IDENTIFICATION OF IRRIGATION RETURN WATER IN THE SUB-SURFACE, PHASE III: KAHUKU, OAHU AND KAHULUI AND LAHAINA, MAUI

by

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IDENTIFICATION OF IRRIGATION RETURN WATER IN THE SUBSURFACE -- PHASE III

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ABSTRACT

This study continued the joint research effort undertaken by the Water Resources Research Center and the Honolulu Board of Water Supply in 1967 to investigate the physical and chemical characteristics of irrigation return water. Initial work concentrated on the Pearl Harbor-Waipahu area of Oahu. The phases reported herein included both Kahuku Plantation on Oahu and the sugar cane cultivation areas of central and West Maui (Pioneer Mill Co. and Hawaiian Commercial and Sugar Co.). Composite well, spring, and stream samples were taken and analyzed in the laboratory for the following constituents: bicarbonate, calcium, magnesium, phosphate, silica, boron, chloride, nitrate, sodium, potassium, bromide, fluoride, sulfate, and total hardness.

On the basis of increased index constituents over uncontaminated ground-water sources used to identify the presence of irrigation return water, it is evident, as previously concluded by Visher and Mink (1964), such irrigation return water, is definitely present in the basal water bodies underlying the three study areas. Considerable increases in the nitrate and sulfate indices, especially, and in the bicarbonate and silica indices, as shown by various methods of interpretation of water quality data obtained over a period of approximately two years or exceeding one complete cycle of planting and harvesting of sugarcane, verify the strong influence of irrigation and agricultural practices in altering the overall quality of the basal water sources in the three areas.

The basal water quality of the HC&S aquifer is most affected regionally, as well as locally, by the prevailing agricultural practices. The deterioration of the water is due in part to fertilization and to a greater extent to heavy pumping and recycling of the basal water. Water quality in the Pioneer Mill area parallels that of HC&S, although on a regional basis, the basal water quality, unlike that of the Pioneer Mill area, is not as deteriorated. Local effects of pumping are also especially noticeable in the Pioneer Mill area.

Ground-water quality in the Kahuku area shows the obvious presence of irrigation return water indices, but, unlike the two plantations on Maui, the magnitude of the increases relative to uncontaminated water sources is considerably smaller. The effect of fertilization on Kahuku may be considered to be a principal factor in the regional distribution of index constituents with a relatively uniform nitrate distribution throughout. Local effects of pumping are quite pronounced and influence overall increases of indices, indicating that where heavy pumping takes place for irrigation, the increase in index constituents are correspondingly greater.

CONTENTS

LIST OF FIGURES

INTRODUCTION

Neither the influence of irrigation nor that of agricultural practices on the quality of Hawaiian basal water bodies has been studied to any considerable extent. In comparison, the influence of surface runoff, sewage disposal, solid waste disposal, and other domestic and industrial disposal practices affecting stream or coastal waters has been rather extensively documented. Almost no quantitative or qualitative assessment of the effects of irrigation water has ever been made on the principal basal water lenses. Water quality data relating the chemistry of the water to its suitability for different uses has often depended on chloride content alone. The monitoring of ground-water resources for their overall physical and chemical properties has been undertaken only recently on a relatively long-term basis.

The changes in the chemistry of the water quality of the basal aquifer which have been attributed to agricultural and irrigation practices have been documented for some areas in the Hawaiian islands where sugarcane cultivation is practiced. A study by Visher and Mink (1964) on the qualitative effects of irrigation water on the basal water aquifer in southern Oahu based the evaluation of such effects as the magnitude of increases in the specific index constituents normally found in uncontaminated waters from various ground-water regions on Oahu. The parameters used as criteria in identifying the presence of irrigation water were silica, nitrate, sulfate, and bicarbonate.

Perhaps, because irrigation return water was not considered a significant factor, no really detailed short-term or long-term study of its possible public health significance has ever been carried out. Previous studies, particularly those dealing with ground-water resources and geology, have only reported detailed chemical analyses of some water samples collected. With the exception of studies by Visher and Mink (1964), which evaluated irrigation return water qualitatively and quantitatively, and the State Board of Health study (included in Takasaki and Valenciano, 1969), which specifically evaluated the presence of nitrate in the ground water of Kahuku, Oahu, all other geologic and ground-water resources studies previously carried out merely showed tabulations of chemical data collected and include little or no discussion on the effects of irrigation return water. In the report of the initial work accomplished under Phase II[1] of the study reported here, Tenorio, *et al.*, (1969) have compiled general water-quality data for the Pearl Harbor-Waipahu and Kahuku regions on Oahu and parts of Maui and included an interpretation of the presence of irrigation water, mainly in the basal lens of the Pearl Harbor-Waipahu region.

One of the most important conclusions that Visher and Mink (1964) made in their study on the effects of irrigation water on the chemistry of the basal aquifer was the verification that a significantly large volume of irrigation water moves into the basal aquifer underlying irrigated areas, carrying with it large amounts of dissolved solids contributed by fertilizers and related agricultural practices as well as from the irrigation water itself.

Purpose and Scope

This report describes the work conducted in the third and final phase of a study to obtain qualitative proof of the presence of irrigation water in the basal ground-water bodies and to assess the magnitude of the index constituents present in three different agricultural areas, each characterized by a more or less unique subsurface geology, hydrologic properties, and modes of recharge, but having a common base in the changing land use from agricultural to urban.

The effects of irrigation return water and associated agricultural practices were identified for the basal ground-water bodies underlying three hydrologically and geologically different areas on the islands of Oahu and Maui which are planted with sugar cane, the principal agricultural crop of the state and one of its major sources of income. The three areas studied were 1) Kahuku Plantation on the island of Oahu, 2) Pioneer Mill Company in West Maui in the Lahaina district, and 3) Hawaiian Commercial and Sugar Company (HC&S) in Puunene in Central Maui, comprising a part of the Wailuku district, otherwise known as the Isthmus.[2]

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[1] Project No. B-012-HI, funded by the Office of Water Resources Research under Grant Agreement No. 14-01-0001-1495.

[2] The geology and hydrology of the study areas was described in a previous report by Tenorio, *et al.*, 1969.

LOCATIONS OF WATER SAMPLING STATIONS

In general, all sampling locations, except for a few which will be discussed later, may be considered to be within or in the vicinity of sugar cane fields.

Kahuku

In Kahuku, as shown by Figure 1, all the wells sampled, except Well No. 337-1, are within the boundary of the sugar cane fields. A spring near Well No. 341, at which an irrigation pump is located, was also sampled.

The principal wells in Kahuku from which water is obtained for irrigation and which were analyzed for this study are designated as Pump Nos. 25, 15, 12, 8, 5, 3, and 2. These designations and their corresponding USGS numbers are given in the data tables in the Appendix. Non-irrigation wells which are located within sugar cane fields and pump water from the basal aquifer for domestic and other non-irrigation needs, include USGS designated Well Nos. 367, 339, 352A-K, 338, and 338-1. Well No. 337-1 is thought to tap water from the Koolau dike-zone and is located some distance away from sugar cane fields. Well Nos. 356, 348, and 365 are non-pumping wells, the latter two are located in sugar cane fields. Well No. 356, a USGS water-level station, located mauka (mountainward of inland of some of the sugar cane fields, yields water for cattle watering, irrigation, and also serves as an emergency domestic water supply.

Pioneer Mill

In the Pioneer Mill plantation, ten principal irrigation wells of the vertical and inclined Maui-type shafts (Figs. 2 and 3) and dug wells were sampled for this study. All sampling locations of the basal water source are within or near sugar cane fields with the exception of Pump Nos. N and P. Water samples from Pump Nos. R, N, and P are collected from Maui-type inclined shafts. Pump No. M is a vertical Maui-type shaft and the remaining basal water sampling stations are from open pits and sumps dug a few feet below the water table.

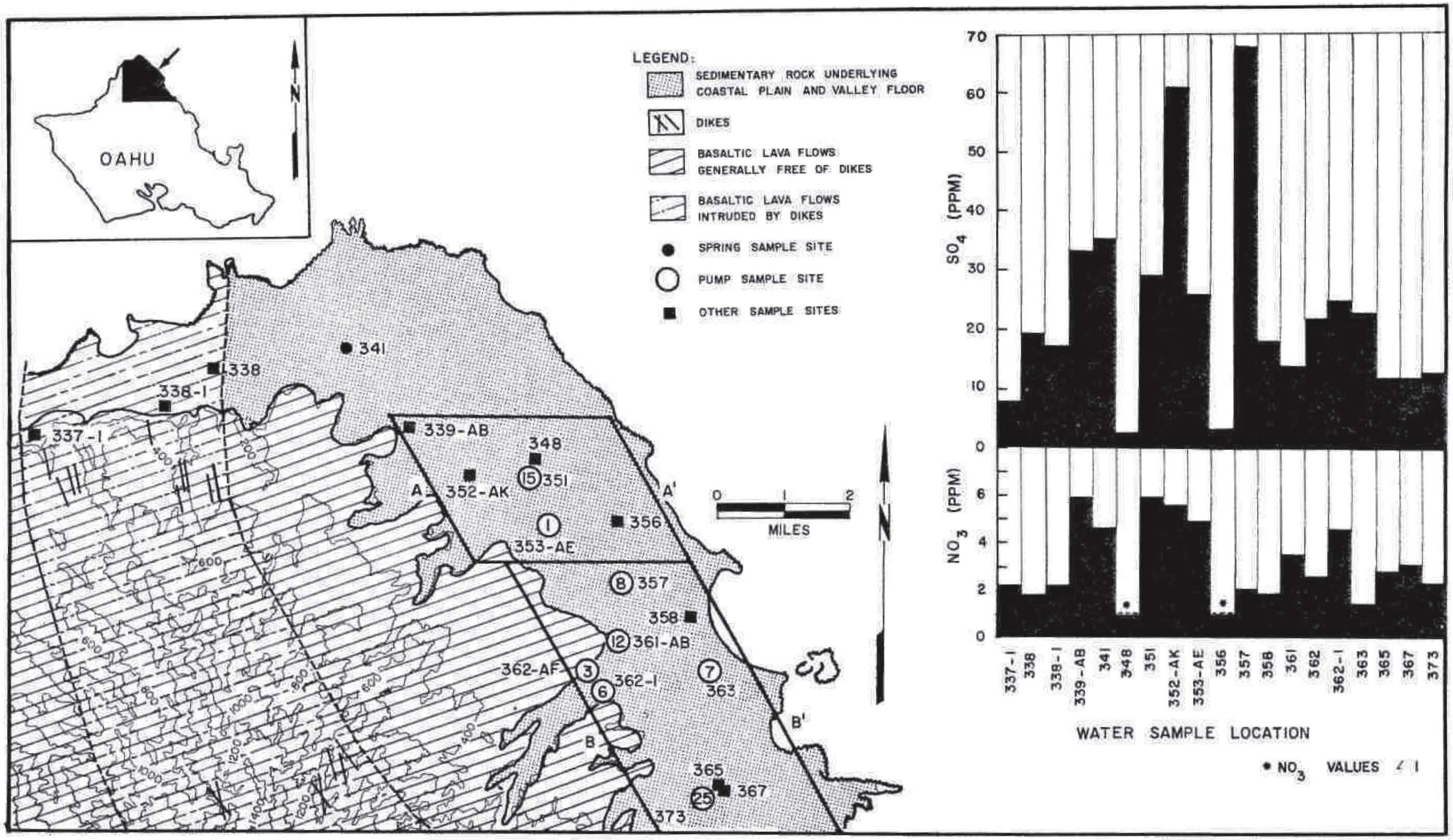

FIGURE 1. GENERALIZED GEOLOGIC MAP SHOWING LOCATIONS OF WATER SAMPLING STATIONS AND NITRATE AND SULFATE DISTRIBUTIONS IN THE KAHUKU PLANTATION STUDY AREA.

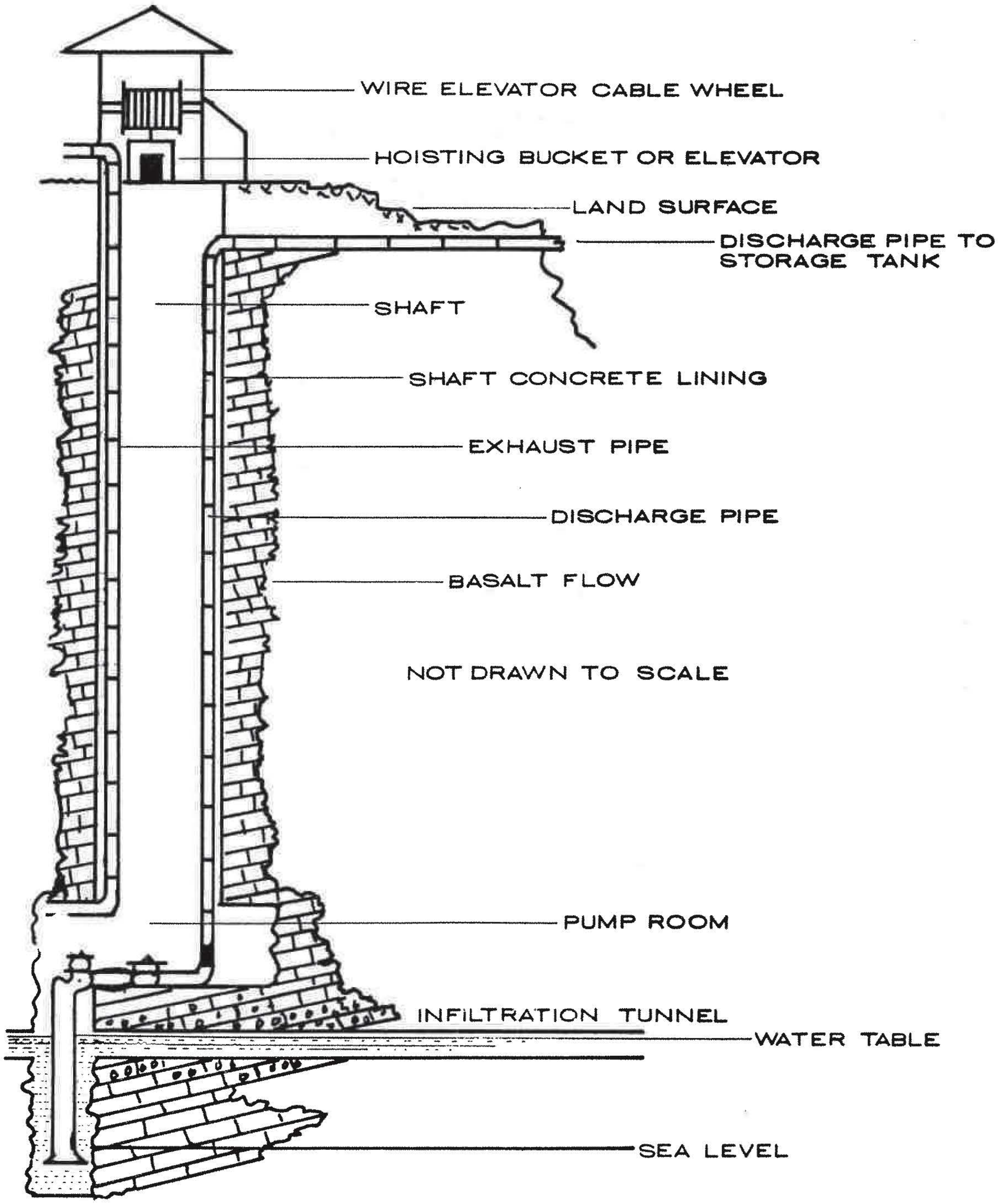

FIGURE 2. TYPICAL CROSS-SECTION OF A VERTICAL SHAFT MAUI-TYPE WELL. (REDRAWN FROM HAWAII ENGINEER, 1956)

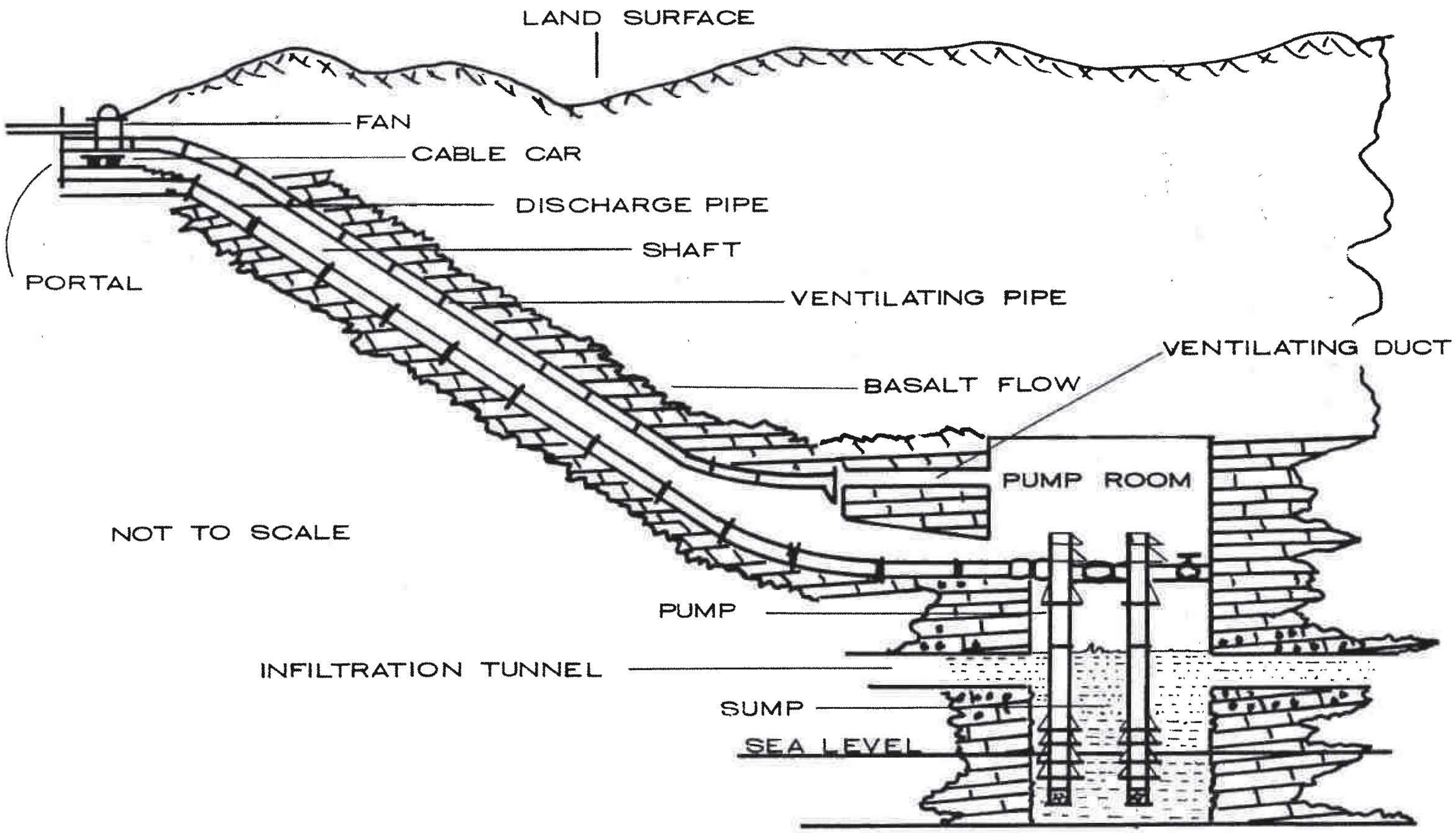

FIGURE 3. TYPICAL CROSS-SECTION OF AN INCLINED SHAFT MAUI-TYPE WELL (REDRAWN FROM BULLETIN 5, HAWAII DIVISION OF HYDROGRAPHY, 1940)

Dike-water from a tunnel intake in the uplands of Honokowai valley was also sampled periodically. The locations of water sampling stations in the Pioneer Mill area are given in Figure 4.

