein to provide a summary of recent and pertinent research in the United States.

The study by Flynn et al. in 1958 of ground water contamination in Suffolk County, Long Island, New York, was among the first to conclude that synthetic detergents in a water supply are indicative of sewage contamination (6). Nichols and Koepp in 1961 utilized synthetic detergents to indicate ground water pollution in Wisconsin (12). They obtained good correlation between the presence of detergents and bacterial contamination and emphasized that the presence of detergents may also indicate intestinal virus contamination since the detergent molecule is approximately the size of a virus particle.

Butler et al. were able to effect reductions in most probable number (MPN) of coliforms from 179,000 to 1.2 and 4,000,000 to 1.6, respectively, for final effluent and settle sewage in reclamation studies with spreading basins on sandy loam soils (13). Page et al. found that coarse sand and sandy loam effected 90% removal of bacteria, but had little effect on ABS
and dissolved solids (14).

Butler et al. cited a report indicating that the travel of bacterial and chemical pollution from pit privies may extend only about 5 feet in dry or slightly moist soils (13). McGauhey and Krone concluded that chemical pollution travels much farther than bacteria in a water bearing stratum (15). A spreading basin study at Lodi concluded that ammonia was completely removed after only 4 feet percolation due to both base exchange and biological action (13).

McGauhey and Klein showed that successful operation of ground disposal systems for ABS removal from sewage required intermittent dosing to maintain an aerobic biological system (16).

The Whittier Narrows study with activated sludge effluent placed in spreading basins effected removals of ABS and ammonia nitrogen in only a few feet of travel with an intermittent loading schedule (17).

Wayman and Robertson found ABS removal by clay to be complex and ineffective compared to removal by activated carbon (18). Sorption is enhanced by high ABS and dissolved salt concentrations.

Suess reported ABS adsorption capacities for pulverized sandstone and limestone aquifer material, and several silty clays under static equilibrium conditions (19,20). Adsorption for each material was found to follow the Freundlich isotherm and the adsorption intensity (weight adsorbed/surface area) was directly proportional to grain size. Adsorption (weight adsorbed/weight soil) was found also to vary with the square root of surface area.
METHODS AND PROCEDURE

Introduction

The ultimate capacity of four soils for removing three pollutants introduced at known strength in the continuous percolating feed solution was to be determined. Further, sufficient data was obtained to determine the level of breakthrough of the pollutants at different times or throughput equal volumes.

The pollutants were applied in solution one at a time to a fresh soil sample. The ultimate retention and/or removal capacity was individually isolated and evaluated. It is recognized that interaction of these pollutants during percolation through the soil can take place but was not studied here.

The flow system for each test passed through a saturated soil without atmospheric air contact. The small soil sample was chosen to represent an underground point. In effect, the pollution removal studied can be effective either at some depth in a saturated soil or on the ground under ponding condition.

Except in the feed solution for the coliform removal series, neither the soils nor the feed solutions were seeded purposely with bacteria or sterilized. The duration of each test was on the order of hours and no longer than a day. For these reasons, the removal of the two chemical pollutants, ABS and NH₃-N was principally due to non-biological actions.

Soil Properties

Various properties of the tested soils have been previously reported in literature but it was felt desirable within available time and effort to confirm selected properties that have been known to
correlate to pollution removal. These included clay content, pH, permeability, and organic matter content.

The soils utilized in this study were obtained from sites selected by the U.S. Soil Conservation Service for sample pits utilized in preparation of soil maps for Oahu. Approximate locations of the sample sites are marked in Figure 1. The samples were collected from about the one-foot depth.

**Specific Gravity.** Specific gravity was determined according to the American Society for Testing and Materials (ASTM) Standards (21) and were utilized in computing the pore volume of the four soils. This step involved computing the void ratio for the soils and determining the volume of voids according to the bulk density. For comparison, the values of bulk density for the Wahiawa, Manana, and Lolekaa soils were also obtained from a report by Yamamoto (22). The bulk density for the Lahaina soil was estimated from those for the other soils.

**Grain Size Distribution.** The hydrometer method as described in ASTM was used in grain size analysis. However, the following procedure for separating the soil particles was utilized rather than as per ASTM in order to obtain a better dispersion of the sample. A 10-gram portion of the soil passing a #10 sieve was treated with 5 ml of 1N sodium oxalate and 3 ml of 1N sodium hydroxide and dispersed in a Waring blender (23). The sample was transferred to a 1000-ml graduated cylinder, filled to the mark, and hydrometer readings were obtained with a Taylor soil hydrometer. Calculations of grain size were then made according to ASTM (21).
pH. A Beckman model G pH meter was used for pH measurements performed on a paste formed from 10 gm of the soil fraction passing a #10 sieve.

Permeability. Data for permeability calculations was obtained during the test runs for ABS, ammonia, and E. coli. The equipment for those tests is described later in this section and is illustrated in Figure 2. Percolant samples were collected in 100-ml graduated cylinders and the time required to collect that volume was recorded. The hydraulic head applied on the percolation system was measured as the difference in the elevation between the burette outlet and the level of the solution in the feed bottle. Since the volume of the feed bottle was large in comparison to the 100-ml sample volume, the solution level in the feed bottle remained essentially constant. Therefore, the percolation system may be termed a constant-head permeameter.

Organic Matter Content. Organic content was measured by the chromic acid-sulfuric acid heat of dilution test (Walkley-Black) (24). A 0.5 gm portion of the soil passing a #80 sieve was treated with 10 ml of 1N chromic acid, 20 ml of sulfuric acid, mixed and allowed to stand for 30 minutes. The sample was diluted to 200 ml with distilled water. Ten milliliters of phosphoric acid, 0.2 gm of sodium fluoride, and diphenylamine indicator were then added. The sample was titrated with ferrous ammonium sulfate to a bright green endpoint.

The results of the physical tests on the soils are summarized in Tables 1 and 2.
Percolation Columns

The percolation columns were basically constant-head permeameters made for saturated flow. They are standard straight 100-ml burettes with stopcock and were mounted on standard burette supports. The column set-up is illustrated in Figure 2. Underdraining was provided by filling the burette to the 100-ml mark with 3 to 4 diameter glass beads. A small section of nylon screen was placed across the burette bottom prior to placing the glass beads to prevent clogging of the stopcock opening. The column was then filled with approximately 50 ml of distilled water and then of soil. The latter procedure deaerated the soil mass prior to the actual test run, and eliminated the possibility of "short-circuiting" through the column. A fresh sample of each soil type was used in each of the different tests: ABS, ammonia, and E. coli. Soil samples were made up to proper volume by weighing out sufficient soil as per the bulk density according to Yamamoto (22).

A two-gallon polyethylene bottle was used to feed the test solutions into the columns by gravity-flow. The feed bottle was set on a shelf above the burette stand and connected to the column by 3/8" tygon and 1/2" rubber tubing. The hydraulic head applied was 67.3 cm for Lolekaa and Wahiawa soils, and 110.5 cm for Lahaina and Manana soils.

Percolant Analysis

The analysis for E. coli, ABS, and ammonia of the feed solutions and percolants was performed in accordance with Standard Methods but with slight modifications (25).

The multiple tube fermentation technique or presumptive test with lactose broth was used to determine the most probable number (MPN) of
coliforms. The feed solution was prepared from sewage samples obtained at the Ala Moana Pumping Station. The sewage was filtered through a Whatman #1 paper to remove suspended solids that could clog the soil sample. This filtration may be likened to treatment of the sewage by primary sedimentation. The filtered sewage was fortified by the addition of coliforms from a pure culture of E. coli. The resulting solution was percolated through the soil column and the percolant sampled at 50 ml intervals. Three sets of three tubes each were inoculated with the sample for testing. The dilutions were 1.0 ml, 0.1 ml, and 0.01 ml of sample per set of three tubes. The tubes were incubated for 24 hours at 35°C and the MPN of coliforms was interpreted as per Standard Methods.

The detergent feed solution was made from a standard alkyl benzene sulfonate, containing 49.3% ABS, obtained from the Soap and Detergent Association. ABS has the recognized formula of $\text{RC}_6\text{H}_{4}\text{SO}_3\text{Na}$. Feed solution strength was approximately 5 to 6 ppm. Samples were drawn at 20-ml intervals for the first 100 ml, and thereafter, at 50 or 100-ml intervals when possible. A 20-ml aliquot was made up to volume and analyzed by the methylene-blue method. On every sample, three extractions were made with 10 ml of chloroform each, and the chloroform drawn off and made up to a 50-ml volume. The transmittance was then determined at 650μ in a Bausch & Lomb Spectronic 20 colorimeter. A calibration curve was made from the analysis of samples of a standard ABS solution of known concentration.