Hawaiian Commercial and Sugar Company

All water samples collected from the HC&S plantation are basal in origin and are from pump sumps or tunnels located a few feet to a few hundred feet below the ground surface. Open pits where the water table is only a few feet below the ground surface or vertical Maui-type shafts are used for water development. Figure 5 shows the location of sampling stations in the HC&S area.

Additional water samples were collected from other areas in Maui, especially at the Wailuku Sugar Company plantation and adjacent upland areas from stream and dike water sources, coastal areas, and an irrigation pond. A well (Maui County Board of Water Supply Mokuhau well) tapping basal water of the Waikapu aquifer was also sampled. These peripheral sampling stations are shown in Figure 5.

DESCRIPTION OF INVESTIGATION

Sampling Method

The water samples collected from various sources were stored in acid-rinsed polyethylene bottles which had been vigorously rinsed three times with the water from the sample source before the sample was taken. Field measurements included pH and temperature which were determined immediately after the sample was collected. The samples were stored in an ice cooler and the remaining tests were done in the laboratory.

Laboratory tests were done as soon as possible to avoid possible deterioration of some constituents. During sampling trips to Maui, a one to three-day storage period of the samples in the cooler was necessary before transportation to Oahu for the remaining analyses. For trips involving this length of time, a Hach chemical kit (Hach Chemical Co., Ames, Iowa) was used to determine alkalinity in the field. Nitrate and phosphate contents were determined immediately upon transport of the

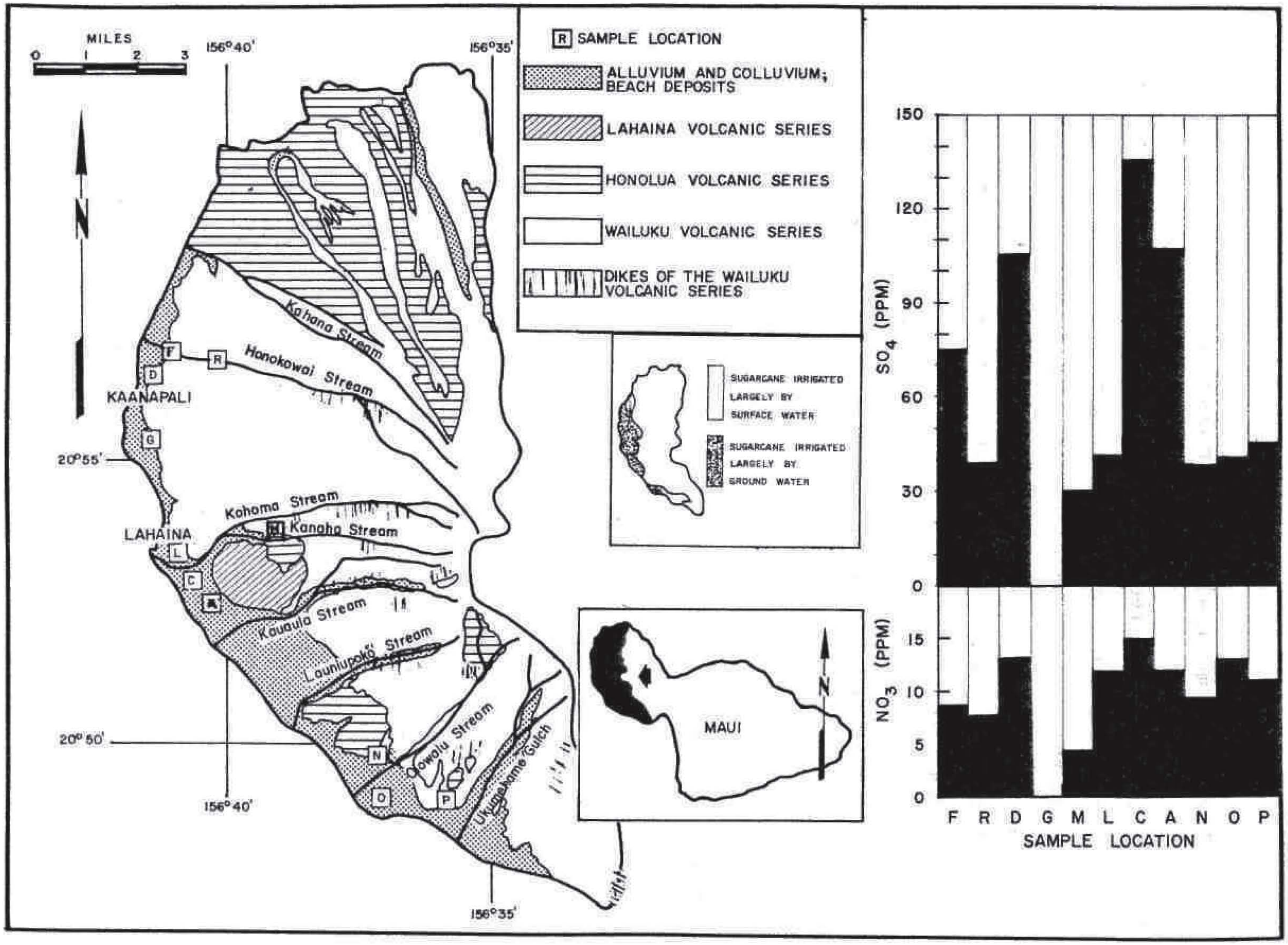

FIGURE 4. GENERALIZED GEOLOGIC MAP SHOWING LOCATIONS OF WATER SAMPLING STATIONS AND NITRATE AND SULFATE DISTRIBUTIONS IN THE PIONEER MILL STUDY AREA (GEOLOGIC UNITS FROM STEARNS AND MACDONALD, 1942, AND YAMANAGA AND HUXEL, 1969).

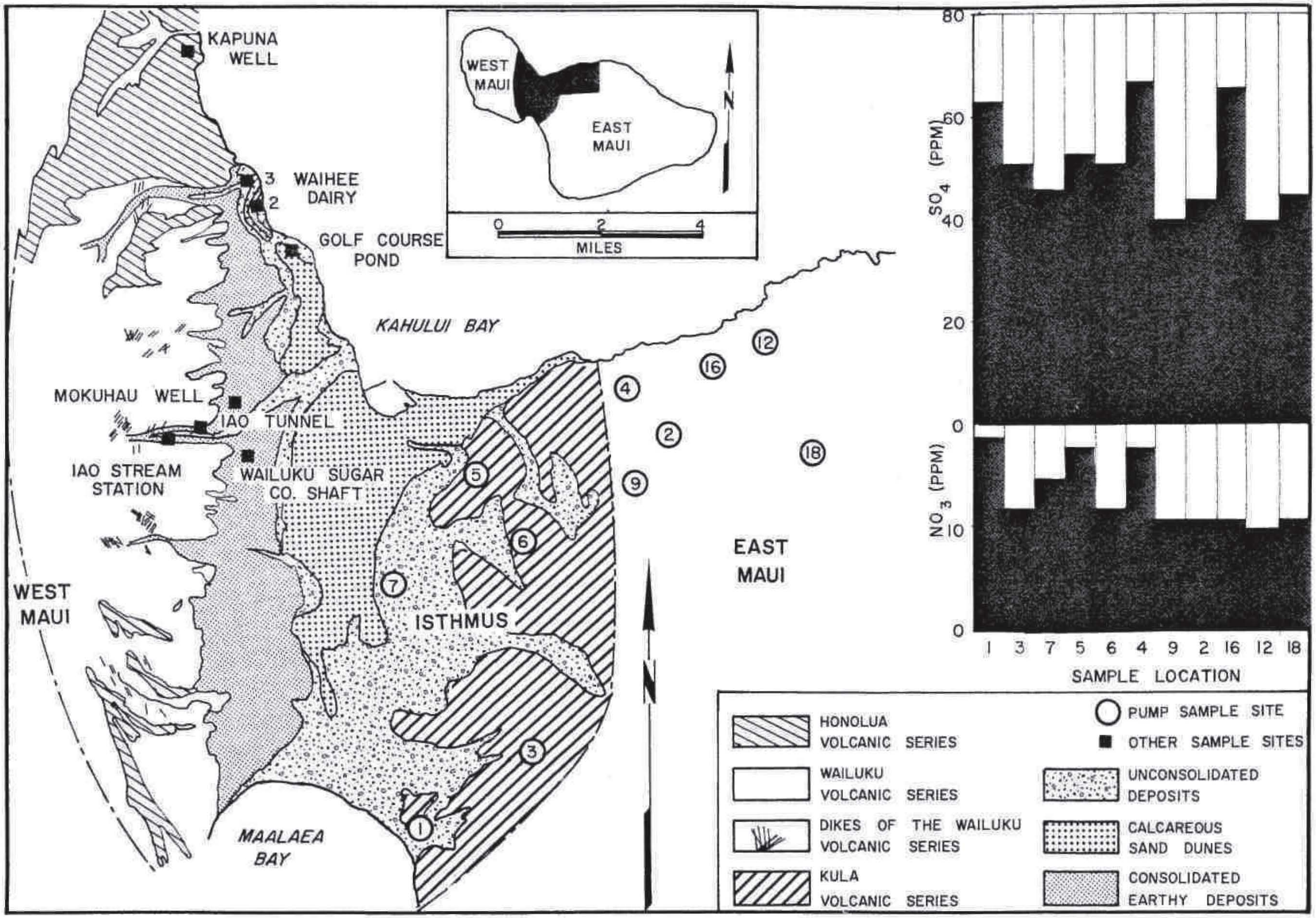

FIGURE 5. LOCATION OF WATER SAMPLING STATIONS IN THE HC&S STUDY AREA.

samples to the laboratory. Tests for these two constituents and for other chemical analyses were carried out according to established analytical procedures which are described in detail in the report on Phase II of this project (Tenorio, *et al.*, 1969).

DISCUSSION OF THE RESULTS

A series of graphs and maps have been constructed to aid in the interpretation of the results of this study. Graphical methods previously used in studies by Visher and Mink (1964), Takasaki and Valenciano (1969), and from Tenorio, Young, and Whitehead (1969) have been widely utilized here for the interpretation of results obtained by chemical analyses of water samples.

In order to show the magnitude of the increase of the index constituents in the water samples analyzed for this study, a comparison was made with data from previous studies in the islands. In particular, water quality data from Visher and Mink (1964), Takasaki and Valenciano (1969), Tenorio, Young, and Whitehead (1969), Yamanaga and Huxel (1969), and Division of Water and Land Development and Belt-Collins and Associates (1969), were used.

In this report, uncontaminated ground and surface waters is defined as water "whose composition has not been affected by mixing with intruded water or by the addition of irrigation or other water affected by the activity of man."[1]

As in most studies of water-quality evaluation, simple statistical procedures have been applied in summarizing water-quality data obtained over the two-year period of study. The collection schedule varied to correspond to irrigation and non-irrigation schedules of the plantation.

Because less than 10 analyses are available, in most cases, for each well sample, the mean is most frequently used in the evaluation of data for comparison with other data and for the construction of graphs and maps intended to show pertinent variations of water quality, principally the index constituents in the various wells sampled. Water

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[1] The definition is taken from the report by Visher and Mink, 1964.

quality data collected from analyses were carefully scrutinized to insure their reliability by eliminating unreasonably extreme values which were believed to have been due to experimental errors. All chemical analyses have been corrected by cation-anion balancing to within ±5 percent. The data are generally grouped into two parts: those obtained during irrigation or pumping periods and those obtained during non-irrigation or non-pumping periods, which correspond generally to March-October and November-February, respectively.

Histograms have been constructed to show the relative distributions of the index constituents in waters from the areas studied and to compare their magnitude of increase over uncontaminated water sources. Bar graphs for the index constituents and other water quality constituents have also been constructed and evaluated. Raw data are tabulated in the Appendix.

Concentration of Nitrate and Sulfate with Time and Areal Distribution

Figures 6 to 8 show the nitrate and sulfate concentrations in the various wells studied in each of the three areas with the corresponding time of irrigation and non-irrigation periods over three two-year periods of study, beginning in November 1968 and ending in February 1970. In general, the index values of nitrate and sulfate of the water samples obtained from the study sites are all appreciably greater than values normally found in uncontaminated water sources (Visher and Mink, 1964), and clearly point to the obvious presence of irrigation water and its influence on the chemical composition of the basal water bodies. Baselines showing nitrate and sulfate values in representative uncontaminated ground-water sources graphically indicate the relative degree of increase. The variation in the concentration of the two constituents in samples obtained during pumping and non-pumping periods is also quite marked, particularly for Pioneer Mill and HC&S plantations, though less evident for Kahuku Plantation.

The time lag for irrigation water to reach the basal water body is generally reflected in most of the graphs. This is especially noticeable in those wells in which high concentrations of the two index constituents

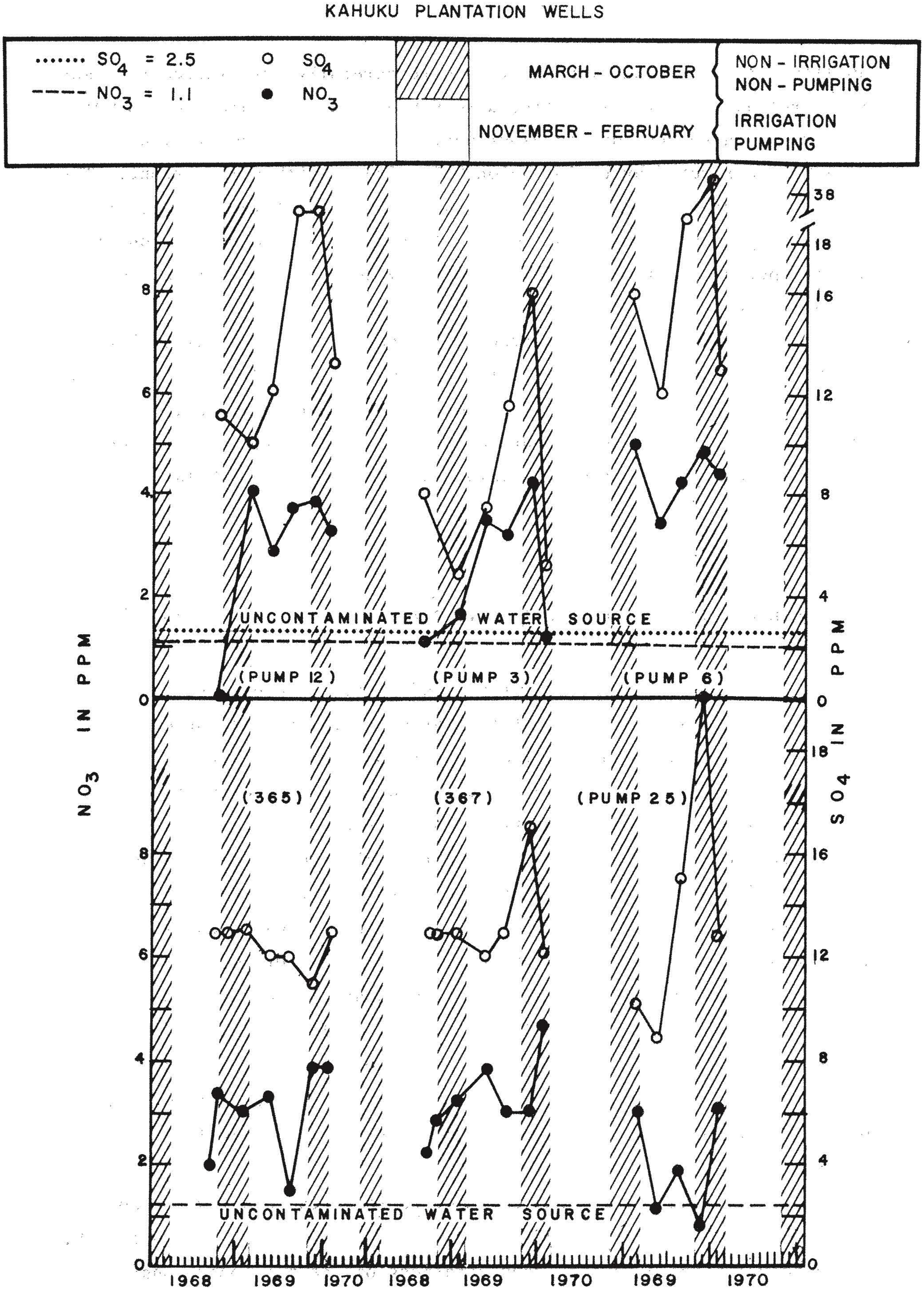

FIGURE 6. VARIATION OF NITRATE AND SULFATE WITH TIME IN KAHUKU WELLS.

PIONEER MILL WELLS

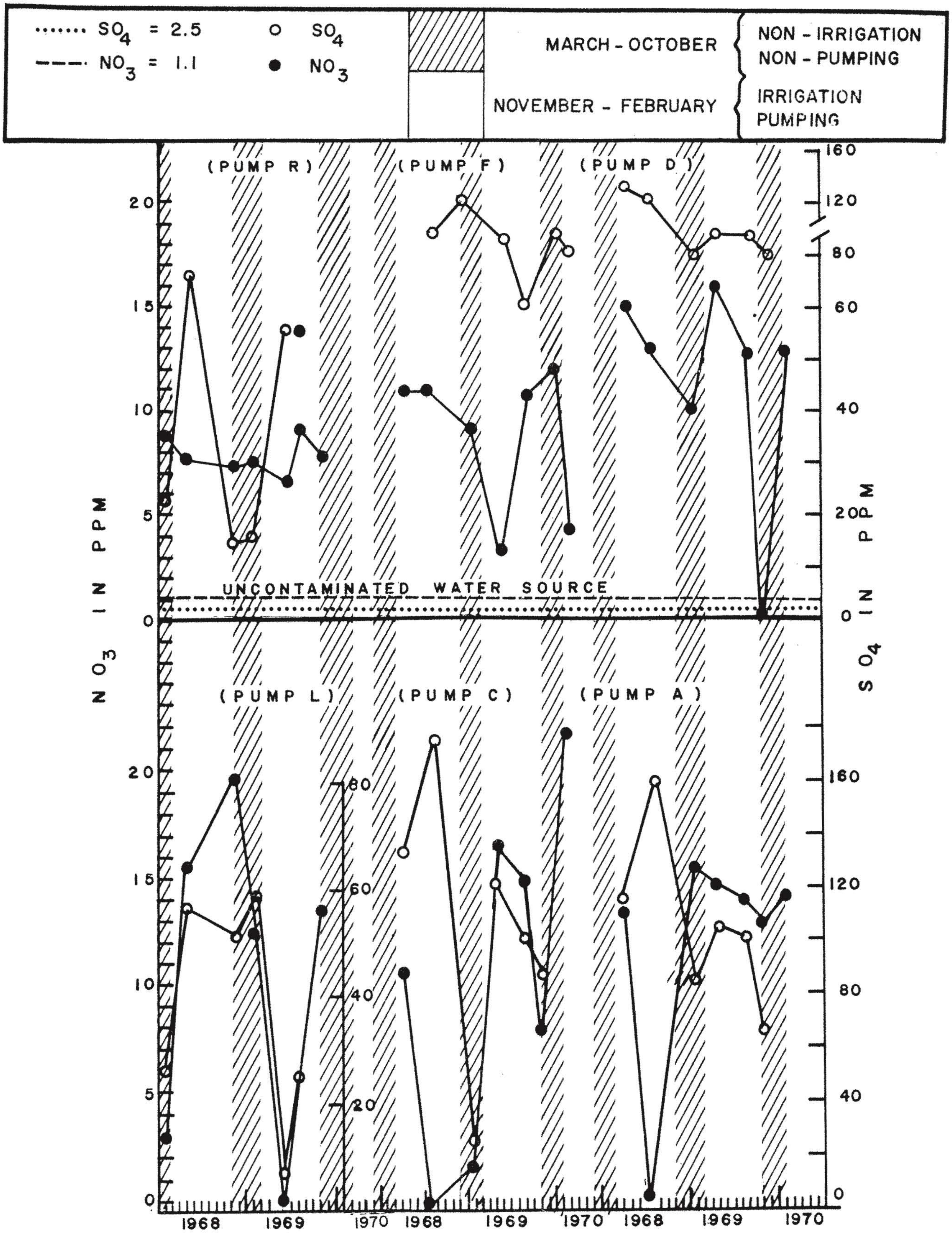

FIGURE 7. VARIATION OF NITRATE AND SULFATE WITH TIME IN PIONEER MILL WELLS.

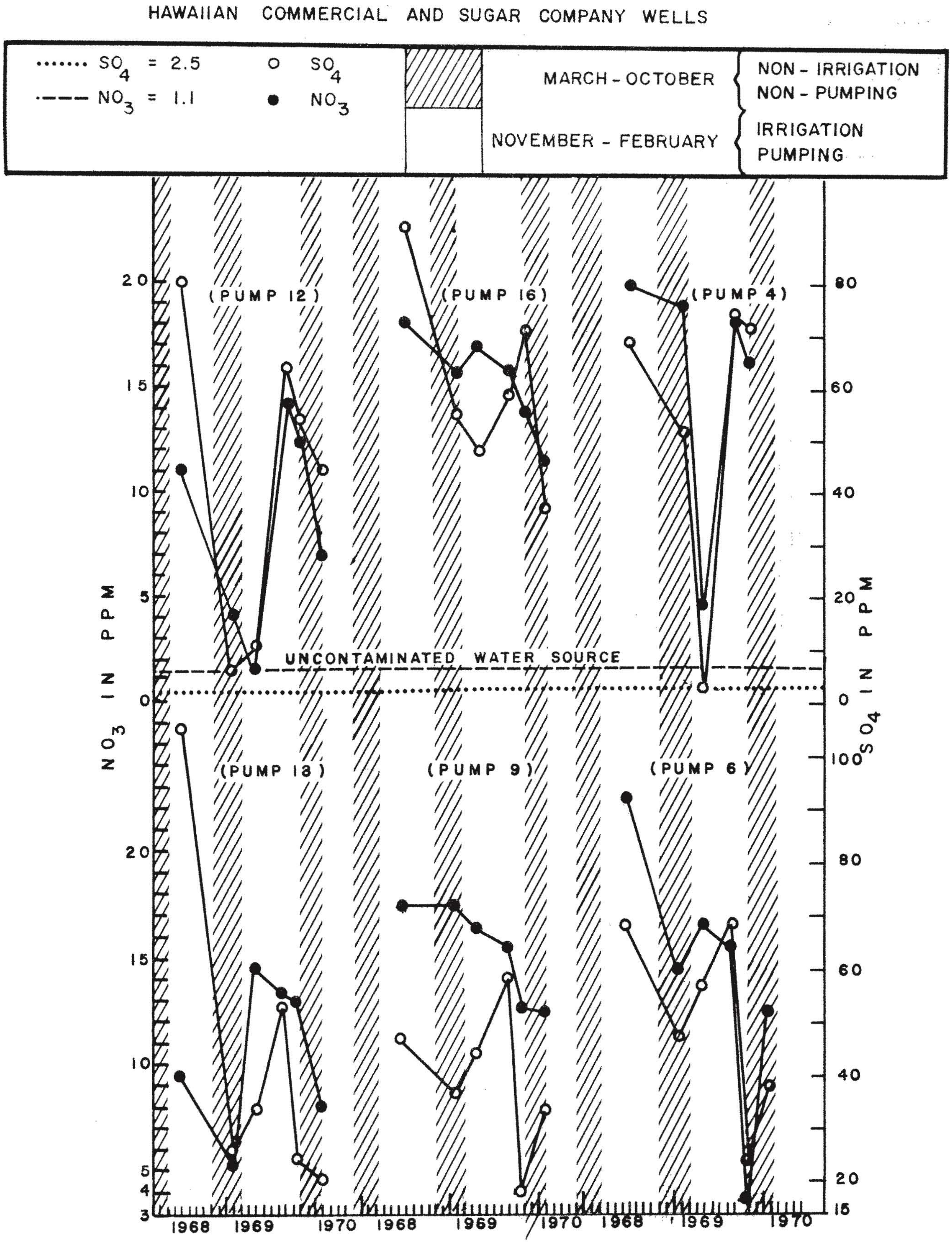

FIGURE 8. VARIATION OF NITRATE AND SULFATE WITH TIME IN HC&S WELLS.

were encountered during normally wet seasonal periods and low values found during normally dry seasonal periods and, consequently, irrigation periods. The correspondence between high values and excessive pumping during dry periods is much more noticeable in the Maui plantation wells than in the Kahuku wells which generally showed the opposite trend. In Kahuku, where the depth to the point of withdrawal of basal water from the land surface averages about 200 to 300 feet, high nitrate and sulfate values were observed several months after the actual periods of pumping and irrigation. In contrast, the wells at both plantations in Maui show a much more rapid increase, although not instantaneous, of the index constituents following periods of pumping and irrigation. This difference is probably due to the shorter recycling time of the irrigation water on Maui because of the relatively shallow depth to the water table as compared to that at Kahuku Plantation. In some of the wells, this trend is not readily observed; instead, an erratic pattern is more common. The pattern depicted in the graphs for the Maui plantations roughly indicates a correlation of seasonal variations of nitrate and sulfate to irrigation practices. Six factors that may have a direct influence on the time it takes the irrigation water to reach the ground-water table are 1) amount of natural recharge and irrigation water entering the basal water body, 2) aquifer permeability, 3) depth to the water table, 4) depth of well penetration with respect to thickness of the return irrigation water and thickness of the fresh water lens, 5) hydrogeologic relationships of area, and 6) amount of pumping.

The extremely large difference of the index constituents, especially nitrate, found at the Maui sites and that found at Kahuku were probably due to the greater depth to the basal aquifer at Kahuku rather than to differences in the amount of fertilizer applied or the pumping pattern. Comparatively lower values were also found in the Pearl Harbor-Waipahu wells studied (Tenorio, *et al.*, 1969) where well depth into the basal aquifer were generally comparable to that in Kahuku.

The behavior of sulfate infiltrating to the ground-water table followed the general pattern described previously for nitrate. In general, the sulfate content of the water samples decreases correspondingly to the increase in the depth from which the samples were taken. A more noticeable variation showing sulfate reduction with relation to depth in the well can be seen in the Kahuku and Pearl Harbor-Waipahu areas.

Index constituent values for Well Nos. 348 and 356 in Kahuku are persistently low and indicate a complete absence of irrigation return water in these two non-pumping wells. They were bored to relatively shallow depths in the coastal plain caprock and the index constituent values obtained are considered to be unreliable. Previous findings in the Pearl Harbor-Waipahu area by Tenorio, *et al.*, (1969) in Well No. T-241, which taps the caprock water, showed appreciable amounts of the index constituents at the various depths sampled. A possible explanation for the low indices obtained in the Kahuku wells could be the manner in which samples were obtained. It is possible that the samples obtained at Well Nos. 348 and 356 were not representative of the actual ground water as they were taken from the top of the well casings and sufficient time was not allowed for water to flow from the lower portion of the well.

Areal distribution of nitrate and sulfate, in relation to well locations in the three areas, are depicted in Figures 1, 4, and 5. The distribution in Pioneer Mill and HC&S wells are easily delineated and appear to be continuous and uniform over the sugar cane fields. The distribution for Kahuku appears to be less clearly related to areas of cane cultivation.

In general, the index constituents at Pioneer Mill are lowest to the north and west toward the dike and basal water hydrologic boundary, as shown by values from Well Nos. R and M. This trend was expected as these two wells are upgradient from the principal irrigated fields and also in close proximity to the principal perennial streams in the area, which are zones of natural recharge.

The bar graphs, depicting the distribution of the index constituents in the wells in relation to sampling periods, indicated even more clearly a distinct presence of irrigation return water associated with agricultural practices in the basal aquifer and its influence on water quality.

HC&S WELLS. Figures 9 to 15 show the distribution of the index constituents in the HC&S wells. The graphs show that the overall basal water quality of this area is influenced most by irrigation and agricultural practices. The high nitrate values may be virtually all

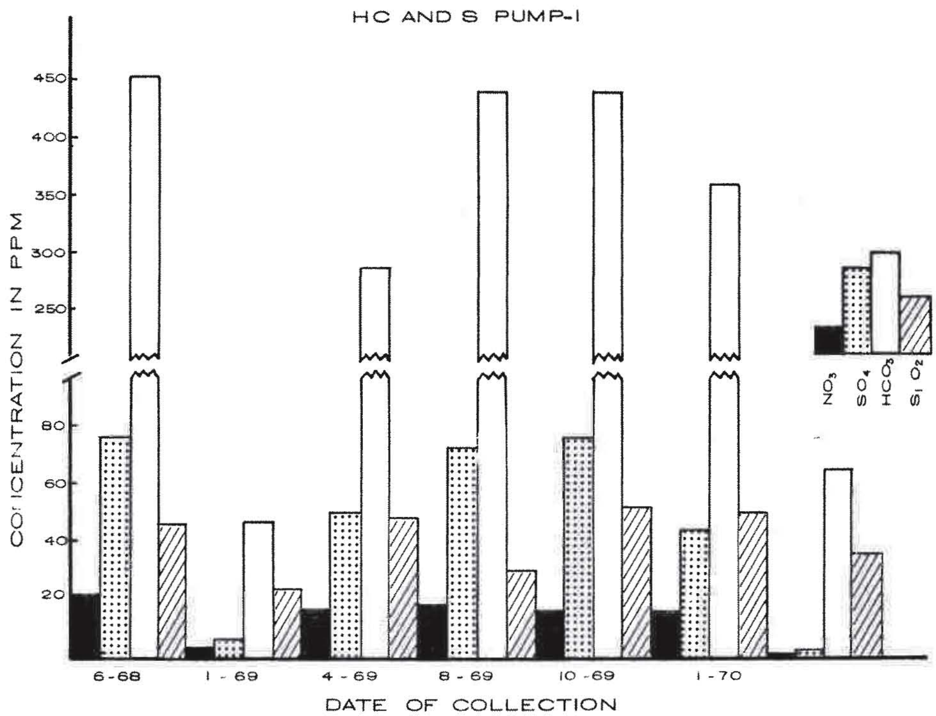

FIGURE 9. VARIATION OF INDEX CONSTITUENTS WITH IRRIGATION AND NON-IRRIGATION PERIODS IN THE HC&S PUMP 1.

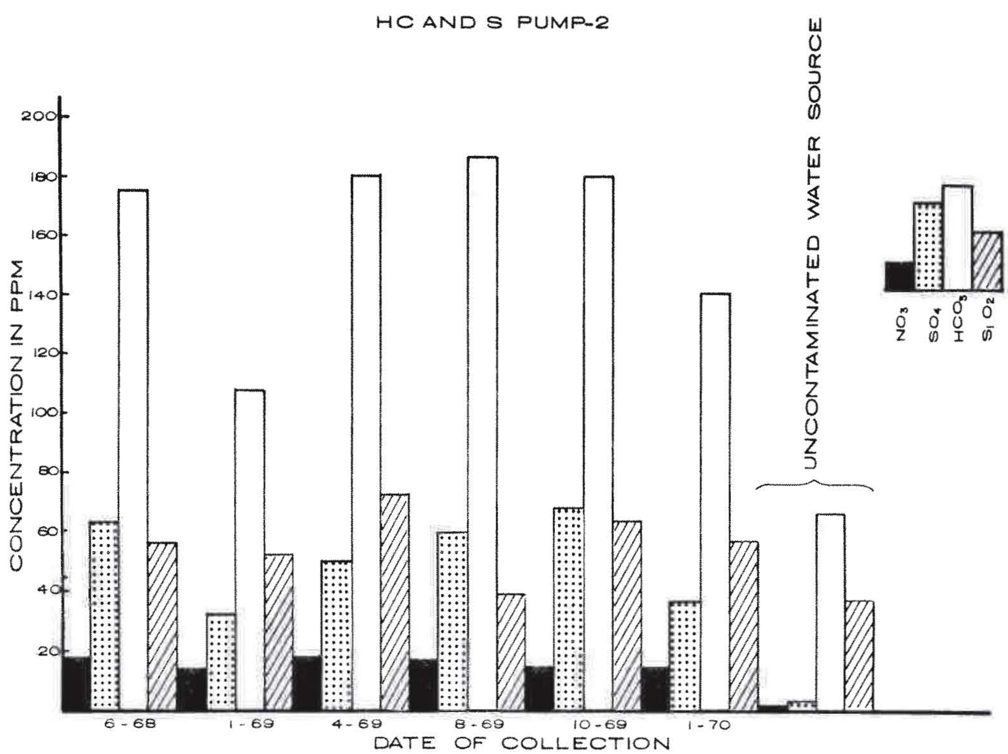

FIGURE 10. VARIATION OF INDEX CONSTITUENTS WITH IRRIGATION AND NON-IRRIGATION PERIODS IN THE HC&S PUMP 2.

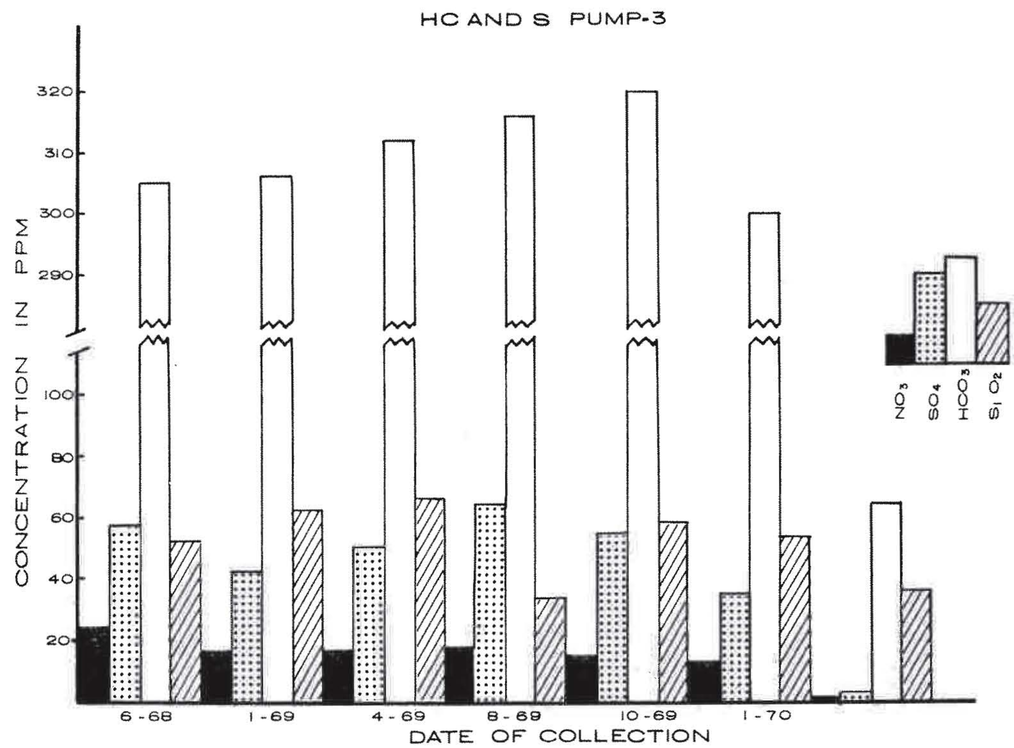

FIGURE 11. VARIATION OF INDEX CONSTITUENTS WITH IRRIGATION AND NON-IRRIGATION PERIODS IN THE HC&S PUMP 3.

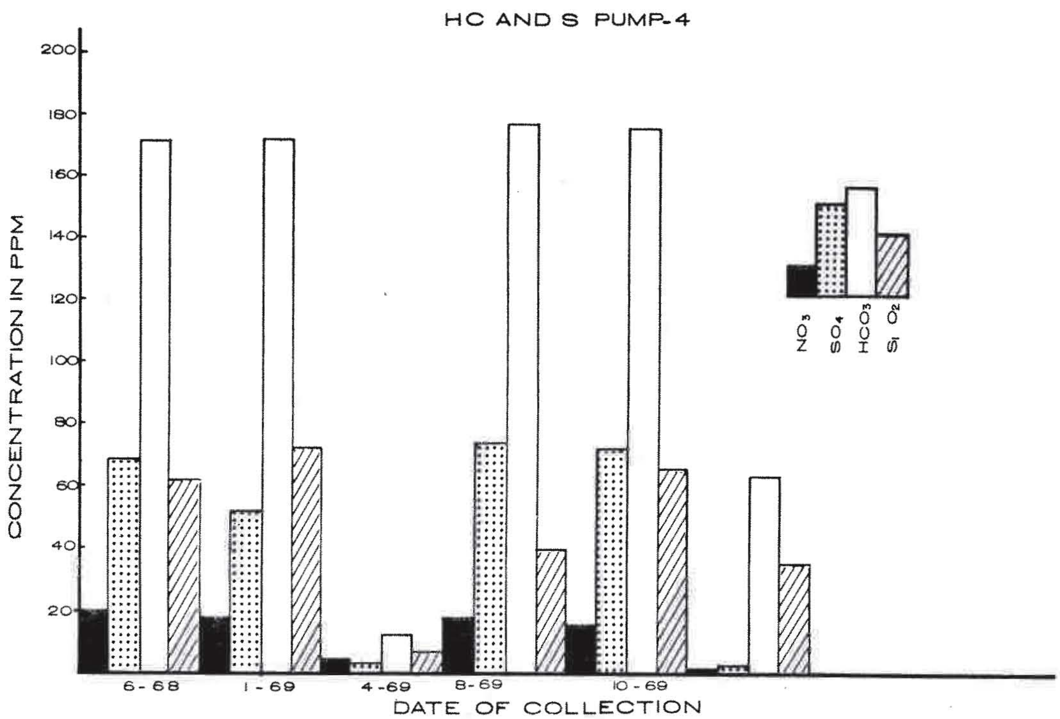

FIGURE 12. VARIATION OF INDEX CONSTITUENTS WITH IRRIGATION AND NON-IRRIGATION PERIODS IN THE HC&S PUMP 4.