Analysis for ammonia was made by the direct nesslerization procedure. The feed was an ammonium hydroxide solution containing approximately 7.1 mg/l of ammonia nitrogen. Samples were drawn at 50-ml intervals for the first 300 ml, and thereafter, the samples were taken at 100-ml intervals.
FIG. 2. EQUIPMENT FOR PERCOLATION TEST
SCHEMATIC DIAGRAM
As the throughput volume approached 1000 ml, sampling intervals were spread out to 300 to 400 ml. When 100% breakthrough was approached, the sampling interval was once again reduced to 100 ml. Samples were collected in 100-ml graduated cylinders and passed through a 0.45-micron Millipore filter to remove soil particles that had been leached from the column. The filtration procedure was considered necessary owing to continual leaching of some of the fine particles from the soil mass in each test run.

After filtration, a 50-ml portion of the sample was treated with 1 ml of nessler’s reagent. The concentration of ammonia in the sample was measured by determining the transmittance at 505μ in the Spectronic 20 colorimeter. A calibration curve was prepared from ammonia standards of known concentration.
RESULTS AND DISCUSSIONS

Soil Properties

Soil characteristics, except permeability, as determined by physical analysis are listed in Table 1. The results of the physical tests on the soil approximated the work of previous researchers, except in the case of the grain-size determination. Noticeably these soils have a low pH, high organic content and, excepting Manana, high clay content.

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<td>SPECIFIC GRAVITY, GM/CC</td>
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<td>% ORGANIC MATTER</td>
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<td>GRAIN SIZE</td>
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<td>% SAND</td>
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<td>% SILT</td>
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<td>% CLAY</td>
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<td>% VOIDS</td>
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Grain Size and Clay Content. Comparison of the grain size determinations for the four soils with the U.S. Bureau of Soils triangular classification chart indicates that the Wahiawa, Lahaina, and Lolekaa are clays with approximately 50% clay-size particles. The results of the same determination show that the Manana soil is a clay loam with a high amount of sand and about equal proportions of silt and clay-sized particles.

By the use of differential thermal analysis on several soil samples
Matsusaka obtained the average values of clay content for the three soil families utilized in this investigation, Low Humic Latosols - 80.9%, Humic Latosols - 74.6%, and Humic Ferruginous Latosols - 41.2% (26).* Average values of clay content for the Manana, Wahiawa, and Lolekaa soils of 61%, 66.5%, and 66.5%, respectively, were obtained by Yamamoto.

*Consultation with Dr. Uehara leads the investigators to believe that the dispersion method used in the grain size analysis was not adequate. Some of the clay fraction of the soil probably remained in large clumps greater than 2 to 10 microns in size and thus settled rapidly instead of remaining in suspension during analysis. These large particles were thus measured as sand and/or silt instead of clay.

Organic Matter Content. The Manana soil was obtained from a roadside excavation adjacent to a grazing area at the Randolph Crossley ranch and contained the highest proportion of organic matter, 12.7%. The Lolekaa soil was also obtained from a pasture area in Haiku Valley and had the next highest proportion of organic matter, 8.1%. The Lahaina and Wahiawa soils were obtained from roadside sites near cultivated pineapple fields and only contained 4.1% and 3.1% organic matter, respectively. The organic matter content obtained by Yamamoto was 1.6% for the Wahiawa soil, 4.7% for the Lolekaa soil, and 3.6% for the Manana soil (22).

Soil Acidity. All the soils investigated are acidic. The range of acidity is narrow, the Lahaina being the least acidic at pH 6.3 and the Manana the most acidic at pH 5.2. A comparison of the pH values obtained in this study against those of Yamamoto (22) and the Soil Conservation Service (27) may be made from Table 2.

Voids. Per cent voids in the soils were computed based on the specific
gravity, soil volume, and dry weight of the soil. The Lolekaa showed the highest void volume, 77.1%. The Wahiawa and the Lahaina, of the same soil family, had 68.2% and 67.2% voids, respectively, and the Manana had 72.8% voids. Yamamoto's report gave the following figures for void volume, Lolekaa 65.4-68.8%, Wahiawa 59.2-60.1%, and Manana 60.8-62.8% (22).

**Permeability.** During the test runs for ammonia and ABS, data was obtained on each of the soils so that their permeabilities could be calculated. The average flow rate for the Lolekaa and Wahiawa test runs was 0.65 cc/sec (cubic centimeters/second) and 0.06 cc/sec, respectively, with a head of 67.3 cm on the soil sample. The average flow rate for the Lahaina and Manana test runs was 0.098 cc/sec and 0.058 cc/sec, respectively, with a head of 110.5 cm on the soil sample. As listed in Table 3, the Lolekaa soil was the most permeable, and the Manana the least permeable. The Wahiawa and Lahaina had nearly identical values of permeability.
Ammonia Removal

Measured breakthrough curves for the ammonia exchange are shown in Figures 3 to 6 and those for the ABS adsorption are shown in Figures 7 to 10. For each of these curves, the ordinates represent the concentrations of pollutant found in the particular grab samples from the continuous discharge of the percolant through the soils. The abscissas represent the cumulative volume of the continuous discharge of the percolant or simply the throughput volume.

The ammonia exchange curves for the Manana, Lahaina, and Lolekaa soils have approximately the same configuration. The curves rise sharply in the first 200-ml throughput volume indicating fast exchange, then as the slopes of the curves decrease slowly, the curves approach the feed concentration for 100% breakthrough. The 100% breakthrough for these curves occurs between 4400 and 4700 ml of throughput volume. The dip in the Lahaina curve at approximately 2 liters of throughput volume was probably caused by the change in the feed solution at that point, as the original feed had been almost completely emptied.

The ammonia breakthrough curve for the Wahiawa soil showed a somewhat erratic pattern after approximately 2500 ml of throughput volume. The one-hundred per cent breakthrough for this exchange was taken to be about 3400 to 3450 ml of the throughput volume. Beyond that point, the samples analyzed showed that when the soil was rested overnight, the amount of adsorption was greater than for the periods of continued percolation. Klein, et al. in ABS adsorption studies found that although 100% breakthrough may have been achieved under flow conditions, further adsorption takes place during static contact (28). This same phenomenon may have occurred during
the ammonia exchange test with the Wahiawa soil.

The total ammonia exchange capacities for the soils are computed and listed in Table 4. For a given throughput volume, the weight of ammonia adsorbed may be found by taking the difference between the weight of ammonia applied and the weight of ammonia rejected. The cumulative total of the weights of ammonia adsorbed divided by the gross soil sample weight is the ammonia exchange capacity under a percolating condition, expressed in micro-grams of ammonia nitrogen exchanged per gram of soil. The Manana soil had the highest and the Lolekaa had the lowest exchange capacity for ammonia.

An exchange of ammonia feed was performed with a cation exchange resin, "Nalcite HCR", a product of the Nalco Chemical Company. The percolation apparatus was the same as used in the soil test and the volume of the resin sample in the percolation column was 10 ml. The throughput volume at 100% exchange for the resin was 450 ml, and the total exchange capacity was approximately 333 micro-grams of ammonia per gram of resin. The exchange capacity of this resin was in the general order of magnitude as exhibited by the four soils in the study.

The total cation exchange capacity is the sum of the individual

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<th>SOIL TYPE</th>
<th>THROUGHPUT VOLUME MILLILITERS</th>
<th>AMMONIA EXCHANGE MICROGRAM/GRAM</th>
<th>CAPACITY MEG/100 GRAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>MANANA</td>
<td>4700</td>
<td>501.3</td>
<td>2.95</td>
</tr>
<tr>
<td>WAHIAWA</td>
<td>3450</td>
<td>469.2</td>
<td>2.76</td>
</tr>
<tr>
<td>LAHAINA</td>
<td>4400</td>
<td>408.2</td>
<td>2.36</td>
</tr>
<tr>
<td>LOLEKAA</td>
<td>4600</td>
<td>293.4</td>
<td>1.72</td>
</tr>
</tbody>
</table>

TABLE 4. AMMONIA EXCHANGE CAPACITY
FIG. 3. BREAKTHROUGH CURVE FOR WAIANA SOIL, AMMONIA EXCHANGE
(Average time lapse = 4.6 hours per liter)

FIG. 4. BREAKTHROUGH CURVE FOR MANANA SOIL, AMMONIA EXCHANGE
(Average time lapse = 4.8 hours per liter)
FIG. 5. BREAKTHROUGH CURVE FOR LAHAINA SOIL, AMMONIA EXCHANGE
(Average time lapse = 2.8 hours per liter)

FIG. 6. BREAKTHROUGH CURVE FOR LOLEKAA SOIL, AMMONIA EXCHANGE
(Average time lapse = 0.4 hours per liter)
exchange capacity of the several cations in the soil, mostly Ca, in smaller percentages Mg, K, Na, and in even smaller percentages H (46). This capacity is greater for soils of higher clay and organic matter content. Its value ranges from a few to 50 or 60 meq per 100 g. It is further affected by many parameters including the concentration of the exchange ions and pH in the solution, but none of these were systematically tested in this study. Consequently, meaningful evaluation of the results obtained in this study was not possible in the usual framework of cation exchange in soils. Further, the procedure used to produce data on exchange capacity was different from the normal soil analysis. Comparison of results would, therefore, not be valid. It should be noted that the NH$_3$-N results obtained in this study are caused principally by base exchange rather than biodegradation, and applicable for continuous flow rather than intermittent flow.
ABS Removal

The breakthrough curves of the four soils for the ABS adsorption have configurations similar to the ammonia breakthrough curves but with a considerably smaller order of magnitude. The ABS breakthrough curves start with a rapid rise in the first 50-ml of throughput volume, then level off as the curves approach 100% breakthrough. There is a wide variation in the throughput volumes for 100% breakthrough and adsorptive capacity as shown in Table 5.

<table>
<thead>
<tr>
<th>SOIL TYPE</th>
<th>THROUGHPUT VOLUME: MILLILITERS</th>
<th>ADSORPTIVE CAPACITY: MICRO-GRAM/GRAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>MANANA</td>
<td>530</td>
<td>36.44</td>
</tr>
<tr>
<td>WAHIWA</td>
<td>300</td>
<td>22.98</td>
</tr>
<tr>
<td>LAHAINA</td>
<td>400</td>
<td>31.09</td>
</tr>
<tr>
<td>LOLEKAA</td>
<td>150</td>
<td>8.60</td>
</tr>
</tbody>
</table>

* 10-ML GROSS SOIL SAMPLE.

Comparison of ABS Adsorption and Ammonia Exchange Results

Under comparable hydraulic conditions, the ABS front advanced much faster than the ammonia front for continuous, saturated flow for all four Oahu soils; the ratios of the liquid volume for 100% breakthrough of ABS to ammonia being about 1:10 for Manana, Wahiawa, and Lahaina soils and about 1:30 for Lolekaa soil (Figure 10). Hence, the soils exhibit a faster "uptake" for ABS than for ammonia nitrogen. The adsorbed ABS in μ/g was very small compared with the exchanged ammonia for all soils, the order of magnitude being 1:14 for Manana, 1:20 for Wahiawa, 1:13 for Lahaina and 1:33 for Lolekaa. Hence, the soils exhibit a smaller "uptake" for ABS than for ammonia nitrogen.

These results have significant implication in a continuous disposal
FIG. 7. BREAKTHROUGH CURVE FOR WAHIWA SOIL, ABS ADSORPTION

FIG. 8. BREAKTHROUGH CURVE FOR MANANA SOIL, ABS ADSORPTION
5.5 mg/l, ABS concentration in feed

FIG. 9. BREAKTHROUGH CURVE FOR LAHAINA SOIL, ABS ADSORPTION

5.6 mg/l, ABS concentration in feed

FIG. 10. BREAKTHROUGH CURVE FOR LOLEKAA SOIL, ABS ADSORPTION
of liquid waste into a natural ground water flow. Considering the
effectiveness of dilution by natural flow alone, the level of attenuation
of pollutant in water downstream from the point of disposal will be great­
er for ammonia than for ABS at all times and for all soils. However, a
more effective disposal arrangement is still the employment of biologically
active soil under intermittent dosing condition.

Parameters of ABS Adsorption and Ammonia Exchange

Possible parameters for indicating the magnitude of exchange and/or
adsorption capacities are listed in Table 6.

The best parameter appears to be the soil group. Humic Ferruginous
Latosol has the highest capacities, Low Humic Latosol (Wahiawa and
Lahaina*) next and Humic Latosol last. Factors that enable identification
of soil groups must exert some combined effect in producing this different
level of performance.

In a finer study of the parameters, it appears that the second best
parameter is permeability of the soil and that the most permeable soil,
the Lolekaa, has the least adsorption capacity for both ABS and ammonia.
Contact opportunity probably is responsible for this inverse relationship.
The slower movement of the percolating solution through soil of low per­
meability would allow a greater contact time between the perco1ant and
soil, increasing the opportunity for adsorption to take place. The precise
functional relationship of this variation cannot be defined from the
results of this study.

The next two parameters, organic matter and pH, do not vary in a

*Wahiawa and Lahaina soils have similar values in this comparison.
consistent trend with the adsorptive and exchange capacities. Neverthe-
less, Manana (Humic Ferruginous) which has the highest organic content
and lowest pH, exhibits the highest capacities. Organic matter is known
to enhance these capacities; therefore, the absence of a consistent trend
appears to be an anomaly although there may be some other factors that
offset the trend. The pH of a soil indicates the exchangeable hydrogen
ions in the soil. The exact relationship between pH of soil and these
capacities is not certain.

In addition to contact times, an important factor in adsorption
and/or ion exchange is surface area. Adsorption has been defined as
"the tendency exhibited by all solids to condense upon their surfaces a
layer of any gas or liquid with which they are in contact" (29). The
Wahiawa and Lahaina, having a greater proportion of clay-size particles
than the Lolekaa, also should have a greater soil particle surface area
for a given volume of soil. Similarly, the Lolekaa should have a greater
soil particle surface area than the Manana. Consequently, on the basis
of amount of clay-size particles determining particle surface area, the
Wahiawa and Lahaina soils should have the highest exchange capacity for
ABS and ammonia, the Lolekaa the next highest, and the Manana the lowest.
However, the results as listed in Table 6 do not support this argument
that is based on surface area inferred by clay content.

A quantitative determination of surface area of the soil may be
approximated from the "Kozeny equation" describing flow through porous
media (30). This relation is:

\[ k = \frac{cP^3}{S^2} \]
where $k$ is the permeability, $P$ is the porosity, $S$ is the surface area, and $c$ is a shape factor dependent on the cross-section of the pores. Substitution of the values of $k$ from Table 6, $P$ from Table 1 and assuming a value of $c = 0.6$ (shape factor for equilateral triangle), enables the calculation of surface area for each soil. For comparison, the surface area for the Lolekka is arbitrarily considered as 100 and the surface area for other three soils is expressed as percentages of the surface area for the Lolekka.

It may be seen in Figure 11 that an almost linear relationship exists between the soil surface area and exchange or adsorptive capacity. Furthermore, it is evident that as the surface area of the soils increase, the exchange capacities also increases.

Other factors affecting adsorption and/or ion exchange, such as pH and temperature of feed solution, may be discounted in this investigation because the experiments were carried out in a temperature controlled room and with a feed solution made up from distilled water that had little variation in pH.

Dimensionless plots have been made of the adsorptive capacities and
FIG. 11. SOIL SURFACE AREA - EXCHANGE OR ADSORPTIVE CAPACITY RELATIONSHIP

FIG. 12. AMMONIA EXCHANGE CAPACITY VS. THROUGHPUT VOLUME/PORE VOLUME

FIG. 13. ABS ADSORPTIVE CAPACITY VS. THROUGHPUT VOLUME/PORE VOLUME
the ratio of throughput volume to pore volume for the soils. These plots provide a more valid comparison for the soils on the basis of exchange adsorptive capacity at a given throughput volume to pore volume ratio. The ammonia exchange plots are shown in Figure 12 and the ABS plots are shown in Figure 13.