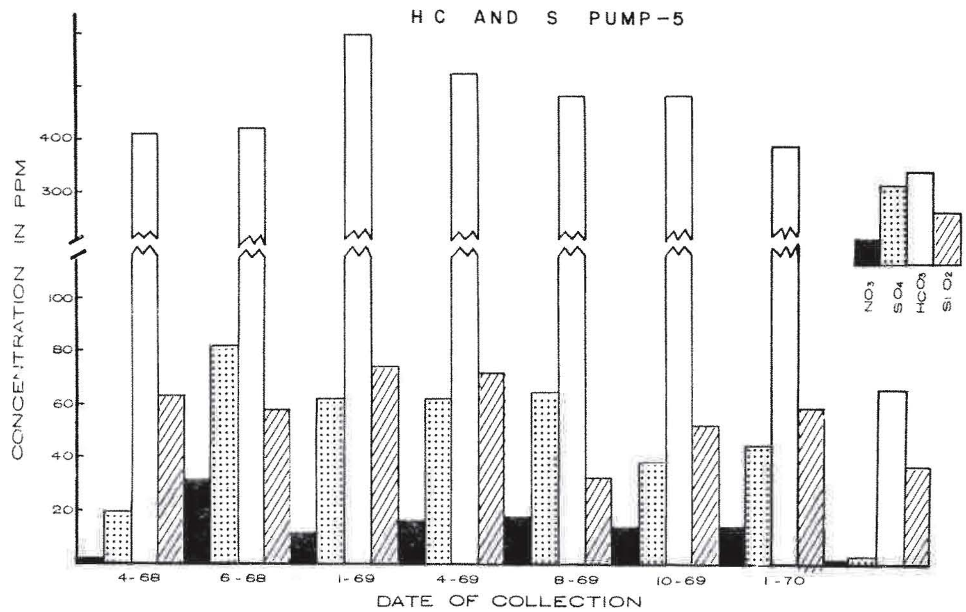

FIGURE 13. VARIATION OF INDEX CONSTITUENTS WITH IRRIGATION AND NON-IRRIGATION PERIODS IN THE HC&S PUMP 5.

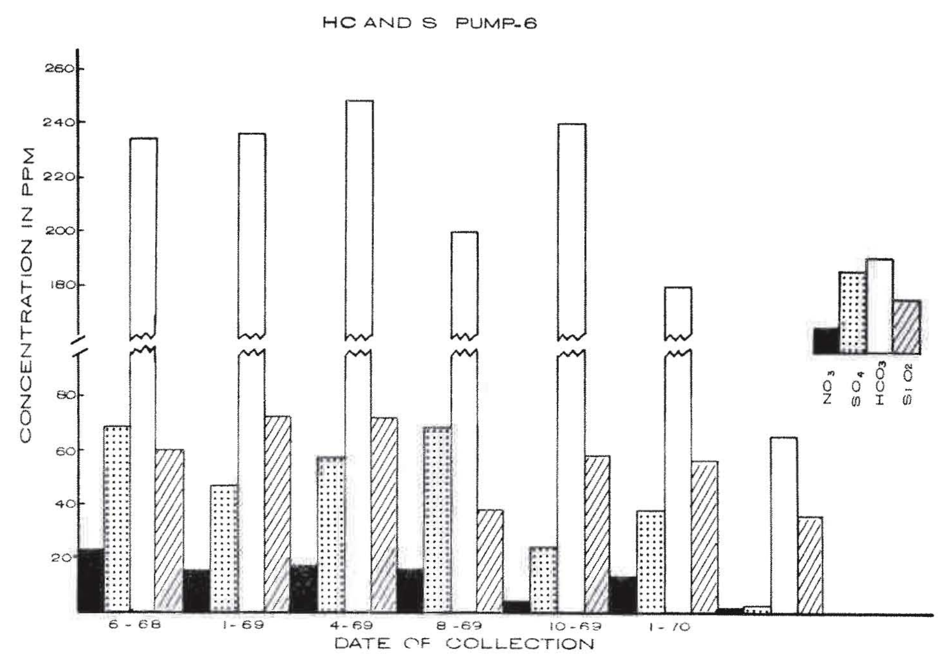

FIGURE 14. VARIATION OF INDEX CONSTITUENTS WITH IRRIGATION AND NON-IRRIGATION PERIODS IN THE HC&S PUMP 6.

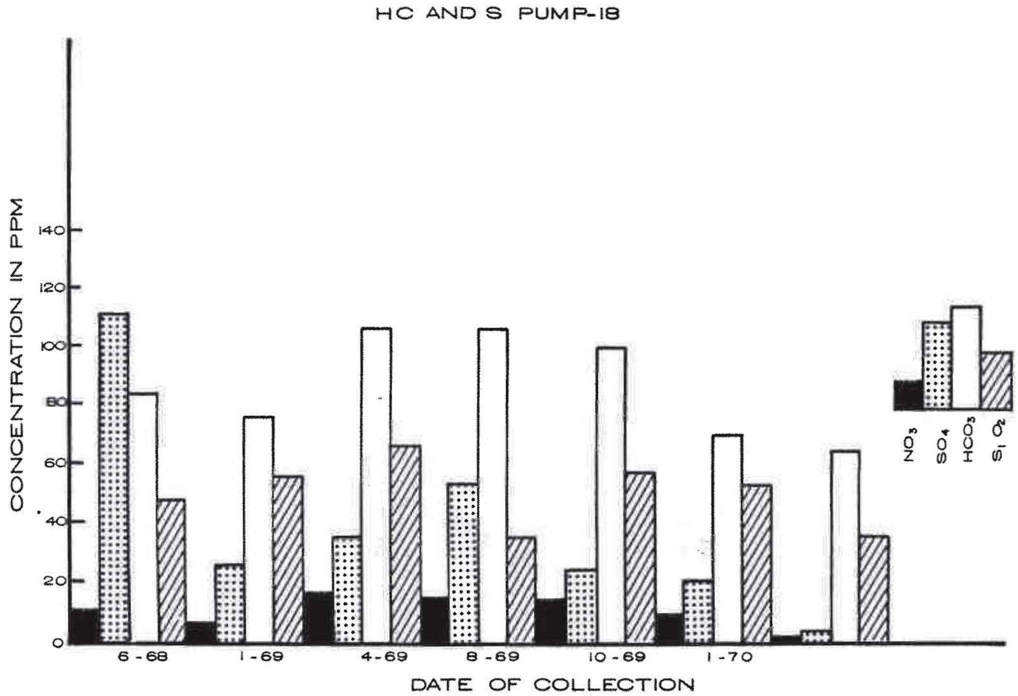

FIGURE 15. VARIATION OF INDEX CONSTITUENTS WITH IRRIGATION AND NON-IRRIGATION PERIODS IN THE HC&S PUMP 18.

attributed to contributions from the fertilizer applied on the fields. The presence of high sulfate values may be attributed partly to fertilizer application and partly to the presence of intruded water as evidenced by the generally high chloride content of the water in most of the wells. The exceptionally high bicarbonate content is most probably caused by the frequent recycling which tends to accelerate the reaction of water with organic matter, the soil horizon, and underlying materials, principally the calcareous sediments. The silica content of the water is fairly uniform but shows some seasonal variation and this may be the effect of water recycling and fertilizer application according to Visher and Mink (1964). Extremely high values of silica are found in some wells in the HC&S fields as well as at the Pioneer Mill and Kahuku plantations. These high values could be the result of silica addition as explained by Davis (1969), probably contributed partly by leaching of burned sugar cane material and partly by other dissolved silica sources applied over the fields.

It is shown from the series of bar graphs that the effects of dilution by fresher water sources, such as the surface water diverted from dikes and streams and from precipitation, are masked by the apparently greater influence of the underlying sea-water intruded basal water on the quality of irrigation water.

In general, the most persistently high values found, in decreasing order of magnitude, are bicarbonate, silica, sulfate, and nitrate. This distribution follows the normal concentration pattern found in uncontaminated water sources, although the values in the HC&S wells are considerably higher. The index constituents for uncontaminated water are included in each bar graph for comparison.

PIONEER MILL WELLS. The distribution of the index constituents found in the Pioneer Mill wells (Figs. 16-20) follows the trend found in the HC&S wells. However, the magnitude of the sulfate index is generally higher than that found in the HC&S wells. The high sulfate content may be due to irrigation and fertilization practices, as in the case of the HC&S wells, and also to sea water intrusion, as is evident by the high chloride content of most of the water samples which were analyzed. The nitrate content of water samples from Pioneer Mill is generally lower than that from HC&S, but it is considerably higher than that found in uncontaminated water. The relatively lower nitrate values in the water samples from Pioneer Mill wells, as compared to those from the HC&S wells, may be due to the greater amount of surface and dike-water available for dilution and to the comparatively rapid flushing effect of the topmost portion of the lens in the Pioneer Mill area. The latter area has a steeper hydraulic gradient, averaging about two feet per mile, as compared to an average of one foot per mile in the HC&S area. The high bicarbonate content of the water probably reflects frequent recycling and reaction with the vegetative mantle, the soil, and rock materials.

A bar graph of the index constituents found in water from a pond which collects surface runoff from irrigated fields as well as shallow subsurface flow is shown in Figure 21. The graph may reflect typical concentrations of the index constituents before the water infiltrates into the ground-water body. The bicarbonate content is particularly high and is suggestive of effects of recycling and accelerated reaction of the water with the soil and vegetative mantle at the initial period of irrigation water application onto the fields. A bar graph of the

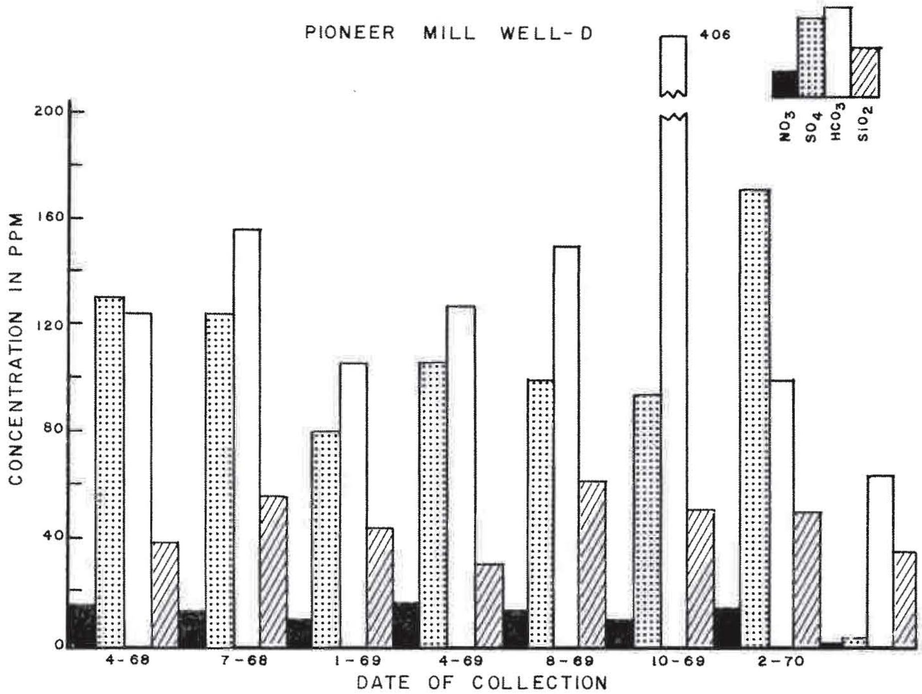

FIGURE 16. VARIATION OF INDEX CONSTITUENTS WITH IRRIGATION AND NON-IRRIGATION PERIODS IN PIONEER MILL WELL D.

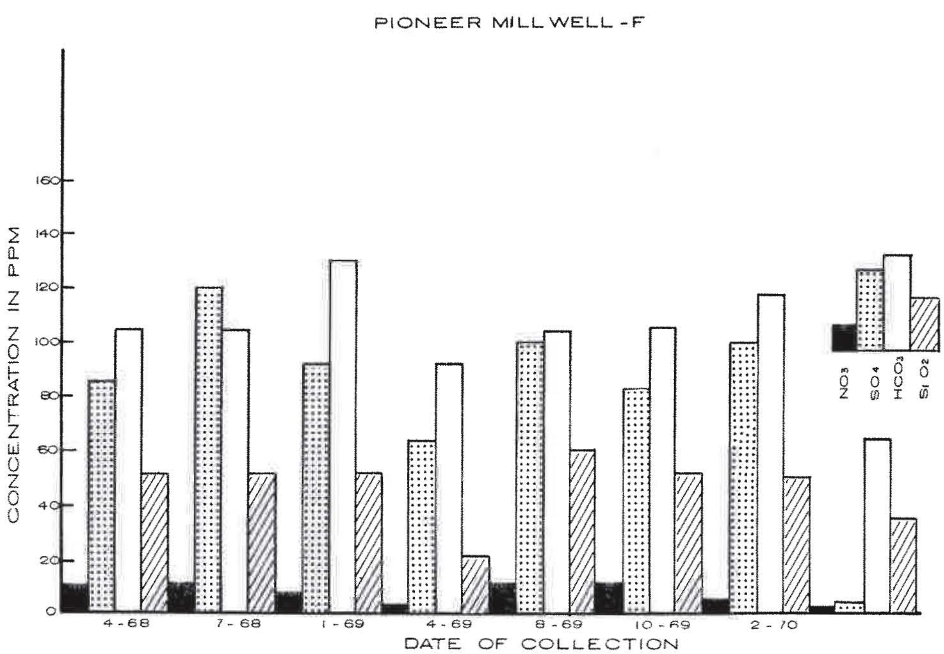

FIGURE 17. VARIATION OF INDEX CONSTITUENTS WITH IRRIGATION AND NON-IRRIGATION PERIODS IN PIONEER MILL WELL F.

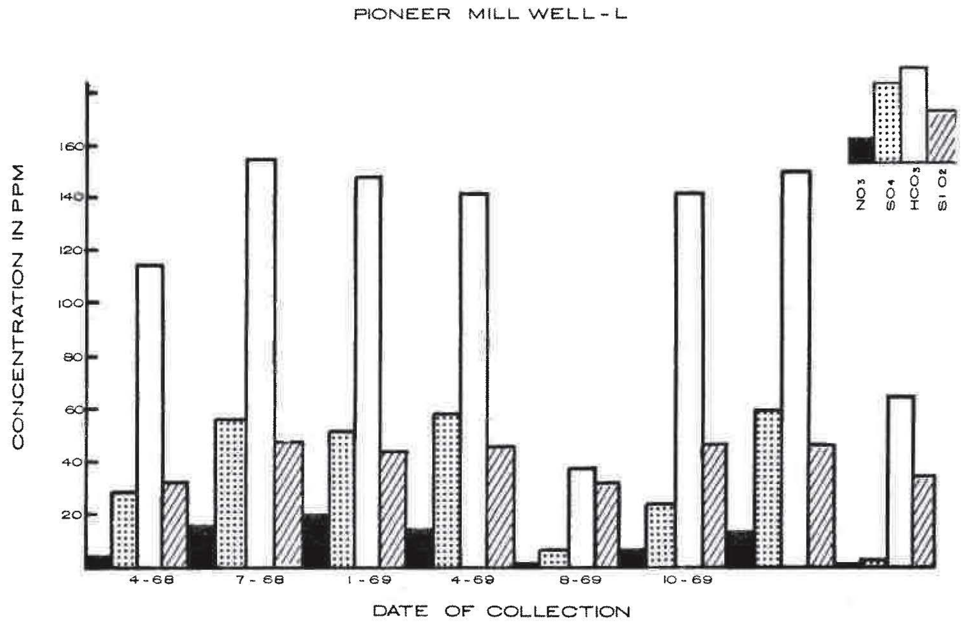

FIGURE 18. VARIATION OF INDEX CONSTITUENTS WITH IRRIGATION AND NON-IRRIGATION PERIODS IN PIONEER MILL WELL L.

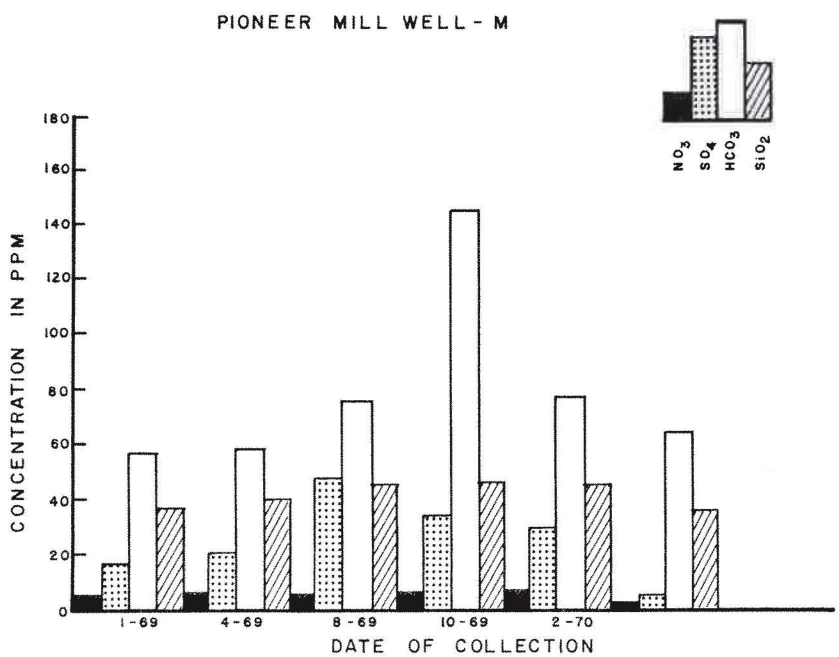

FIGURE 19. VARIATION OF INDEX CONSTITUENTS WITH IRRIGATION AND NON-IRRIGATION PERIODS IN PIONEER MILL WELL M.

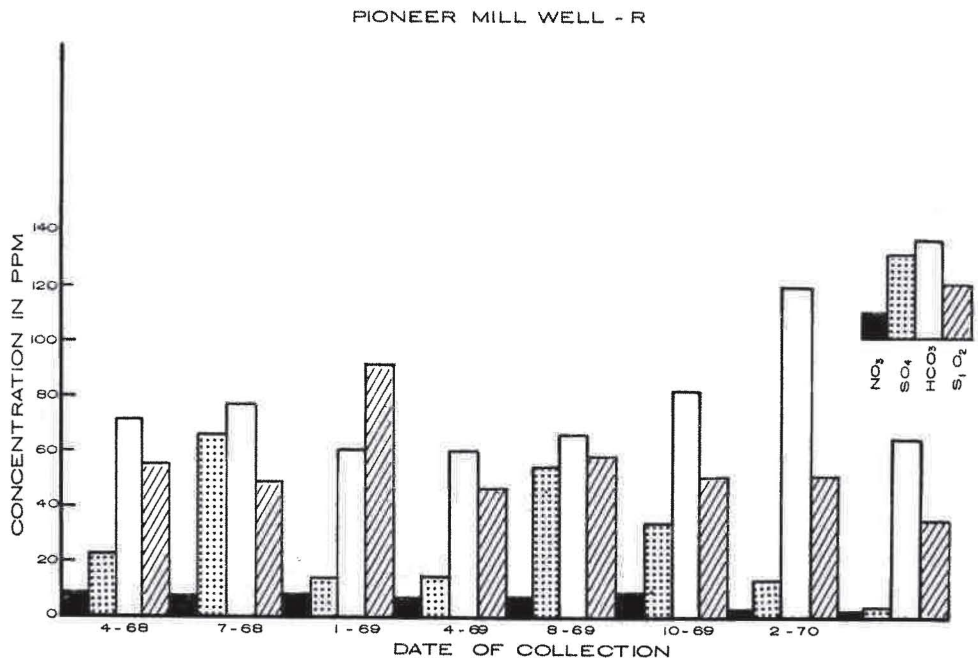

FIGURE 20. VARIATION OF INDEX CONSTITUENTS WITH IRRIGATION AND NON-IRRIGATION PERIODS IN PIONEER MILL WELL R.

index constituents of a domestic well (Mokuhau), located in a cane-field, generally reflecting high quality is given in Figure 22. The distribution of silica in the wells again shows a nearly uniform and unchanging trend, although in the Pioneer Mill wells, the mean silica value is lower than that found in the HC&S wells.