It will be noted on both graphs that the curves for the Manana—the Humic Ferruginous Latosol, and the Lolekaa—the Humic Latosol, form an envelope for the curves of the Wahiawa and the Lahaina, both Low Humic Latosols.

In Figures 12 and 13, a comparison of the number of pore volumes required to achieve breakthrough shows that the Lolekaa required 597; the Manana, 644; the Lahaina, 657; and the Wahiawa, 507 pore volumes for complete ammonia exchange. For the ABS exchange, the number of pore volumes for breakthrough were Lolekaa, 19.5; Manana, 72.6; Lahaina, 58.9; and Wahiawa, 44.8.

The results can be compared in another relative way if the ratio of throughput volume to pore volume of the Lolekaa soil at 100% breakthrough is considered to be unity. The number thus derived may be called the "relative rate of 100% breakthrough". On this basis, in Figure 13 for the ABS adsorption, the Wahiawa required 2.2, the Lahaina 3.4, and the Manana 3.8 times as many pore volumes for breakthrough as the Lolekaa soil. In the ammonia exchange, there is not as much variation. The Wahiawa soil required 0.85, the Manana 1.0, and the Lahaina 1.1 times as many pore volumes for breakthrough as the Lolekaa soil.

From Figures 12 and 13 the throughput volume required for complete adsorption on each soil can be determined. This data has practical sig-
nificance for it allows the computation of the amount of contaminant that may be applied on soil cover before significant leaching of the contaminant into ground water occurs.

Comparison with other ABS Studies

Many notable research studies in ABS removal from soils and other solid media have been made as indicated in the literature survey but seldom were they conducted under comparable conditions (Table 7). Recognition of these differences is crucial in comparing results.

Adsorption of ABS by California soils was reported by Klein, et al. for sterile, saturated flow condition in 1961 (29). For three sandy loam soils, the adsorption was 4.43, 3.54 and 5.40 mg of ABS per gram of soil based on an ABS concentration of 1 mg/l in the infiltrate. These three soils had an average clay content of 19%. A fine sandy loam soil with a clay content of 17.5% had an adsorption capacity of 6.00 micro-gm/gm. A sandy soil with 12% clay content had an adsorption capacity of 2.75 micro-gm/gm. By comparison, the Oahu soils have clay contents from 2 to 5 times higher than the California soils. With an ABS feed concentration 5 times greater than that applied to the California soils, the ABS adsorption on the four Oahu soils is from 4 to 15 times higher.

Klein, et al. (28) fitted their results of ABS adsorption on soil to the Langmuir adsorption isotherm:

\[ M = KC^n \]

where K is a constant, M is the amount of ABS adsorbed in mg per gram of soil, and C is the concentration of ABS solution in mg/l when equilibrium is reached.

Langmuir's isotherm will plot as a straight line with log M as
<table>
<thead>
<tr>
<th>Year</th>
<th>SOIL</th>
<th>LIQUID</th>
<th>ABS CONC. mg/l</th>
<th>MECHANISMS FOR REMOVAL</th>
<th>BIOLOGICAL ENVIRONMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>8/64</td>
<td>UNIV. OF HAWAII YOUNG &amp; LAU</td>
<td>COLUMNS</td>
<td>FIVE CALIF. SOILS AERATED</td>
<td>5.5-6.3</td>
<td>ADSORPTION PRINCIPALLY FOR BOTH WATER AND SOIL</td>
</tr>
<tr>
<td>12/61</td>
<td>UNIV. OF CALIF. BERKELEY KLEIN &amp; MCGAHEY</td>
<td>COLUMNS</td>
<td>FIVE CALIF. SOILS AERATED</td>
<td>1.0</td>
<td>ADSORPTION PRINCIPALLY</td>
</tr>
<tr>
<td>5/64</td>
<td>U.S. GEOLOGICAL SURVEY WAYMAN &amp; ROBERTSON</td>
<td>BATH</td>
<td>PURE CLAYS</td>
<td>3-10</td>
<td>ADSORPTION PRINCIPALLY</td>
</tr>
<tr>
<td>1/66</td>
<td>U.S. GEOLOGICAL SURVEY PAGE &amp; WAYMAN</td>
<td>COLUMN</td>
<td>EIGHT GREATLY DIFFERENT SOILS</td>
<td>3-8</td>
<td>BOTH BIODEGRADATION AND ADSORPTION</td>
</tr>
<tr>
<td>11/54</td>
<td>UNIV. OF ILLINOIS SEUSS</td>
<td>BATH</td>
<td>PULVERIZED SANDSTONE AND LIMESTONE, AND SILTY CLAYS</td>
<td>UP TO 50</td>
<td>ADSORPTION PRINCIPALLY</td>
</tr>
<tr>
<td>9/64</td>
<td>CALIF. INSTITUTE OF TECHNOLOGY MOORE &amp; MCMICHAEL</td>
<td>CONTINUOUS</td>
<td>COARSE SAND</td>
<td>5-10</td>
<td>BOTH BIODEGRADATION AND ADSORPTION</td>
</tr>
</tbody>
</table>
ordinate and log C as abscissa. The measured slope of the straight line is \( n \) on 1 and the intercept of the line log C = 1 is K. The data obtained by Klein, \textit{et al.} yielded a value of \( n \) to be 1 and the value of K to be 5.88 \( \times 10^{-4} \) liter/gram.

It is not possible to compute such constants from data obtained in this study because the concentration of ABS feed was not a variable. Mere-ly for the sake of computation, using the above values of \( K \) and \( n \) together with an average value of 5.5 mg/l for C, the theoretical adsorption of the soils in this study would be about 3.23 micro-gm/gm. This computed value is very low and would be an underestimate when compared with the actual exchange capacities as listed in Table 5.

Also, considering the same factor of concentration of the ABS solution to be of prime importance in the exchange phenomenon, the data may be described by the Freudlich adsorption equation:

\[
M = K C^{1/n}
\]

with \( M \), \( K \), \( C \), and \( n \) representing the same quantities as in the Langmuir equation. Tsuji applied this relation to the adsorption of detergent by the Akaka soil and obtained an average \( K \) value of 3.22 \( \times 10^{-2} \) l/g and an \( n \) value 1.01 (31). The \( n \) value is nearly identical with that of Klein, \textit{et al.} (28), but the \( K \) value is about 100 times greater. Application of this relation to the data would result in a hypothetical adsorption of over 177.1 micro-grams of ABS per gram of soil, which is larger than measured values. It should be pointed out that the work by Klein, \textit{et al.} was performed with percolation columns, as in this study, and that the work by Tsuji involved static contact between the soil and ABS solution.

Static contact apparently produces greater adsorption than percola-
tion. The finding by Klein, et al. of the additional adsorption upon further static contact after 100% breakthrough under percolating condition, tends to support the difference noted above.

Because there was little variation in the concentration of ABS in the feed solution applied to the four soils, the data does not lend itself to a rigorous application of the adsorption isotherms. However, a numerical value of K may be computed by use of the average value of feed concentration, 5.7 mg/l as M and the average value of ABS adsorbed, 0.02737 mg/g as C. As previous reported, the value of n derived by Klein, et al. is 1 and that of Tsuji is 1.01. Klein, et al. also referred to similar work by others that yielded a value of 0.947 for n. Thus, it is reasonable to use a value of n = 1. Then with n=1, K can be computed to be 4.88 x 10^{-3} l/g. This value is about midway between those reported by Klein, et al. and Tsuji.

E. coli Removal

The results of the bacteriological test runs with paper-filtered raw sewage appear to be fragmentary and insignificant.

The lactose broth tubes inoculated from all four soils for the presumptive test were positive, showing gas formation. Thus breakthrough of the coliform organisms occurred within the first 50 ml of percolant. Only three tubes were inoculated in each dilution from every grab sample, and the dilutions were 1.0, 0.1, and 0.01 ml respectively. With all nine tubes inoculated from each 50 ml sample for every soil proving positive, the lower limits of 95% confidence per Standard Methods give a bacterial count of 4600. This lower limit may be estimated as 21% of the MPN according to Standard Methods. For a lower limit of 4600, the MPN is, therefore,
at least 21,900.

Two preliminary test runs were performed on the Lolekaa soil with a feed solution prepared with a pure culture of E. coli and distilled water. The MPN of the feed solution in the first test was 46, and in the second test it was 460. In each case, 2800 ml of feed was percolated through the soil sample and some breakthrough of coliforms occurred in the first 100 ml of percolant for a count of 3 and 30 coliforms respectively for the two test runs. This early breakthrough was probably due to the fact that the soil sample obtained from the field contained some coliform organisms. These coliforms would be flushed out with the first sample of liquid percolated through the soil. No further positive samples occurred in both test runs until the final sampling at 2800 ml. The MPN for that sample was once again 3 and 30 repeating 100-ml sample results which appear to show that the soils are effective in coliform removal when the bacteria are in low concentration.

Since the Lolekaa soil is acid with a pH of 5.9 (Table 2), and the feed solution was prepared with distilled water of pH of 5.6 - 5.9, some of the bacterial removal effected may have resulted from the toxic effect of the low pH. At low pH, the hydrogen ion causes denaturation of the enzyme proteins required in the bacterial metabolic processes (7). This may not have been a significant factor in the burette columns with sewage feed because the sewage is well buffered to a near neutral pH.

Another test was performed to determine the effect of depth of soil column on bacterial removal. This test was performed with a 30" column of the Wahiawa soil in a 1" diameter lucite cylinder. The feed solution was
prepared by filtering two gallons of raw sewage through Whatman #1 paper and diluting the filtrate to five gallons with distilled water. Samples were drawn at 100 ml, 400 ml, 1000 ml, and 2000 ml of percolant. The dilutions used in inoculation were the same as for the burette test runs. All tubes proved positive for coliforms thus giving the same MPN for the 30" soil column as for the 3" column in the burette.

A further test was carried out in a new 30" column of Wahiawa soil with secondary clarifier effluent from the Pacific Palisades trickling filter plant. Dilutions for the inoculation of the lactose broth tubes were 0.01, 0.0001, and 0.0001 ml for three sets of three tubes each. The filtrate was collected and sampled at 500 ml intervals. A total of 2500 ml of treated sewage was passed through the column. The MPN of the sewage was reduced from over 2,000,000 in the feed to an average of about 300,000 in the filtrate, a reduction of about 90%.

Results of the last test with dilution 1/100 that of the burette test runs indicate that some removal may have taken place in those test runs but that the presumptive test with dilutions of 1.0, 0.1, and 0.01 ml was not sufficiently sensitive to detect such removal. However, in all tests conducted with E. coli, the bacterial removal effected did not approach that achieved by Butler et al. (13), Page, et al. (14), and Krone, et al. (32), except when the E. coli in the feed was in low concentration.

Observations by Butler, et al. of the coliform organism counts in the soil of the lysimeters used in their study produced evidence of an organic mat in the top 0.5 cm of soil that effectively reduced the bacterial numbers (13). Krone, et al. reported an abrupt drop in bacteria numbers in the percolant below the soil surface in their study (32). Evidently,
filtering the sewage feed through Whatman #1 paper removed sufficient solids to minimize the possibility of depositing an organic mat and eliminated the effective filter area below the soil surface, thus, limiting the possibility of coliform removal. These few fragmentary tests tend to confirm some of the general principles of bacterial removal in a ground disposal system as demonstrated in previous well-known investigations. However, they do not produce much useful and detailed working knowledge for the Oahu soils. Hence, much more research is needed not so much to confirm general principles, but to produce data by pilot tests to aid the evaluation of ground disposal of domestic sewage on Oahu and determination of possible improvements to minimize the potentials of ground water pollution.
SUMMARY AND CONCLUSIONS

This study was intended to develop some basic laboratory information for continuous saturated flow, on the capacity and manner of some Oahu soils to retain and remove ABS, ammonia nitrogen, and coliform bacteria from percolating waters. The study was exploratory in nature; to uncover the similarity or dissimilarity of reactions to ground water pollutants between the Oahu tropical basaltic soils and the U. S. mainland soils under some specific conditions, and to identify approaches for future research pursuits under the overall program of pollution effects of ground water recharge in Hawaii.

The study consisted of laboratory experiments in which four typical Oahu soils were packed in columns and subjected to continuous percolation of water and sewage carrying known concentration of pollutants. Analyses were made of the percolants at regular intervals to characterize the manner of breakthrough and the amount of retention of the pollutants. The four soils are: Manana in the humic ferruginous latosol group, Lahaina and Wahiawa, both in the low humic latosol group and Lolekaa in the humic latosol group. All soils are acidic, high in clay content, and widespread in the watershed recharge areas of the huge important ground water body under the Honolulu-Pearl Harbor region.

Each pollutant was applied in solution one at a time to a fresh 10-ml soil sample packed in a column. The flow system was continuous downward through the saturated soil without atmospheric air contact and without resting periods. Except in the coliform experiments, neither the soils nor the feed solutions were seeded with bacteria or sterilized. The duration of each test was on the order of hours, and no longer than a day.
The major conclusions of this study are:

1. All four soils, the Lolekaa, Manana, Wahiawa, and Lahaina are effective in the removal of ammonia and ABS from percolating waters at the applied concentrations of approximately 7.5 mg/l and 5.5 mg/l for each contaminant respectively.

2. The Manana soil had the highest exchange capacity for ammonia and adsorptive capacity for ABS, the Wahiawa and the Lahaina soils the next highest, and the Lolekaa soil the lowest. Numerically, the ammonia nitrogen exchange capacities were 3.0, 2.8, 2.4 and 1.7 meq/100 grams; the ABS adsorptive capacities were 36, 23, 31 and 9 microgram/gram.

3. The ABS capacities were somewhat larger than those for some California soils subject to similar conditions.

4. The best parameter for indicating the relative magnitude of these capacities appears to be the soil group, Humic Ferruginous Latosol highest, Low Humic Latosol next and Humic Latosol last.

5. These capacities appear to relate linearly to soil surface area which was computed from porosity, permeability and a shape factor according to the Kozeny equation.

6. The next best parameter appears to be the permeability of the soil. This relative standing is in reverse ranking of the permeability of the soils, the Manana being the least permeable and the Lolekaa the most permeable.

7. Organic matter content, pH of the soil and clay content do not individually appear to have consistent correlation with the capacities.

8. One-hundred per cent breakthrough of ABS and ammonia nitrogen occurred and sustained for all four soils upon continuous percolation of the feed solution.
9. Numerically as percentage of pore volume, these 100% breakthrough volumes of percolants are: 644, 507, 657, 597 for ammonia, 73, 45, 73, and 20 for ABS, listing given in order of Manana, Wahiawa, Lahaina and Lolekaa.

10. ABS breakthrough occurred much earlier than ammonia nitrogen breakthrough, by a factor of about thirty for the most permeable Lolekaa and about ten for the other three soils.

11. The soils exhibited a smaller uptake for ABS than for ammonia nitrogen by a factor of up to thirty for Lolekaa and better than ten for the other three.

12. Static contact produces much larger ABS adsorptive capacities than continuous percolation, as evidenced by an indirect comparison. In studies conducted on the mainland, adsorption was dismissed as an inconsequential mechanism compared with biological degradation through intermittent dosing.

13. Likewise, static contact produces far greater $\text{NH}_3$-$\text{N}$ exchange capacities than continuous percolation, as evidenced by indirect comparison.

14. It is expected that removal of both the ABS and $\text{NH}_3$-$\text{N}$ can be greatly improved in an aerobic biologically active soil which can be developed under the combined condition of intermittent dosing, non-ponding, seeding with bacteria and supplementing with nutrients as carried in sewage. However, this expectation requires laboratory confirmation.

15. The value of pure adsorption alone in abating ground water pollution depends on 1) the retention characteristics of the pollutant by the soil or aquifer material, and 2) the availability of dilution. Under a suitable combination of these two, a pollutant can be attenuated to a predictable level.
16. Desorption of ABS from soils or aquifer materials remains to be a menace of ground water quality, in spite of the discontinuance of the use of ABS in the manufacture of commercial synthetic detergents.

17. Future research approach should involve biodegradation and variation of parameters identified in this study so that the level of steady state removal and its optimization can be determined.

18. Future research approach should involve more realistic simulation of the active portions of the system. Pilot studies should be useful.

19. Test results on E. coli removal were considered inconclusive owing to the small soil samples and insufficient opportunities to develop an aerobic biologically active soil-water system.
ACKNOWLEDGEMENTS

Supporting organizations of this study included the Water Resources Research Center, Departments of Civil Engineering and Public Health of the University of Hawaii, and the Public Health Committee of the Honolulu Chamber of Commerce.