KAHUKU PLANTATION WELLS. The index constituents found in Kahuku, depicted in Figures 23 to 26, show a general agreement in trends with the two areas in Maui. However, the magnitude of the indices is comparatively lower with the exception of silica whose mean value for this area is intermediate in range between the two areas previously discussed. Because of the presumably identical practices in agricultural management for the profitable production of sugar in the three areas, the great difference in magnitude of the index constituents, especially of nitrate and sulfate, is not readily explainable. Irrigation areas underlain by basalt is small compared to caprock areas of Kahuku. Water applied to caprock areas is recycled within the caprock or discharged out to sea.

A possible explanation for high index values on Maui is related to

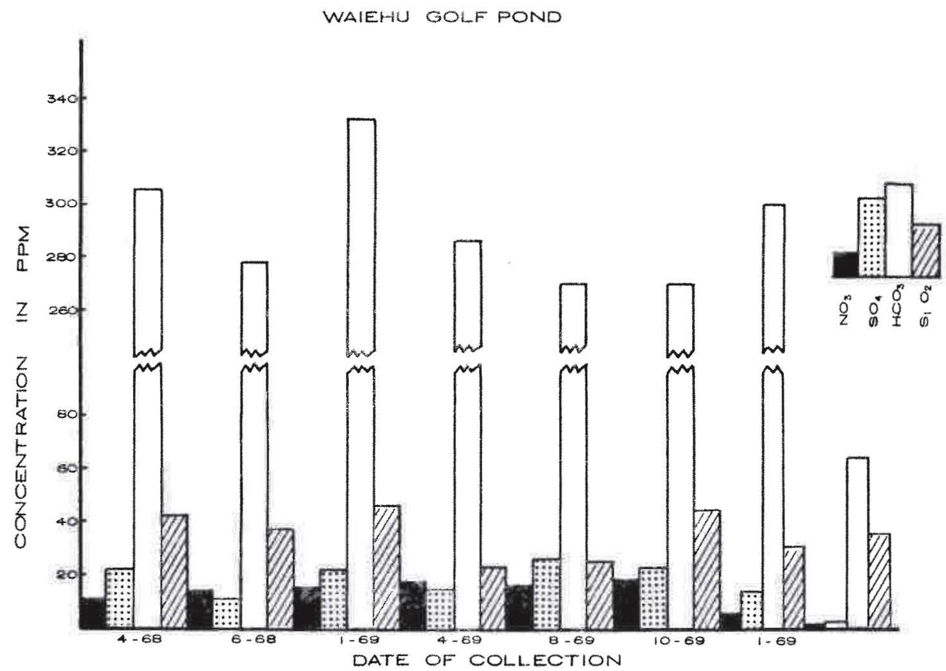

FIGURE 21. VARIATION OF INDEX CONSTITUENTS WITH TIME IN WAIEHU GOLF COURSE IRRIGATION POND, WAILUKU COMPANY PLANTATION, MAUI.

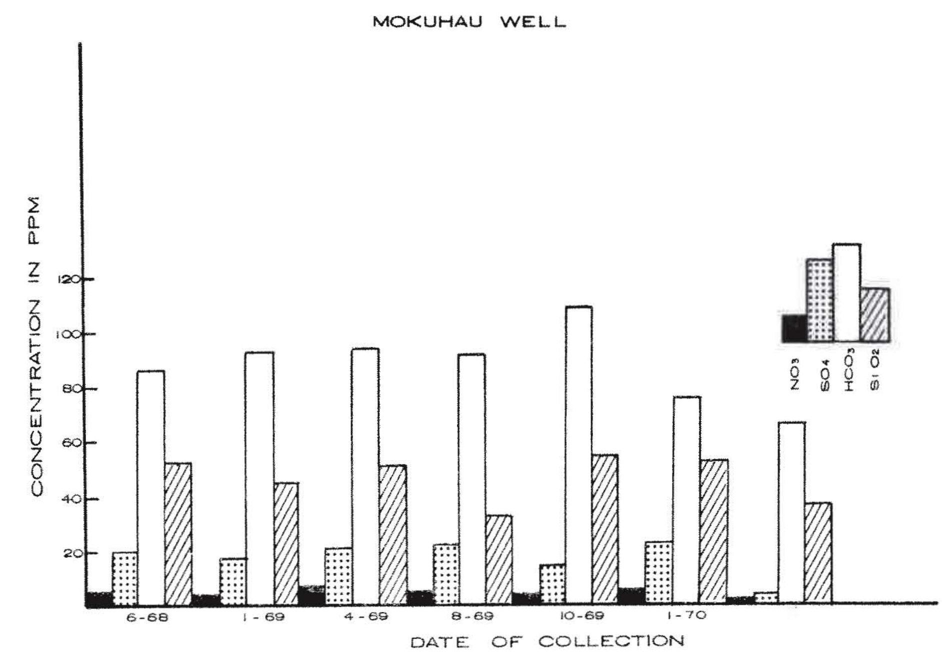

FIGURE 22. VARIATION OF INDEX CONSTITUENTS WITH TIME IN MAUI COUNTY BOARD OF WATER SUPPLY MOKUHAU WELL.

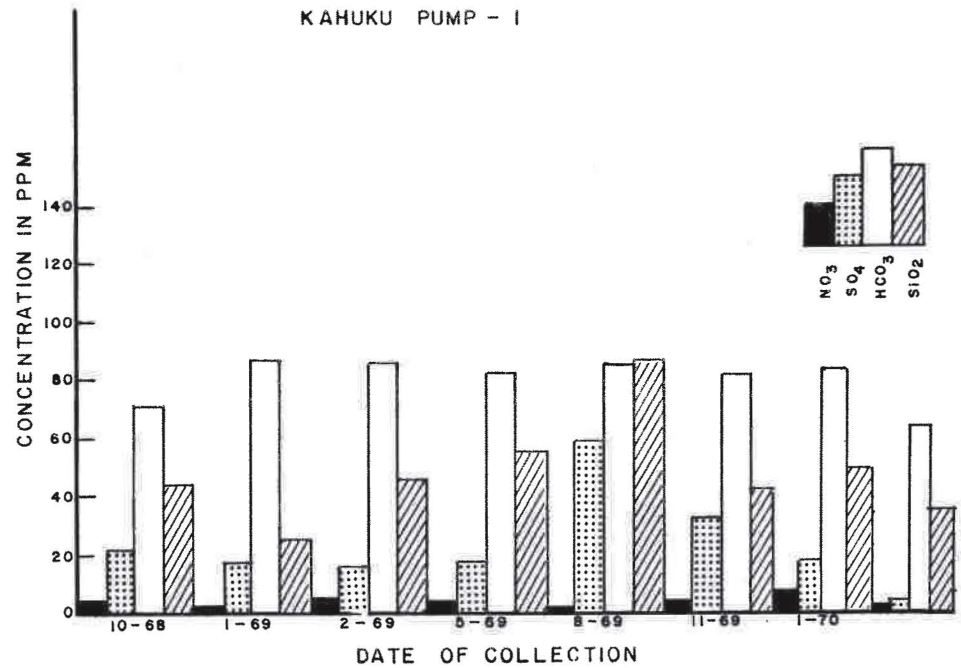

FIGURE 23. VARIATION OF INDEX CONSTITUENTS WITH IRRIGATION AND NON-IRRIGATION PERIODS IN KAHUKU PUMP 1.

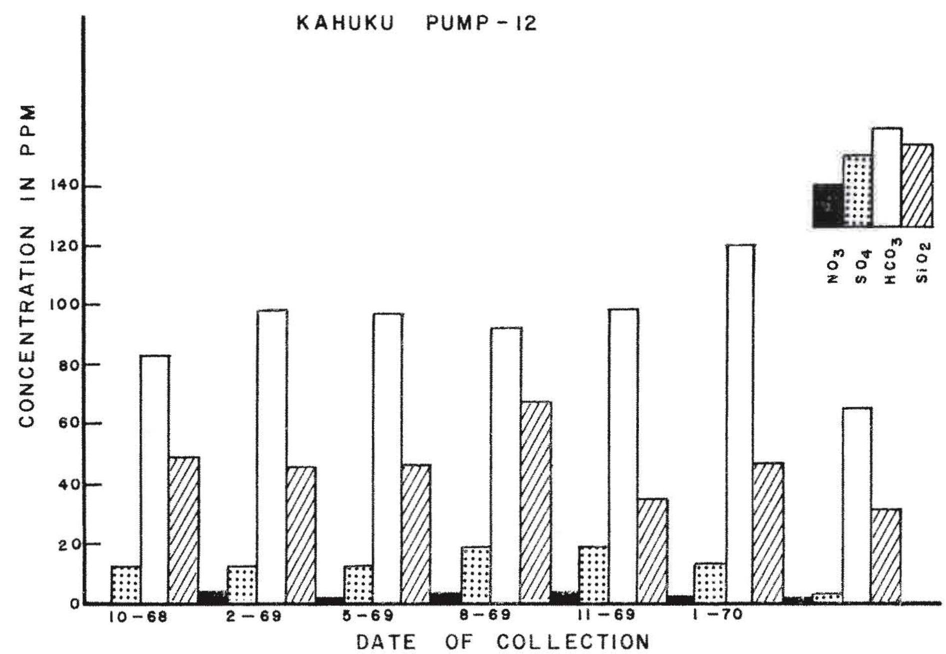

FIGURE 24. VARIATION OF INDEX CONSTITUENTS WITH IRRIGATION AND NON-IRRIGATION PERIODS IN KAHUKU PUMP 12.

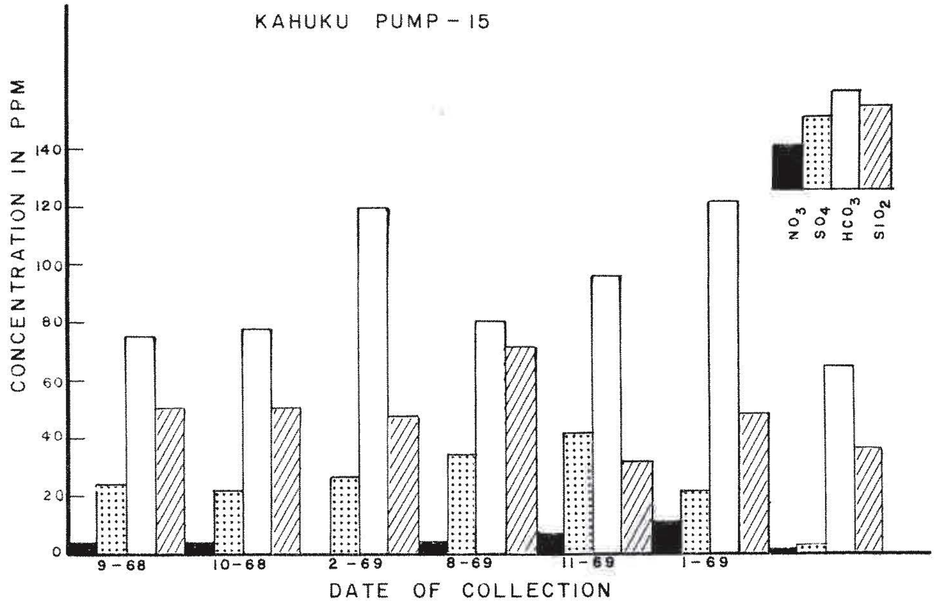

FIGURE 25. VARIATION OF INDEX CONSTITUENTS WITH IRRIGATION AND NON-IRRIGATION PERIODS IN KAHUKU PUMP 15.

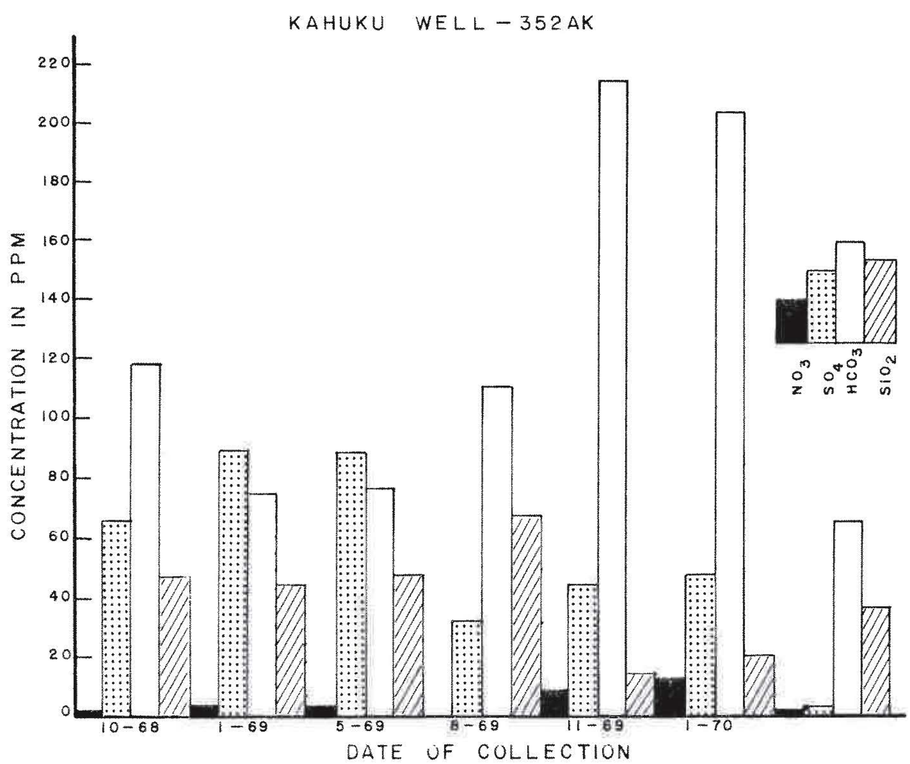

FIGURE 26. VARIATION OF INDEX CONSTITUENTS WITH IRRIGATION AND NON-IRRIGATION PERIODS IN KAHUKU WELL 352-AK (PUMPS 5, 11).

the greater flushing of the upper portion of the basal water lens, as suggested previously for the Pioneer Mill area, in which flatter hydraulic gradients associated with little or no caprock promotes faster seaward movement of the ground water. This greater ground-water movement may be especially apparent at the topmost portion of the basal lens where irrigation water has been presumed to be present, thus being reflected by the composition of samples taken in this study which generally were from the top of the lens at the two Maui plantations.

In Kahuku, water samples were collected below the water table, normally at the end of the casing or intake points well below the top of the basal lens. Takasaki and Valenciano (1969) have shown the decreasing trend of the nitrate content in the Kahuku wells in relation to increasing depth below the water table. This is shown in Figure 27. Similar results were reported in studies of nitrate distribution with depth in the Pearl Harbor-Waipahu wells of southern Oahu by Tenorio, *et al.* (1969). A comparison of index constituents found in wells and springs in the Pearl Harbor-Waipahu region with those in Kahuku and Maui wells is shown in Figure 28.

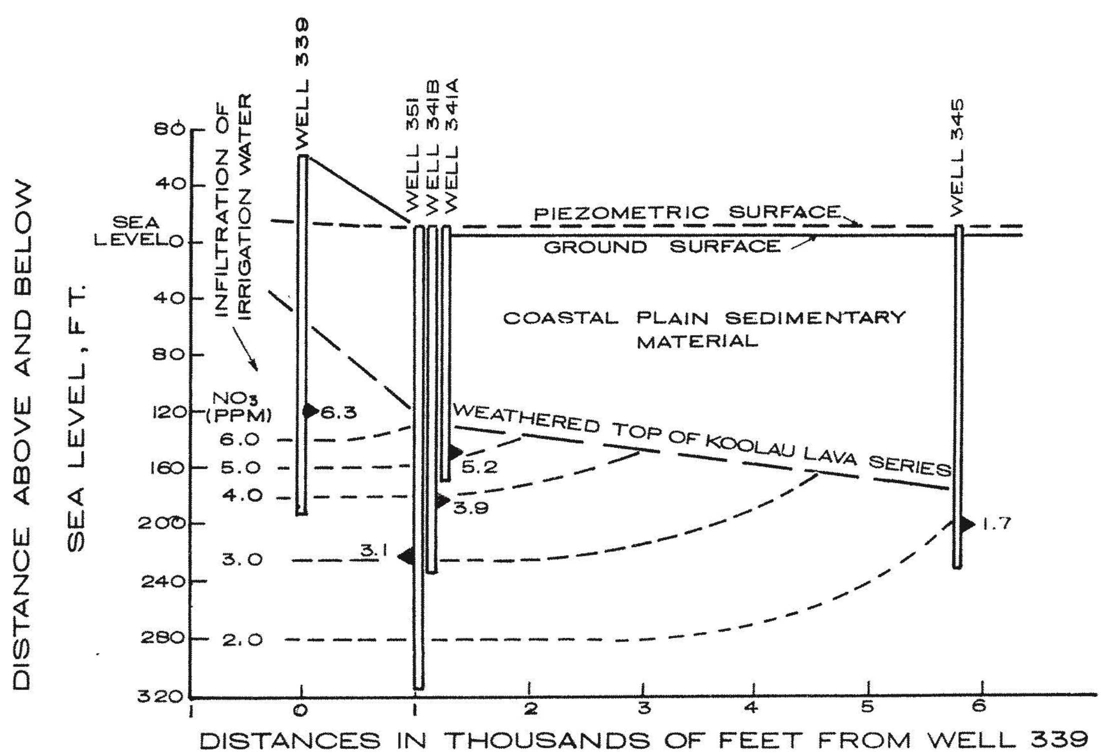

FIGURE 27. DISTRIBUTION OF NITRATE WITH DEPTH IN KAHUKU WELLS (REDRAWN FROM TAKASAKI AND VALENCIANO, 1969).