Thanks are due to the U.S. Soil Conservation Service for advice in locating sample sites and for the soil descriptions provided by Mr. Elmer Hill. Thanks are also due to Professor Goro Uehara, Department of Agronomy and Soil Science, for his invaluable advice regarding the characterization of the soils.

This edition of the report was completed in December 1966 jointly by R.H.F. Young and L.S. Lau. Professors N. C. Burbank, Jr. and Richard K. C. Lee, School of Public Health, assisted in the study.
BIBLIOGRAPHY


APPENDICES
## APPENDIX A: DESCRIPTION OF WAHIWA SOIL

### LOCATION:

Dole Corporation Field No. 4101-02, Plot No. B-30, about one thousand feet east of the main road, pit just north of plot road.

### CLASSIFICATION:

Low Hemic Latosol.

### PARENT MATERIAL:

Not known for certainty. Presumed to be weathered from olivene basalt. Possibility that soil was weathered from alluvium.

### RAINFALL:

40 inches.

### ELEVATION:

500 feet.

### VEGETATION:

Pineapple.

### PHYSIOGRAPHY:

Low nearly level upland. Relief about 2 percent convex to west.

### DRAINAGE:

Well drained. Runoff slow.

### PERMEABILITY:

Moderate to moderately rapid.

### STONINESS:

None noticed.

### REMARKS:

Upper solum dry when described. This soil mapped Waiau Silty Clay in 1955 report.

### A1 0-6"

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<th>Sample</th>
<th>Depth</th>
<th>Classification</th>
<th>Color</th>
<th>Texture</th>
<th>Reaction</th>
<th>Permeability</th>
</tr>
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<tbody>
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<td>S61Ha7-7-1</td>
<td>6-12&quot;</td>
<td>Dark reddish-brown (2.5YR 2/4)</td>
<td>Clay that feels like a silty clay, same color when crushed; weak coarse subangular blocky structure; firm, sticky, plastic; very fine roots; common fine and very fine tubular pores; few coarse tubular pores; nearly continuous pressure cutans; many small patches that look like clay skins; many fine distinct black motiles; moderate to strong reaction with 3 percent hydrogen peroxide; clear wavy boundary.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S61Ha7-7-2</td>
<td>6-12&quot;</td>
<td>Same color and texture as A1. Common medium and coarse dark reddish-brown mottles (8 horizons mixed in by tillage); weak coarse subangular blocky structure (tillage pan); extremely hard, very firm, sticky, plastic; few roots; few fine and very fine tubular pores; cracks about a quarter inch wide and formed at intervals of 2 to 4 inches in walls of pit in about 6 days; common medium and fine hard round black concretions; violent reaction with 3 percent hydrogen peroxide; clear wavy boundary.</td>
<td></td>
<td></td>
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### A2 12-16"

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<th>Permeability</th>
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<td>12-16&quot;</td>
<td>Dark reddish-brown (2.5YR 2/4)</td>
<td>Moist, clay that feels like a silty clay, same color when crushed; weak coarse subangular blocky structure; firm, sticky, plastic; very few fine roots; common fine and very fine tubular pores; few coarse tubular pores; appears to be compacted by tillage; concretions same as above; strong reaction with 3 percent hydrogen peroxide; clear wavy boundary.</td>
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### B2 16-33"

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<th>Texture</th>
<th>Reaction</th>
<th>Permeability</th>
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<td>B22</td>
<td>16-33&quot;</td>
<td>Dark reddish-brown (2.5YR 2/4)</td>
<td>Moist, clay that feels like a silty clay, same color when crushed; weak coarse subangular blocky structure; firm, sticky, plastic; no roots noticed; common fine and very fine tubular pores; nearly continuous pressure cutans; many small patches that look like clay skins; many fine distinct black motiles; moderate to strong reaction with 3 percent hydrogen peroxide; diffuse wavy boundary.</td>
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### B3 33-45"

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<td>B23</td>
<td>33-45&quot;</td>
<td>Dark-red (2.5YR 2/4)</td>
<td>Moist clay that feels like a silty clay, same color when crushed; weak coarse subangular blocky breaking to moderate very fine subangular blocky structure; friable, sticky, plastic; no roots; common fine and very fine tubular pores; almost continuous pressure cutans with little evidence of clay skins; black motles and concretions as above; moderate reaction with 3 percent hydrogen peroxide; diffuse wavy boundary.</td>
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### B4 45-60"

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<td>B24</td>
<td>45-60&quot;</td>
<td>Same color as above, clay that feels like a silty clay; weak coarse subangular blocky breaking to moderate very fine subangular blocky structure; friable, sticky, plastic, no roots; common fine and very fine tubular pores; continuous pressure cutans; many distinct slickensides up to 2 inches long oriented about 30 degrees; few fine black motles and very few black concretions; slight reaction with 3 percent hydrogen peroxide.</td>
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APPENDIX B: DESCRIPTION OF MANANA SOIL

SAMPLES 661187-11-1 THROUGH 7

LOCATION: SAMPLE SITE IN ABANDONED PINEAPPLE FIELD 100 FEET EAST OF MACADAM ROAD AT A POINT 1.8 MILES MAUKA OF JUNCTION OF HIGHWAY 80 AND 808 (HIGHWAY 80 IS ROAD TO WAIANA NAVAL RADIO STATION).

CLASSIFICATION: HUMIC FERRUGINOUS LATOSOL.

PARENT MATERIAL: NOT KNOWN; PRESUMED TO BE WEATHERED FROM ASH OR ALLUVIUM.

CLIMATE: 70-80 INCHES OF RAINFALL PER YEAR, RAIN EVERY MONTH IN A NORMAL YEAR.

VEGETATION: ABANDONED PINEAPPLE.

PHYSIOGRAPHY: UNDULATING LAND SURFACE OF WEST KOOLAU RANGE; SLIGHTLY CONVEX.

SOIL PROFILE:

A p 0-8" DARK REDDISH-BROWN (2.5YR 2/4) SILTY CLAY, REDDISH BROWN (4/4) WHEN DRY; MODERATE MEDIUM SUBANGULAR STRUCTURE BREAKING TO MODERATE FINE AND MEDIUM GRANULAR STRUCTURE; STICKY, PLASTIC, FIRM; MANY FINE ROOTS; MANY VERY FINE AND FINE TUBULAR AND INTERSTITIAL PORES; FEW BLACK VERY FINE CONCRETIONS THAT WILL NOT EFFERVESCE WITH HYDROGEN PEROXIDE; COMMON VERY FINE GLISTENING SPECKS; HAS HIGH APPARENT BULK DENSITY FEEL IN HAND; IN LOWER PART THERE ARE MOTTLES OF DARK RED (1 OR 3/4) MATERIAL THAT ARE CAUSED BY MIXING OF THE B HORIZON BY TILLAGE; ABRUPT SMOOTH BOUNDARY.

B 21 8-11" DUSKY-RED (1 OR 3/4) SILTY CLAY, SAME COLOR WHEN CRUSHED; MODERATE VERY FINE AND FINE SUBANGULAR BLOCKY STRUCTURE; STICKY, PLASTIC, FIRM; MANY FINE ROOTS; COMMON VERY FINE AND FINE PORES; NEARLY CONTINUOUS CUTANS THAT APPEAR TO BE PRESSURE SURFACES; NOTICEABLE DECREASE IN BULK DENSITY FROM ABOVE; MANY VERY FINE EARTHY LUMPS THAT RESIST BREAKING DOWN ON RUBBING; FEW GLISTENING SPECKS; CLEAR SMOOTH BOUNDARY.

B 22 11-19" SAME COLOR AS ABOVE SILTY CLAY; MODERATE MEDIUM AND COARSE SUBANGULAR BLOCKY STRUCTURE BREAKING TO STRONG VERY FINE SUBANGULAR BLOCKY STRUCTURE; STICKY, PLASTIC, FIRM; COMMON FINE ROOTS; COMMON VERY FINE AND FINE PORES; CONTINUOUS CUTANS ON PED SURFACES THAT APPEAR TO BE PRESSURE CUTANS; MANY VERY FINE EARTHY LUMPS; ABRUPT SMOOTH BOUNDARY.

B 23 19-22" DUSKY-RED (1 OR 3/4) SILTY CLAY, WITH MANY FINE MOTTLES OF DARK REDDISH-BROWN (5 YR 3/3) CRUSHES TO DARK REDDISH-BROWN (2.5YR 3/4); MODERATE MEDIUM SUBANGULAR BLOCKY STRUCTURE BREAKING TO STRONG VERY FINE SUBANGULAR AND ANGULAR BLOCKY STRUCTURE; SLIGHTLY STICKY, PLASTIC, FIRM; TOP OF THIS HORIZON CAPPED BY A 1/4 TO 1/2 INCH ROOT MAT; NO APPARENT ROOTS; COMMON VERY FINE TUBULAR PORES; CONTINUOUS CUTANS THAT APPEAR LIKE PRESSURE SURFACES; VERY COMPACT IN PLACE; CLEAR WAVY BOUNDARY.

B 24 22-32" DUSKY-RED (1 OR 3/4) SILTY CLAY WITH POCKETS OF REDDISH-BROWN (5 YR 4/4) MATERIAL OF WEATHERED SAPROLITE; MODERATE COARSE SUBANGULAR BLOCKY BREAKING TO STRONG VERY FINE SUBANGULAR BLOCKY STRUCTURE; SLIGHTLY STICKY, PLASTIC, FIRM TO VERY FIRM; CONTINUOUS CUTANS THAT FOR THE MOST PART LOOK LIKE PRESSURE CUTANS, SOME OF WHICH ARE MARKEDLY STRIATED BUT WITH SOME THAT APPEAR TO BE STRONGY CLAY FILMS; MANY RESISTANT VERY FIRM EARTHY LUMPS; COMPACT IN PLACE; ABRUPT WAVY BOUNDARY.

C 1 32-42" DARK REDDISH-BROWN (5 YR 3/3) SILTY CLAY WITH MANY LARGE MOTTLES OF DUSKY RED (1 OR 3/4); MODERATE FINE AND MEDIUM SUBANGULAR AND ANGULAR BLOCKY STRUCTURE, STICKY, PLASTIC, VERY FIRM, COMMON VERY FINE PORES; COMMON LARGE SLICKEN SIDES THAT ARE DEEPLY STRIATED; MANY LARGE STRINGY CUTANS ON PED SURFACES THAT LOOK LIKE CLAY FILMS; FEW POCKETS OF WEATHERED SAPROLITE; COMPACT IN PLACE; ABRUPT WAVY BOUNDARY.

C 2 42-63" DARK REDDISH-BROWN (2.5YR 3/4) SILTY CLAY, WITH MANY LARGE MOTTLES OF DUSKY RED (1 OR 3/4) CRUSHES TO DARK BROWN (7.5YR 3/2); MODERATE MEDIUM AND COARSE SUBANGULAR BLOCKY STRUCTURE, STICKY, PLASTIC, VERY FIRM; CONTINUOUS CUTANS PART OF WHICH APPEAR TO BE PRESSURE CUTANS WITH MANY THAT APPEAR TO BE THICK PATCHY CLAY FILMS; MANY VERY FIRM EARTHY LUMPS; FEW SMALL POCKETS OF WEATHERED SAPROLITE.
APPENDIX C: DESCRIPTION OF LAHAINA SOIL

LOCATION: APPROXIMATELY 5 MILES SOUTH-SOUTHWEST OF WAIHAWA TURN EAST ON MACADAN ROAD LEADING TO MILILANI CEMETERY FOR 2300 FT. AT JUNCTION OF ROAD AT SITE OF DOLE PINEAPPLE LOADING STATION, TURN SOUTH BY SOUTHEAST ALONG DIRT ROAD FOR 1300 FT. PIT LOCATED IN PINEAPPLE FIELD 50 FT. TO WEST OF ROAD.

PARENT MATERIAL: NOT EXACTLY Known, presumed to be weathered in place from basic igneous rock, but may be from alluvium.

CLASSIFICATION: LOW HUMIC LATOSOL.

VEGETATION: PINEAPPLE.

PHYSIOGRAPHY: UNDULATING SLOPES OF WEST KUOLAU RANGE, SLOPE 2 PERCENT TO WEST.

ELEVATION: 450 FEET.

CLIMATE: 35 INCHES RAINFALL.

REMARKS: AFTER FEW DAYS DRYING AP HORIZON DEVELOPS CRACKS FROM ONE-FOURTH TO ONE-HALF INCHES.

A 1 0-2" DUSKY-RED (1 OR 3/4 DRY), VERY DUSKY-RED (2/4 MOIST) ON PED SURFACES, DARK-RED (2.5YR 3/6) CRUSHED COLOR WHEN DRY, 2.5YR 2/6 CRUSHED COLOR WHEN MOIST SILTY CLAY; EXTREMELY HARD, FRIABLE, STICKY, PLASTIC, WEAK COARSE MEDIUM AND FINE GRANULAR STRUCTURE; FEW FINE DISTINCT BLACK MOTTLES, PROBABLY CHARCOAL; ABUNDANT ROOTS; MANY MEDIUM AND FINE INTERSTITIAL PORES; STRONG EFFERVESCENCE WITH HYDROGEN PEROXIDE; ABRupt Wavy Boundary.

B 1 14-22" DUSKY-RED (1 OR 3/4 MOIST), SAME COLOR WHEN CRUSHED, COMMON BLACK MOTTLES, SILTY CLAY; WEAK COARSE SUBANGULAR BREAKING TO WEAK MEDIUM SUBANGULAR BLOCKY STRUCTURE; FRIABLE, STICKY, PLASTIC; COMMON MEDIUM AND FINE AND VERY FINE TUBULAR PORES; COMMON TO FEW ROOTS; MANY SMALL PATCHES OF PRESSURE CUTANS; VIOLENT EFFERVESCENCE WITH HYDROGEN PEROXIDE; GRADUAL Wavy Boundary.

B 2 22-36" DARK DUSKY-RED (1 OR 3/4 MOIST), SAME COLOR WHEN CRUSHED, SILTY CLAY; WEAK COARSE SUBANGULAR BREAKING TO STRONG VERY FINE ANGULAR BLOCK AND SUBANGULAR BLOCKY STRUCTURE; FIRM, STICKY, PLASTIC; FEW FINE DISTINCT BLACK MOTTLES; THIS HORIZON APPEARS TO HAVE HIGH BULK DENSITY AND IS DIFFICULT TO DIG; NEARLY CONTINUOUS PRESSURE CUTANS; OF WHAT APPEARS TO BE COMMON PATCHY CLAYSKINS; NO ROOTS; FEW FINE AND VERY FINE TUBULAR PORES; THIS MATERIAL HAS A DISTINCT CRISP BRITTLE FEEL; SLIGHT EFFERVESCENCE WITH HYDROGEN PEROXIDE; ABRupt Wavy Boundary.

B 3 36-48" DARK REDDISH-BROWN (2.5YR 3/4) MOIST ON PED SURFACES, CRUSHED COLOR SAME; SILTY CLAY LOAMS; WEAK COARSE SUBANGULAR BLOCKY STRUCTURE; FRIABLE, SLIGHTLY STICKY, PLASTIC; COMMON DUSKY-RED MOTTLES WHICH APPEAR TO BE CLAYSKINS; HAS FEW SMALL PATCHES THAT RETAIN ROCK STRUCTURE, PRESUMED TO BE RELETS OF WEATHERED GRAVEL; NEARLY CONTINUOUS PRESSURE CUTANS; AND SOME PATCH CLAYSKINS; MANY VERY FINE TUBULAR PORES; NO EFFERVESCENCE WITH HYDROGEN PEROXIDE; GRADUALLY SLOWLY WRINKLING.

A 2 2-14" DARK REDDISH-BROWN (2.5YR 3/4) DRY, 2/4 MOIST, DARK-RED (2.5YR 3/6) CRUSHED DRY, 2.5YR 2/6 CRUSHED MOIST SILTY CLAY; WEAK COARSE ANGULAR AND SUBANGULAR BLOCKY STRUCTURE BREAKING TO WEAK MEDIUM SUBANGULAR BLOCKY STRUCTURE; EXTREMELY HARD; FRIABLE, STICKY, PLASTIC, COMMON MEDIUM AND VERY FINE TUBULAR PORES; COMMON TO MANY ROOTS; COMMON ROUND HARD BLACK CONCRETIONS PRESUMED TO BE MANGANESE DIOXIDE; LOTS OF WORKS AND ANTS ACTIVITY EVIDENCED BY BURROWS AND CASTS; THIS HORIZON SEEMS TO BE COMPACTED BY TILLAGE IMPLEMENTS; STRONG EFFERVESCENCE WITH HYDROGEN PEROXIDE; ABRupt Wavy Boundary.