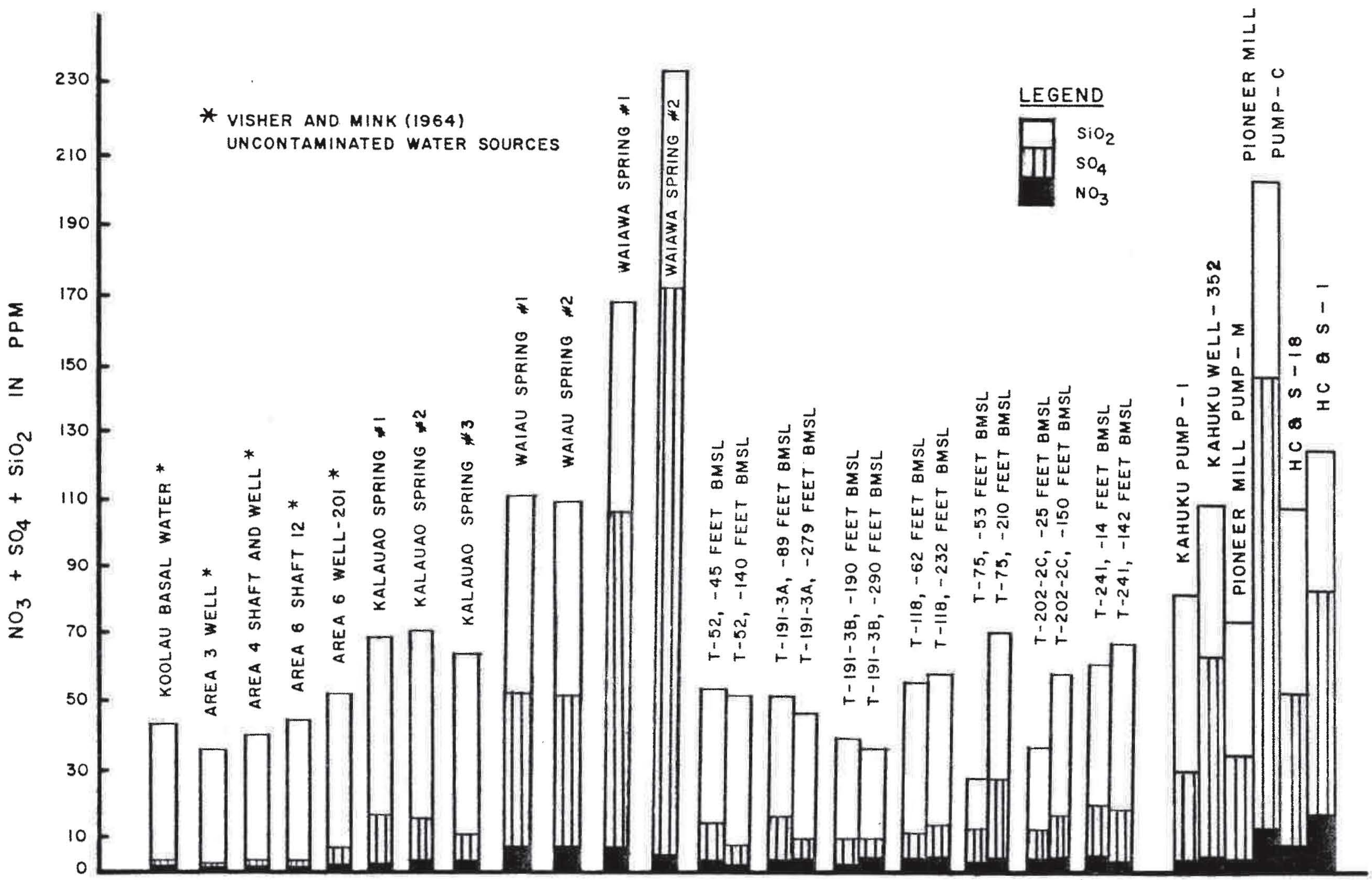

FIGURE 28. AVERAGE INDEX CONSTITUENTS IN UNCONTAMINATED WATER SOURCES AS COMPARED TO SPRING AND WELL SOURCES FROM SOUTHERN OAHU AND KAHUKU PLANTATIONS, AND PIONEER MILL AND HAWAIIAN COMMERCIAL AND SUGAR COMPANY PLANTATIONS ON MAUI. (REDRAWN FROM TENORIO, YOUNG, AND WHITEHEAD, 1969.)

HYDROLOGY IN RELATION TO RETURN IRRIGATION WATER

Kahuku Area

Because of the complex effects of the caprock on the ground-water regime in the Kahuku area, it is difficult to predict with certainty the natural movement of ground water within and between ground-water compartments overlain by caprock. Basal water and dike water, confined and unconfined, constitute the principal bodies of fresh water occurring in the Kahuku region. The retarding effect of the caprock against the free escape of fresh water from the water body has caused the dike water level to rise to a head of 20 feet above sea level. Because of this effect, the fresh-water body may develop to as much as 800 feet below sea level according to the Ghyben-Herzberg principal. Water levels in the basal water area is much less.

In general, ground-water movement in the Kahuku area is controlled by three principal factors: 1) the amount of recharge and discharge, 2) the ground-water gradients within each dike compartment and the presence of caprock on the dike compartments and the basal aquifer, and 3) by artificial discharge imposed on the basal water body of each area.

Geologic and well-log information previously obtained from studies by Stearns and Vaksvik (1935, 1938), Stearns (1940), and Takasaki and Valenciano (1969) have been extensively used in the determination of the areal extent of the principal hydrologic units, the depth of the caprock formation, and the depths and logs of wells.

Figure 29 shows the movement of ground water to be generally in a northerly direction discharging as natural flows at coastal springs, swampy areas, and leaks in the caprock and as artificial discharge by pumping for irrigation and domestic water uses. Pumping appears to impose the greatest influence on the preferred direction of flow of the ground water as is shown by the steepness of the water table gradient near major pumping wells, such as Pump Nos. 351, 352, and 353. Because of the incompleteness of water level information, it is difficult to construct an accurate natural ground water table map and, hence, to precisely identify the effect of each factor on the movement of ground

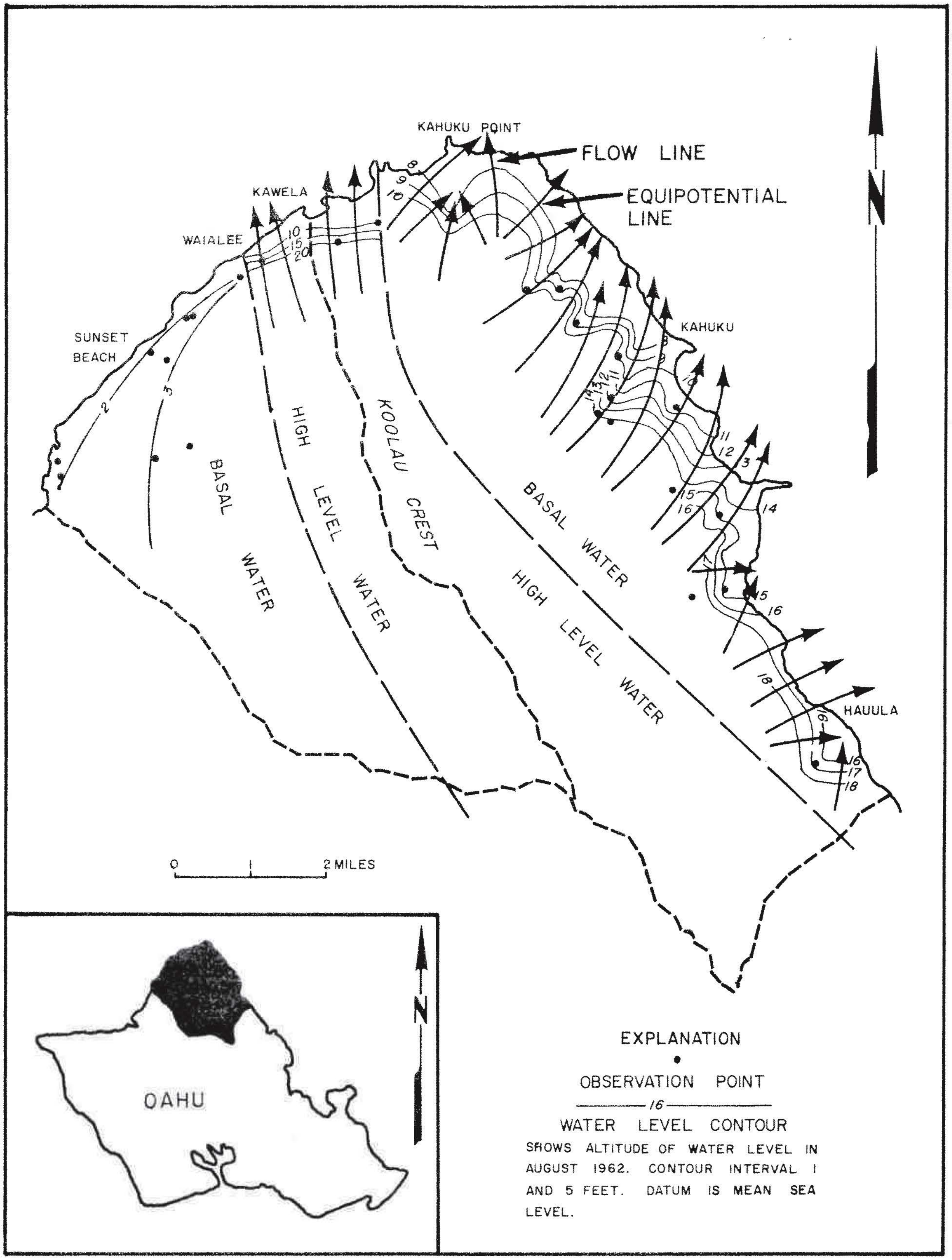

FIGURE 29. GENERALIZED FLOW NET DIAGRAM OF THE KAHUKU GROUND-WATER BASIN (GROUND-WATER OCCURRENCE OF WATER LEVEL DATA FROM TAKASAKI, VALENCIANO, AND HO, 1966).

water. It appears, however, that where intensive pumping for irrigation is taking place, the natural water table contours are influenced by that practice.

Figure 29 indicates a close correlation between the effect of natural hydrogeologic elements and that of pumping on the movement of ground water, suggesting the possible migration of chemical constituents to points of excessive artificial discharge. This relationship is shown by the generally greater values for index constituents as well as other constituents found in the heavily pumped wells as compared to other artificial discharge points in adjacent areas which are not so heavily pumped. In general, as in the panel diagrams shown in Figure 30, the presence of irrigation water as measured by the magnitude of the index constituents is most marked in the heavily pumped areas and appears to be channeled toward the central area of the Kahuku study area in the vicinity of Pump Nos. 351, 352, and 353. The magnitude of the index constituents decreases in proportion to their distance away from the central area. The largest concentrations of the index constituents are found in an area approximately bounded by Well No. 337-1 to the north and Well No. 353 (Pump 1) to the south.

The largest chloride values were also generally found in the heavily pumped wells, especially Well Nos. 351, 339, and 352, indicating that intruded water brought about by excessive pumping is also affecting the area. Figures 31 to 32 show a cross-section of well locations in relation to the coast and areas of irrigation. The high index values caused by irrigation practices tend to verify previous hydrologic assumptions that ground water is diverted to the vicinity of the heavily pumped wells which also show the steepest water table gradients throughout the area. The distribution of index constituents with depth and distance from the shore is given in the bar graphs (Fig. 30) which were plotted from data compiled by Takasaki and Valenciano (1969). Values of some of the index constituents for June 1956 and August 1964 were plotted in Figures 31 to 32 for comparison with the present study. Earlier values generally were noted to be smaller than those values found during the present study. Nitrate values show the greatest variation, indicating an appreciable increase over earlier concentrations. Increases in the other indices are also quite noticeable, however, the effects of irrigation and

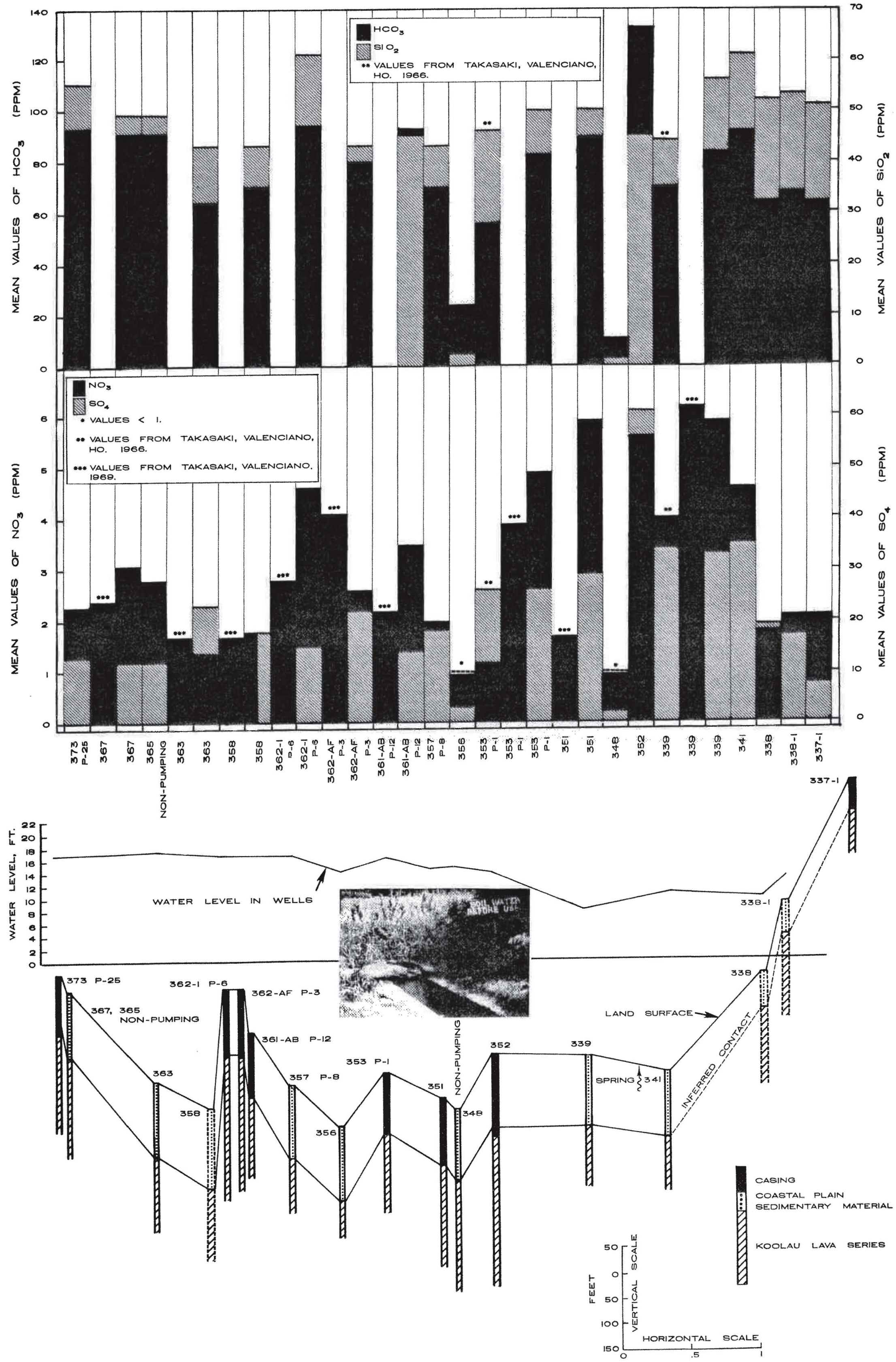

FIGURE 30. GENERALIZED GRAPHIC WELL LOGS AND PANEL DIAGRAM OF BASAL AQUIFER SYSTEM (SOUTH TO NORTH) WITH MEAN VALUES (PPM) OF INDEX CONSTITUENTS OF COMPOSITE WATER SAMPLES IN KAHUKU.

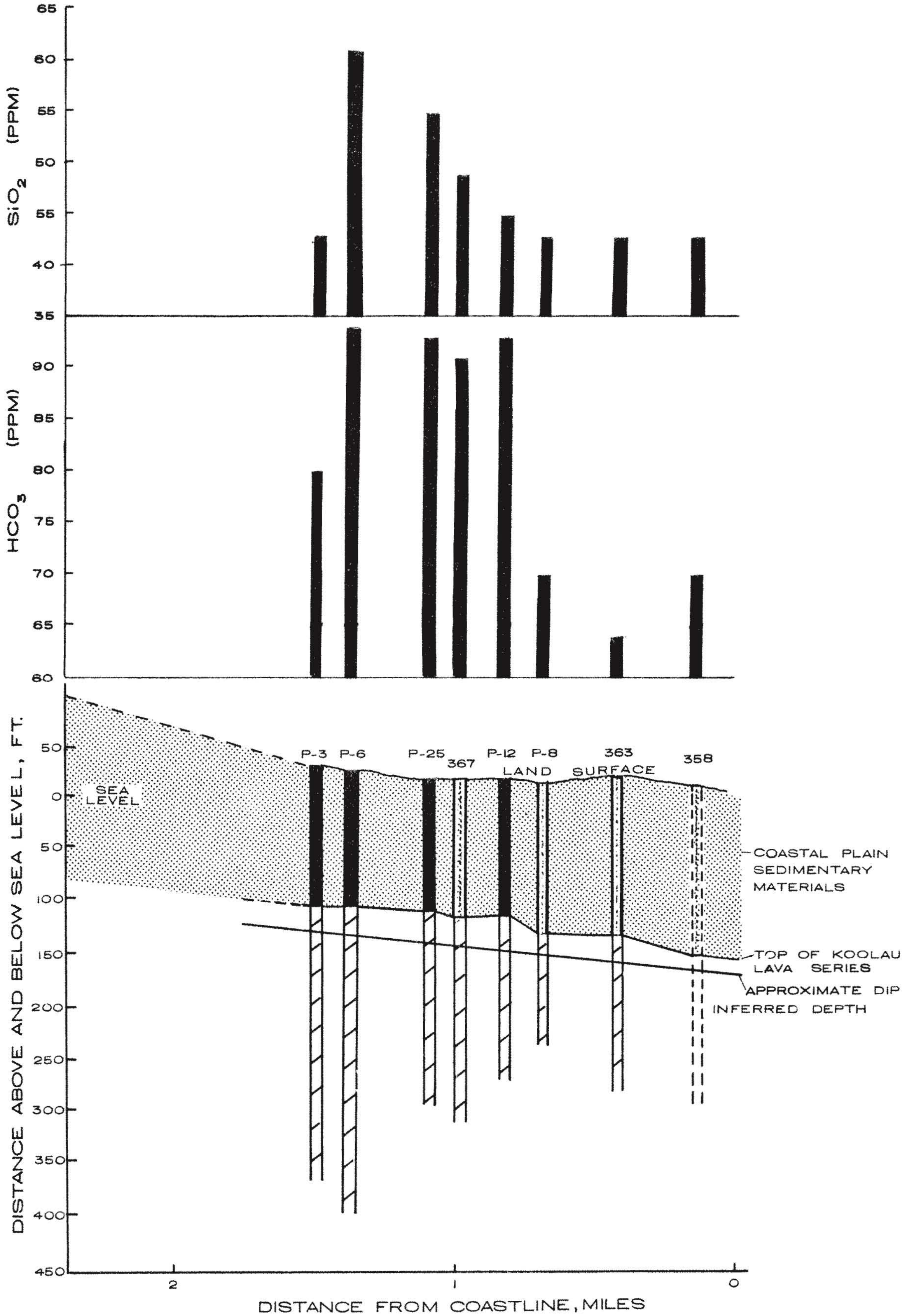

FIGURE 31. GENERALIZED GRAPHIC WELL LOGS AND MEAN INDEX CONSTITUENTS OF COMPOSITE WELL WATER SAMPLES FROM KAHUKU IN AREA A-A' (SEE FIG. 1 FOR TOPOGRAPHIC ORIENTATION).

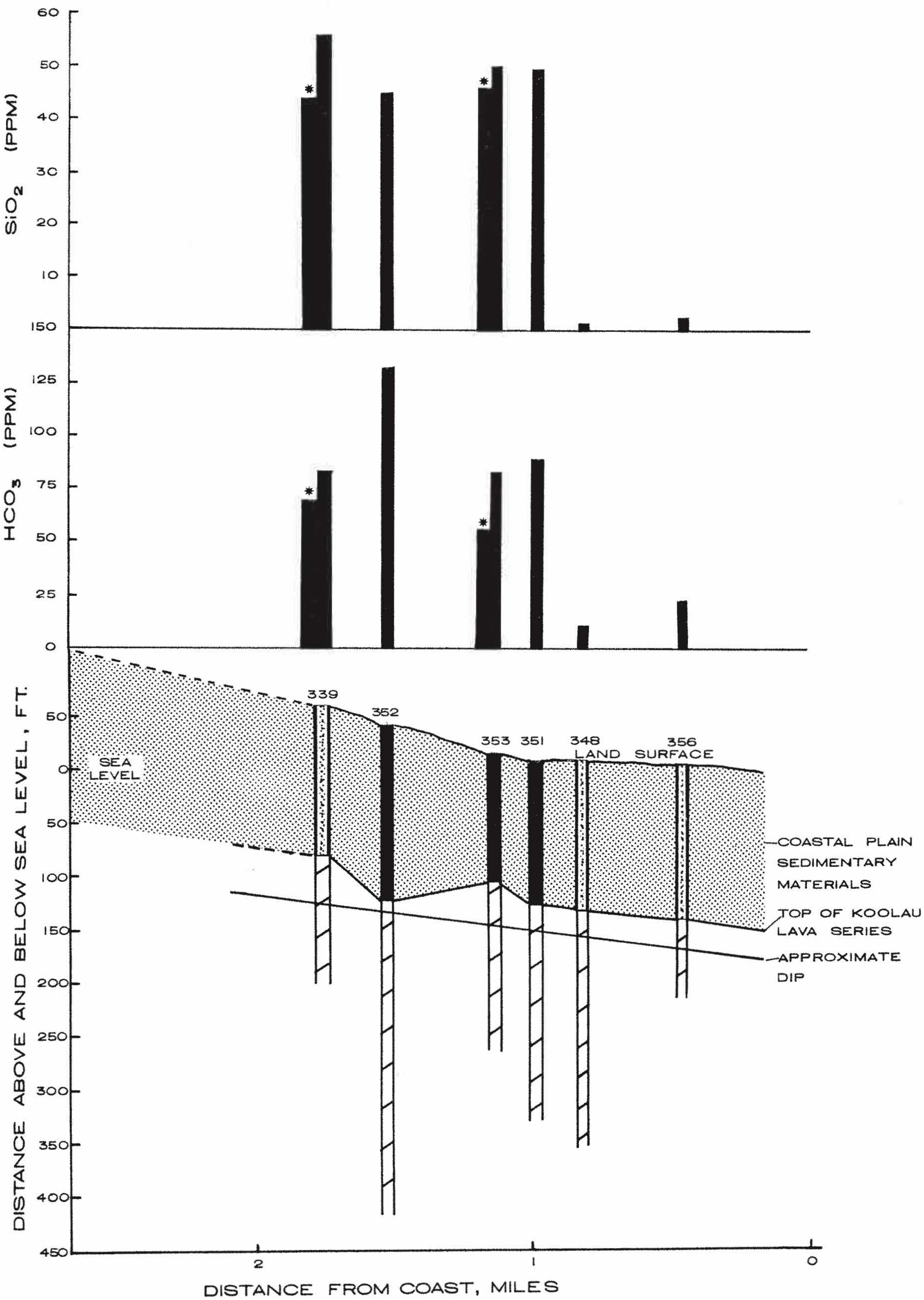

FIGURE 32. GENERALIZED GRAPHIC WELL LOGS AND MEAN VALUES OF INDEX CONSTITUENTS OF COMPOSITE WATER SAMPLES IN KAHUKU FROM AREA B-B'. SEE FIGURE 1 FOR TOPOGRAPHIC ORIENTATION. (*1956 AND 1964 VALUES OF TAKASAKI AND VALENCIANO, 1969.)

fertilization seem to be demonstrated more clearly by the nitrate values.

Pioneer Mill Site

Figure 33 shows the distribution of mean values of index constituents in the Pioneer Mill wells on a longitudinal direction along the coastline. The basal ground-water body in this region is essentially continuous and ground-water movement is little affected by overlying sedimentary deposits in contrast to the ground-water movement in the Kahuku area. The ground-water body is continuous and increases in thickness in a southerly direction relative to the coastline, attaining a height of 6 feet above sea level near Ukumehame Shaft (Pump No. P). Since the basal water body is hydrologically continuous throughout the area, there is a free exchange of water between the basins and the movement proceeds from areas of high heads to areas of low heads toward the coast. The distribution of index constituents and overall constituents was observed to be essentially uniform and the composition of water seemed to be controlled primarily by different conditions of draft, head, and time. As expected, those wells closer to the coastline with low heads show the greatest effect of irrigation water as compared to wells located relatively farther inland and where heads are correspondingly higher. Pump No. M, located inland and away from the influence of extensive irrigation practice, shows the least effect of irrigation on its index constituents with comparatively lower nitrate content than other wells in the area. The same general condition prevails in Pump Nos. N and P at the southern section of Pioneer Mill. In a transverse direction, although both are located in irrigation fields, water from Pump No. F, located down gradient from Pump No. R, shows a noticeably higher content of index constituents. This could indicate the migration of index constituents from an area of low head.

The rate of natural discharge of ground water is probably greatest at the northernmost section where the water table is generally low and the coastal plain sedimentary deposit is narrow (Fig. 34). A gradual decrease in natural discharge rate should take place toward the southern section where the coastal plain sedimentary deposits extend farther inland and where irrigated fields are essentially narrower. Figure 34

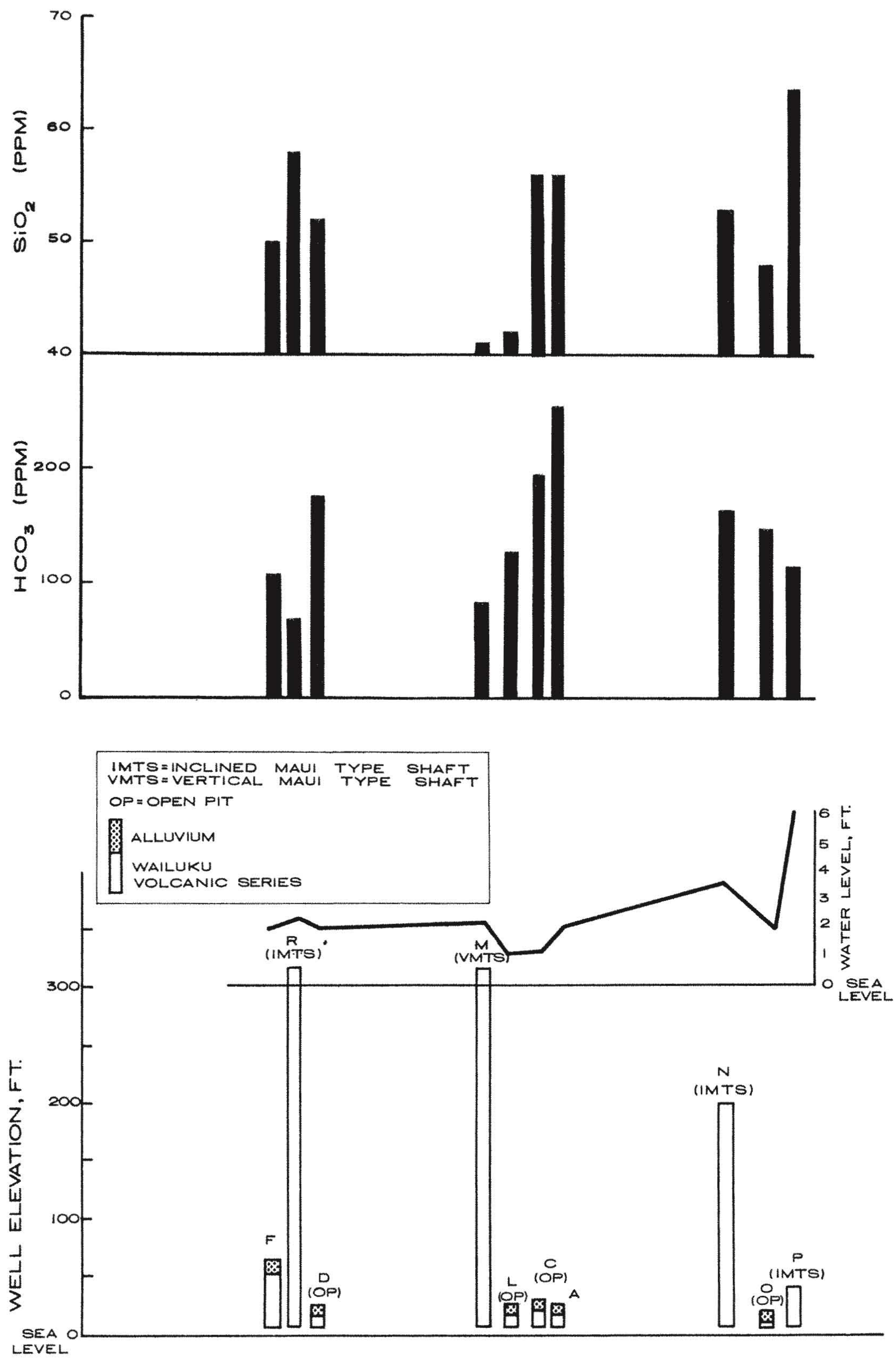

FIGURE 33. GENERALIZED GRAPHIC WELL LOGS WITH MEAN VALUES OF INDEX CONSTITUENTS IN THE PIONEER MILL WELLS.

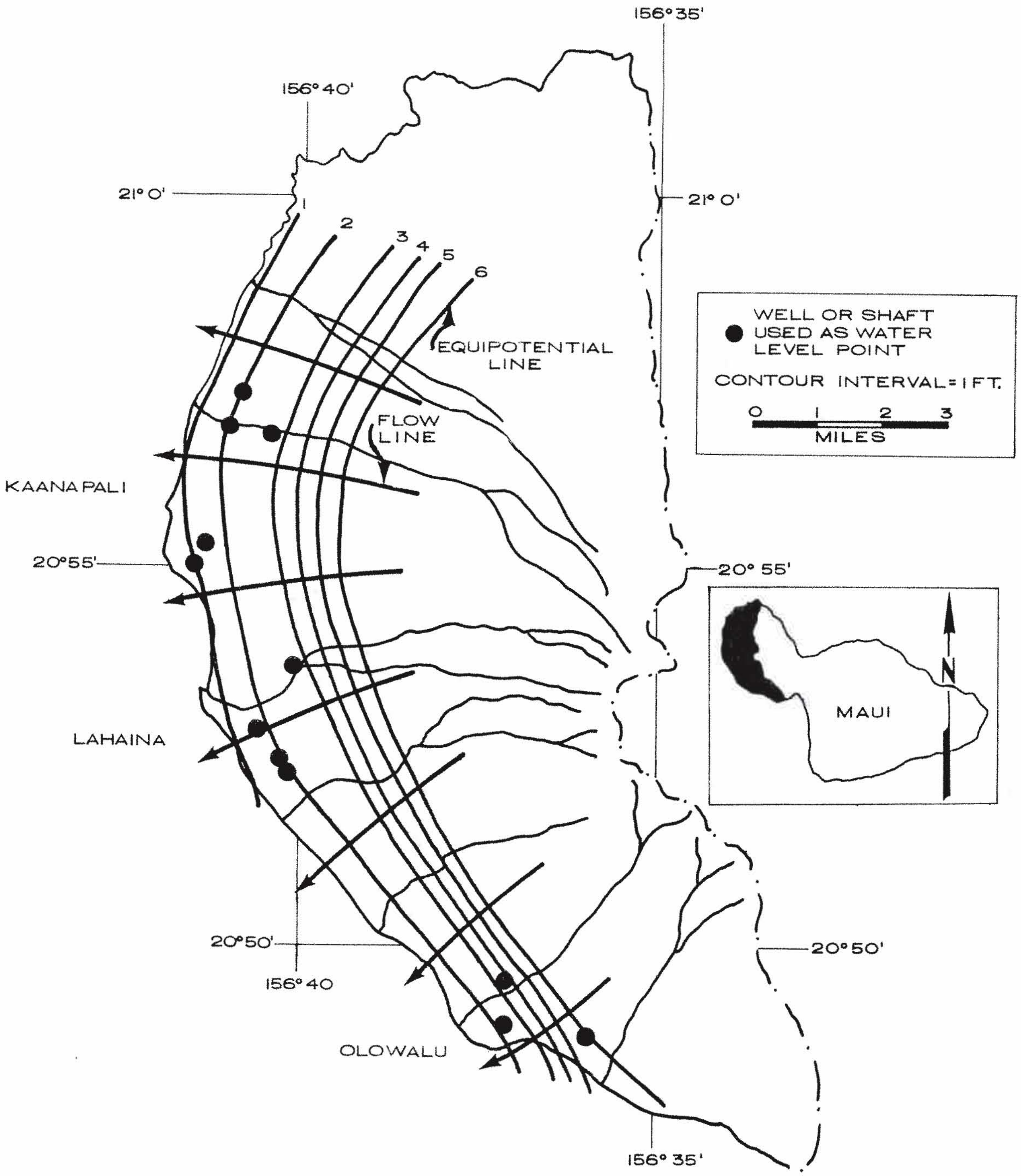

FIGURE 34. GENERALIZED FLOW-NET DIAGRAM OF THE PIONEER MILL GROUND-WATER BASIN.

also shows that all natural ground-water discharge is toward the coast. Hence, in wells where indices are relatively high as compared to other areas, the high values are probably due to the influence of heavily pumped wells which would tend to divert the subsurface irrigation water flow towards them.

Indication of sea-water intrusion as measured by the chloride content of the water is more readily evident in wells near the coast, being especially pronounced in Pump Nos. A, C, D, F, and L (Fig. 4). Pumps located further inland also show increases in chloride content which suggest the presence of intruded water. However, this increase is generally noticeable only during irrigation periods when peak draft is imposed on the lens.

Hawaiian Commercial and Sugar Company Site

Figure 35 shows the generalized graphic well logs and distribution of index constituents in wells found on the HC&S plantation. A cross-section of the wells over the line AA' (Fig. 36) is presented to show the variation in the indices in relation to the coastline bordering the area on two sides and to the water table elevation in the wells.

Ground-water movement in this region is toward the major areas of discharge along the adjacent coastlines and the lower isthmus plain. Areas of relatively faster flushing rates are encountered on the Kihei coastline, inland of Pump No. 1 and the 4-foot water level on the northern coast, and at the central part of the area where a troughlike depression appears to be present (Fig. 35). Relatively slow ground-water movement is encountered north of the 4-foot water table contour on the northern coast where coastal plain sediments are relatively abundant. No correlation of the ground-water movement and chemical concentration of a given water sample was observed. Quality under different conditions of draft, head, and time remained essentially uniform throughout the duration of study.

All of the wells sampled show large increases of most of the index constituents relative to uncontaminated sources, indicating the obvious presence of irrigation water and possibly the highest degree of basal water recycling of the three areas studied. Pump No. 18, located at much greater elevation and away from the coastline in comparison to the

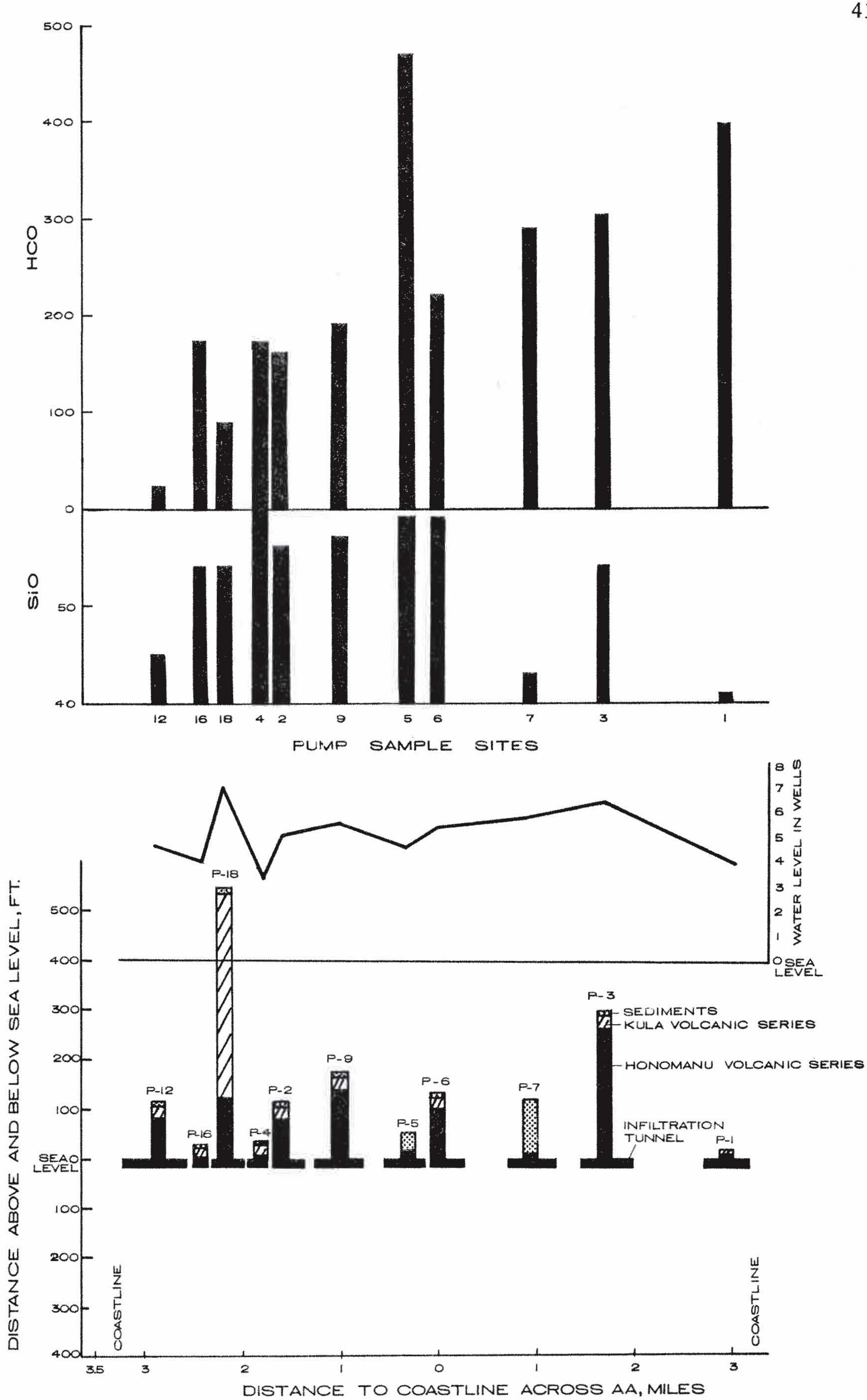

FIGURE 35. GENERALIZED GRAPHIC WELL LOGS WITH MEAN VALUES OF INDEX CONSTITUENTS IN HC&S VERTICAL MAUI-TYPE WELLS.