C 1 48-60"+ DARK REDDISH-BROWN (2.5YR 3/4) MOIST PED SURFACES, SAME COLOR CRUSHED, WITH MANY COARSE AND MEDIUM DARK-RED AND STRONG BROWN MOTTLES DUE TO STRONGLY WEATHERED ROCK, SILTY CLAY LOAM; WEAK COARSE SUBANGULAR BREAKING TO MODERATE FINE AND VERY FINE SUBANGULAR BLOCKY STRUCTURE; FRIABLE, SLIGHTLY STICKY, PLASTIC; FEELS CRISP AND BRITTLE IN PLACES; IN LESS RED MATERIAL MANY DISTINCT PRESSURE CUTANS; IN SOME PLACES MANY REDDISH CLAYSKINS; MANY FINE AND VERY FINE TUBULAR PORES.
APPENDIX D: DESCRIPTION OF LOLEKAA SOIL

LOCATION: WINDMARD OAHU SOIL AND WATER CONSERVATION DISTRICT: NORTH OF KANEOHE ON FEDERAL HIGHWAY NUMBER 83 TO HAUKI VALLEY ROAD, WEST 0.6 MILE, THEN NORTH ON ROAD TO CITY AND COUNTY DUMP. PIT LOCATED 150 FEET NORTHWEST OF ENTRANCE GATE OF THE PASTURE TO THE WEST OF DUMP.

CLASSIFICATION: HUMIC LATOSOL.

RAINFALL: 70 - 90 INCHES PER YEAR.

VEGETATION: CALIFORNIA GRASS, HILO GRASS, RICE GRASS, AND GUAVA.

PHYSIOGRAPHY: NEARLY LEVEL TO FANS TO VERY STEEP DISSECTED TERRACES.

ELEVATION: SEA LEVEL TO 500 FEET.

DRAINAGE: WELL DRAINED.

PERMEABILITY: MODERATELY RAPID PERMEABILITY.

REMARKS: THE TEXTURAL CLASS NAMES REFLECT THE "APPEARANCE" FEEL OF THE SOIL AND NOT THE TEXTURE DETERMINED BY MECHANICAL ANALYSIS.

SOIL PROFILE: LOLEKAA SILTY CLAY (PASTURE).

Ap 0-9" DARK GRAYISH-BROWN (10YR 4/2) SILTY CLAY; STRONG MEDIUM GRANULAR AND VERY FINE AND FINE SUBANGULAR BLOCKY STRUCTURE; FRIABLE, STICKY AND PLASTIC; MANY FINE AND MEDIUM ROOTS; MANY FINE AND VERY FINE INTERSTITIAL AND TUBULAR PORES; EVIDENCE OF MUCH WORM ACTIVITY; MANY HARD EARTH LUMPS; STRONGLY ACID (pH 5.5); ABRupt smooth boundary. 6 TO 9 INCHES THICK.

B1 9-13" BROWN (10YR 4/3) SILTY CLAY; MODERATELY FINE, FINE AND MEDIUM SUBANGULAR BLOCKY STRUCTURE; FRIABLE, STICKY AND PLASTIC; COMMON FINE ROOTS; MANY VERY FINE AND FINE AND FEW MEDIUM TUBULAR PORES; EVIDENCE OF MEDIUM AND WORM ACTIVITY; MANY HARD EARTH LUMPS; THIN CONTINUOUS CLAY FILMS ON PORE SURFACES; TRACE OF REDDISH BROWN (5YR 4/2) WEATHERED ROCK FRAGMENTS; STRONGLY ACID (pH 5.2) CLEAR SMOOTH BOUNDARY. 4 TO 6 INCHES THICK.

B2 13-19" BROWN (7.5YR 4/5) SILTY CLAY; MODERATELY FINE, MEDIUM SUBANGULAR AND BLOCKY STRUCTURE; FRIABLE, STICKY AND PLASTIC; COMMON FINE ROOTS; MANY VERY FINE AND FINE AND FEW MEDIUM TUBULAR PORES; COMPACT IN PLACE; MANY HARD EARTH LUMPS; REDDISH-BROWN (5YR 4/4) THIN CONTINUOUS CLAY FILMS ON PORE SURFACES AND IN PORES; DARK-BROWN (7.5YR 4/4) MOIST CLAY FILMS IN ROOT CHANNELS; STRONGLY ACID (pH 5.2) CLEAR SMOOTH BOUNDARY. 4 TO 6 INCHES THICK.

B3 19-33" DARK-BROWN (10YR 3/3) SILTY CLAY; STRONG VERY FINE AND FINE BLOCKY AND SUBANGULAR BLOCKY STRUCTURE; COMBUST, STICKY AND PLASTIC; FEW FINE ROOTS; MANY VERY FINE AND FINE AND FEW MEDIUM TUBULAR PORES; COMPACT IN PLACE; LESS STICKY AND PLASTIC THAN B21; REDDISH-BROWN (5YR 4/4) MOIST THICK CONTINUOUS CLAY FILMS ON PORE SURFACES AND IN PORES; DARK-BROWN (7.5YR 4/4) MOIST THICK CLAY FILMS IN ROOT CHANNELS; TRACE OF WEATHERED GRAY, YELLOW AND RED ROCK FRAGMENTS; STRONGLY ACID (pH 5.2) CLEAR IRREGULAR BOUNDARY. 8 TO 24 INCHES THICK.

B4 33-44" BROWN (10YR 4/3) SILTY CLAY; MODERATELY TO STRONGLY FINE AND FINE BLOCKY AND SUBANGULAR BLOCKY STRUCTURE; FRIABLE, STICKY AND PLASTIC; COMMON FINE ROOTS; MANY VERY FINE AND FINE AND COMMON MEDIUM TUBULAR PORES; LESS STICKY AND PLASTIC THAN B21; COMPACT IN PLACE; REDDISH-BROWN (5YR 4/4) MOIST THIN CONTINUOUS CLAY FILMS ON PORE SURFACES AND IN PORES; DARK-BROWN (7.5YR 4/4) MOIST THICK CLAY FILMS IN ROOT CHANNELS; 5 PERCENT WEATHERED ROCK FRAGMENTS WHICH APPEAR LESS WEATHERED THAN ABOVE; COMMON KROTIVINAS; TONGUES WITH DEPTHS GREATER THAN WIDTH; STRONGLY ACID (pH 5.2) CLEAR SMOOTH BOUNDARY. 6 TO 22 INCHES THICK.

B5 44-55" BROWN (10YR 4/3) LOAM; MODERATELY TO STRONGLY FINE AND FINE SUBANGULAR BLOCKY STRUCTURE; FRIABLE, STICKY AND PLASTIC; FEW FINE ROOTS; MANY VERY FINE AND FINE AND COMMON MEDIUM TUBULAR PORES; COMPACT IN PLACE; LESS STICKY AND PLASTIC THAN B21; 15 TO 20 PERCENT OF WEATHERED ROCKS WHICH LESS WEATHERED THAN ABOVE; STRONGLY ACID (pH 5.2) GRADUAL WAVE Boundary. 11 TO 16 INCHES THICK.

B2 55-69" BROWN (10YR 4/3) LOAM; MODERATELY TO STRONGLY FINE SUBANGULAR BLOCKY STRUCTURE; FRIABLE, SLIGHTLY TO MODERATELY PLASTIC; FEW VERY FINE ROOTS; MANY VERY FINE, FINE AND MEDIUM PORES; THIN CONTINUOUS CLAY FILMS ON PORE SURFACES; DARK-BROWN (7.5YR 4/4) MOIST THICK CONTINUOUS CLAY FILMS IN ROOT CHANNELS; 30 TO 40 PERCENT RED, BROWN GRAY AND YELLOW ROCK FRAGMENTS WHICH APPEAR TO BE LESS WEATHERED THAN ABOVE; STRONGLY ACID (pH 5.2).