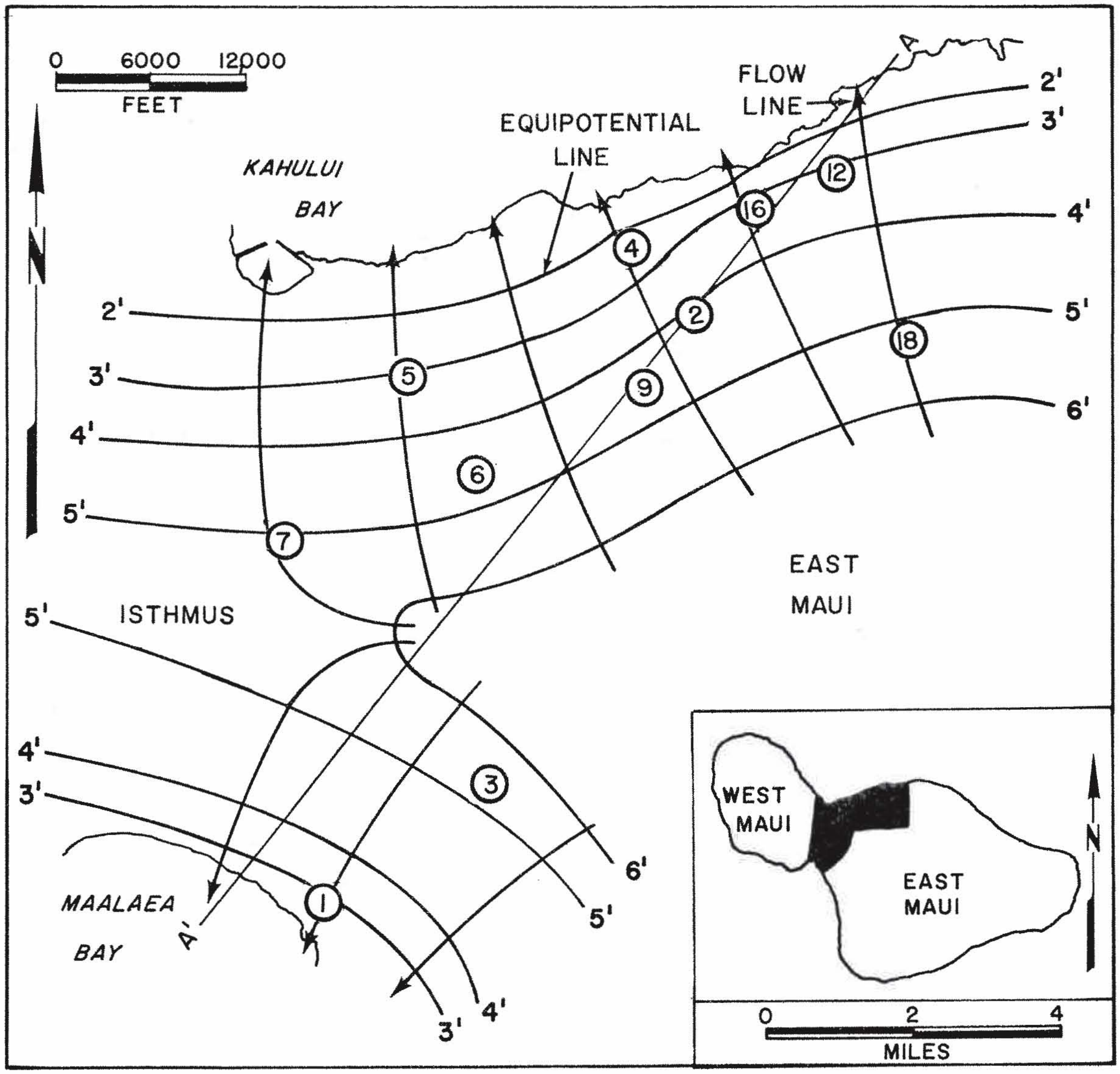

FIGURE 36. GENERALIZED FLOW-NET DIAGRAM OF THE HC&S GROUND-WATER BASIN.

other wells, showed the least effect of irrigation return water, although the indices were significantly high. The presence of large amounts of index constituents seems to be related to the persistent recycling of the basal water, and hence, different conditions of draft, rather than to locations of the wells relative to each other or to the coastline. The average amounts of nitrate and sulfate contained in all of the well water sampled were uniformly high and could be an indication of the upper limits of these constituents in the basal water contributed by irrigation and fertilization. It is suspected that the high values are a result of long-term accumulation of the constituents over successive cycles of irrigation and fertilization, rather than a single cycle.

The bicarbonate content shows the greatest variation and is highest in wells located in the central and lower parts of the isthmus which are the areas where calcareous sedimentary materials predominate. The high bicarbonate values could be the result of accelerated solution of carbonate material by the frequent recycling of the water for irrigation.

Silica values are also relatively high and uniform. Although the silica increase over the representative uncontaminated sources is significantly large, it is difficult to conclude that the increase was caused either by the leaching of soils or of the underlying unweathered rocks by excessive recycling. The relatively uniformly high silica content in the irrigated fields and the relatively lower silica values in flat water table gradients illustrate the difficulty of determining causes of the high values found.

In general, the high nitrate values found in the HC&S area may be due primarily to the slow flushing of the irrigation return water at the top of the lens owing to the uniformly flat gradients in most areas and by the presence of a troughlike water table region in the central and lower portion of the HC&S plantation.

CONCLUSIONS

From the present study, based on the index constituents used as indicators of return irrigation water and on additional observations and evaluation of overall water quality information, the following conclusions are indicated:

1. Qualitative and quantitative evidence have been obtained to verify contentions by earlier studies of the presence of irrigation water in the basal lenses underlying areas of sugar cane cultivation.
2. Conclusive evidence is present that fertilizer components, principally nitrate and sulfate, leach into the basal aquifer as a result of irrigation water application on the fields.
3. Geology and hydrology control the extent and amount of chemical components present in ground water.

4. Excessive withdrawals of the basal water in simple Ghyben-Herzberg lens conditions accelerates saline water intrusion at a rate faster than that found in areas of more complex hydrology, such as Kahuku and southern Oahu.

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APPENDICES

APPENDIX A. CHEMICAL ANALYSES OF KAHUKU WATER SAMPLES.

SAMPLE	DEPTH	DATE OF COLLECTION	SiO_2	Ca	Mg	Na	K	HCO_3	SO_4	Cl	F	Br	I	NO_3	PO_4	B	TOTAL HARDNESS	NON-CARB. HARDNESS	CALC. SOLIDS	pH	T,°C
									PPM												
PUMP 2		5/1/69	56	51	31	78	2.5	90	20	220	0.041	2	----	4	0.07	0.4	268	180	510	7.4	22
337		9/4/68	45	10	8.5	27	1.4	61	7.0	43	0.45	0.2	0.01	1.6	0.22	0.0	60	10	174	6.9	22
WAIALEE SCHOOL		10/31/68	51	10	8.5	26	1.5	62	7.2	43	0.11	0.0	0.04	2.9	0.10	0.0	60	9	180	6.0	21.5
337-1		5/1/69	54	11	9.8	26	1.4	64	7	43	0.39	0.37	----	1.5	0.15	0.8	68	16	187	7.5	20
		8/12/69	77	10	8.5	26	1.9	64	11	37	0.5	0.28	----	1.5	0.001		60	8	206	7.6	20.5
		11/13/69	35	15	6	24	1.3	64	7	42	0.19	0.2	----	1.6	0.2		62	10	164	7.65	22
		1/20/70	49	12	10	20	1.4	68	7	38	0.17	0.37	----	3.4	0.22		72	16	175	7.7	23
338		9/4/68	49	19	19	48	2.5	64	17	118	0.50	0.8	0.01	1.6	0.19	1.5	126	73	309	7.8	25
PUMP 14		1/30/69	45	19	20	43	2.6	66	17	118	0.64	0.1	0.01	2.0	0.24	0.1	132	78	301	7.3	22
		5/1/69	52	17	16	45	2.8	66	15	97	0.066	1.0	----	1.7	0.2		110	56	281	7.7	22
		8/12/69	77	17	16	50	2.8	66	21	99	0.47	0.64	----	1.8	0		110	54	319	7.6	22
		11/13/69	36	18	27	43	2.7	66	25	104	0.25	0.45	----	2.1	0.2		162	103	311	7.8	22.5
		1/20/70	NO SAMPLE																		
338-1		9/21/68	52	12	20	46	1.3	64	17	92	0.49	0.2	0.00	2.3	0.25	0.4	114	60	276	7.3	23
KAWELA TANK		10/31/68	51	15	15	51	1.7	68	16	98	0.29	0.1	0.01	1.8	0.16	0.5	100	43	284	7.2	23
		1/30/69	48	17	18	46	1.6	18	18	108	0.80	0.2	0.02	2.0	0.26	0.1	115	62	293	6.3	21
		5/1/69	54	15	17	49	1.6	66	13	94	0.03	0.84	----	1.5	0.26	1.4	106	52	283	7.2	22
		8/12/69	77	15	13	44	1.9	66	20	84	0.04	0.64	----	1.5	0.76	0.2	92	37	291	7.4	22.5
		11/13/69	36	23	25	55	1.8	84	17	134	0.46	0.62	----	2.4	0.34		160	91	337	7.1	22
		1/20/70	50	18	15	50	1.6	70	18	98	0.12	0.88	----	3.4	0.38		106	49	291	7.2	22
339-AB		9/4/68	54	52	52	96	1.2	83	27	342	0.64	4.0	0.01	5.5	0.23	0.9	342	276	676	7.3	23
		10/31/68	54	54	62	102	2.6	84	28	342	0.08	1.2	0.02	4.6	0.00	0.3	390	321	692	7.2	23.5
		1/30/69	61	52	58	86	2.4	86	30	333	0.47	0.6	0.01	5.8	0.24	0.2	410	340	682	6.5	22.5
		5/1/69	56	52	53	120	2.9	82	27	350	0.41	3.2	----	5.4	0.17	0.2	348	280	710	7.4	22.5
		8/12/69	87	52	54	96	4.2	84	41	328	0.11	1.7	----	1.4	0.001		352	280	706	7.4	22.5
		11/13/69	40	52	60	95	2.7	86	50	322	0.15	1.4	----	5.6	0.2		376	300	672	7.2	22.5
		1/20/70	50	65	53	92	2.6	86	25	323	0.22	2.9	----	8.8	0.24		380	310	665	7.4	22
341		10/31/68	59	54	58	100	3.2	80	30	348	0.19	0.9	0.03	6.1	0.14	0.0	375	308	698	7.1	23
		5/1/69	61	71	78	86	3.5	76	35	400	0.024	3.8	----	3.4	0.09	0.4	500	440	780	7.2	22
		8/12/69	92	98	58	93	4.1	74	55	423	0.04	2.5	----	4.8	0		480	420	867	7.2	22.1
		11/13/69	40	71	77	95	3.5	98	10	414	0.48	1.6	----	4.4	0.17	0.2	500	414	766	7.15	22
		1/20/60	54	91	45	110	3.2	78	32	393	0.18	3.5	----	7.7	0.17		412	350	778	7.2	22
SPRING 341		9/4/68	56	75	105	92	3.0	75	39	455	0.30	4.5	0.02	3.4	0.15	0.4	570	509	871	7.2	22.5
		10/31/68	56	74	72	92	3.4	75	38	415	0.09	1.0	0.02	4.4	0.12	0.8	480	419	794	7.1	23
		1/30/69	70	71	88	80	2.8	81	38	393	0.64	0.5	0.02	4.6	0.22	0.0	540	474	789	6.9	22
348		9/4/68	1.0	56	17	35	1.2	10	1.0	208	0.50	2.2	0.01	0.0	0.02	0.2	210	202	327	8.0	26
		10/31/68	1.0	56	19	37	1.5	10	1.0	198	0.10	0.5	0.02	0.4	0.00	0.0	220	210	319	7.2	32.5
		1/30/69	0.0	56	19	32	1.2	13	0.0	193	0.76	0.6	0.00	0.0	0.00	0.0	217	206	309	6.5	22
		5/1/69	1	54	15	38	1.4	12	0	184	0.066	2.3	----	0	0	0.5	198	188	302	7.6	24.5
		8/12/69	2.5	53	14	38	0.9	11	0.75	179	0.1	1.25	----	3.8	0		188	180	310	7.7	25.5
		11/13/69	1	52	19.5	35	1.3	10	5	188	0.32	0.86	----	0	0		210	202	308	7.10	24
		1/20/70	1.5	64	9.7	32	1.4	10	3	188	0.22	2.1	----	0	0.43		200	195	308	7.4	23.5
351		9/4/68	52	59	44	58	1.8	76	25	255	0.47	2.3	0.02	3.7	0.23	0.0	328	266	538	7.4	21.5
		10/31/68	51	54	33	60	2.2	78	23	220	0.20	0.4	0.05	4.1	0.14	0.0	370	207	486	7.2	21.5
		2/6/69	47	54	39	63	1.8	110	26	208	0.65	0.1	0.01	0.0	0.15	0.0	296	206	494	7.1	24
		8/12/69	72	56	34	60	2.3	81	34	218	0.05	1.3	----	4.3	0	0.35	280	210	522	7.4	21.5
		11/13/69	32	53	37	73	2.3	96	41	224	1	0.9	----	7.1	0.2		286	207	519	6.75	23.5
		1/20/70	49	66	23	54	2	102	22	198	0.34	1.9	----	10.2	0.24		260	175	477	7.7	23
352-AK		10/31/68	46	129	105	160	7.0	119	65	688	0.12	1.8	0.05	1.1	0.54	0.0	750	657	1262	6.0	25
PUMPS 5, 11		1/30/69	44	157	166	242	5.8	74	89	923	0.80	0.0	0.03	3.2	0.14	0.0	1075	1015	1667	6.8	22
		5/1/69	4.7	156	136	260	8	76	88	920	0.048	8.8	----	2.3	0.12	0.3	950	885	1622	7.5	22.5
		8/12/69	67	98	58	110	6.3	110	32	448	0.1	2.7	----	0	0.13	0.2	485	390	876	7.5	25
		11/13/69	14	226	56	114	5.2	214	44	688	0.34	2.6	----	8.3	0	0.1	794	620	1263	7.05	23.5
		1/20/70	20	273	56	124	4	204	47	700	0.39	6.6	----	13	0.76		912	745	1346	7.3	22
353-AE		10/31/68	44	46	34	48	1.8	72	22	195	0.05	0.7	0.01	4.8	0.00	0.0	254	196	431	7.4	26
PUMP 1		1/30/69	25	29	25	38	1.4	87	17	123	0.46	0.2	0.01	2.7	0.12	0.0	173	104	305	6.8	20.5
		2/6/69	47	29	24	44	1.3	86	16	118	0.72	0.3	0.00	5.6	0.28	0.0	171	101	328	7.3	22
		5/1/69	56	34	26	40	1.7	83	18	132	0.18	1.5	----	4	0.24	1.4	194	125	356	7.5	22
		8/12/69	87	39	22	70	1.9	86	59	155	0.1	0.96	----	0.7	0.1		188	118	478	7.45	22
		11/13/69	43	43	36	51	1.7	82	33	390	0.9	0.64	----	4.3	0.3		254	187	643	7.5	22
		1/20/70	50	36	24	38	1.2	84	19	123	0.31	1.3	----	8	0.3		190	120	342	7.6	22
356		9/4/68	3.0	78	50	98	3.4	26	1.0	455	0.16	5.4	0.02	0.0	0.02	0.6	400	379	708	8.0	26
KAHUKU MILL		10/31/68	2.5	76	61	96	4.0	25	0.0	452	0.04	1.2	0.02	1.1	0.00	0.0	440	420	706	6.9	26
		1/30/69	1.5	76	75	84	3.4	27	1.0	428	0.24	0.0	0.01	0.0	0.02	0.0	500	476	682	6.5	21
		5/1/69	2	71	64	92	4	22	1	425	0.023	4.5	----	0	0	0.4	442	424	675	8.2	23
		8/12/69	2.5	70	51	96	3.7	22	0.5	408	0.03	2.6	----	3.2	0	0.1	384	368	648	7.9	25
		11/13/69	1	69	55	100	4	24	11	418	0.1	1.08	----	0.4	0.17		400	380	672	8.25	22.5
		1/20/70	2.5	90	41	82	3.8	24	3	407	0.18	4.6	----	0	0.04		394	374	646	7.6	22
357		2/6/69	9.5	85	67	65	2.5	46	30	363	0.50	0.1	0.02	0.0	0.00	0.0	490	452	650	7.3	25
PUMP 8		5/1/69	45	25	277	165	8.0	63	85	1030	0.016	9.2	----	1.2	0.07	0.5	1200	1150	1677	7.5	22
		8/2/69	59	80	361	66	6.8	63	74	1185	0.44	6.5	----	2.2	0	0.2	1680	1630	1804	7.5	22
		11/13/69	32	83	71	70	2.7	70	30	380	0.38	1.4	----	2	0.1		500	440	708	7.6	22.5
		1/20/70	42	107	42	58	2.8	55	31	361	0.22	3.2	----	2.6	0.17		442	395	677	7.5	23
358		9/4/68	40	32	28	46	2.6	68	19	155	0.58	1.6	0.01	1.2	0.15	1.1	194	138	361	7.9	21.5
LAIE		10/31/68	42	34	21	47	3.1	68	17	148	0.09	0.2	0.02	2.1	0.02	0.3	170	116	348	7.4	21.5
		1/30/69	47	27	19	40	2.4	72	16	123	0.33	0.2	0.00	1.6	0.16	0.0	145	87	312	6.7	22
		5/1/69	42	30	26	42	3.2	70	18	140	0.084	1.5	----	1.2	0.09		184	125	339	7.7	21.5
		8/12/69	58	33	29	40	3.1	72	28	141	0.06	0.9	----	0	0		200	143	369	7.7	22
		11/13/69	30	34	26	41	3	70	11	150	0.25	0.62	----	1.7	0.13		194	136	333	7.85	21.8
		1/20/70	41	40	22	40	3	68	19	150	0.22	1.6	----	2.8	0.13		190	135	354	7.7	22

APPENDIX A. CHEMICAL ANALYSES OF KAHUKU WATER SAMPLES (CONT.).

SAMPLE	DEPTH	DATE OF COLLECTION	SiO_2	Ca	Mg	Na	K	HCO_3	SO_4	Cl	F	Br	I	NO_3	PO_4	B	TOTAL HARDNESS	NON-CARB. HARDNESS	CALC. SOLIDS	pH	T,°C
									PPM												
361-AB PUMP 12		10/31/68	49	21	15	35	1.5	83	13	82	0.11	0.0	0.02	0.0	0.14	0.4	116	46	258	7.6	22.5
		2/6/69	46	18	13	38	1.0	98	12	53	0.27	0.7	0.00	4.0	0.25	0.0	99	18	234	7.5	22.5
		5/1/69	47	18	12	56	1.3	97	12	51	0.038	0.57	----	2.8	0.17	0.9	94	14	249	7.5	22.5
		8/12/69	67	21	15	33	1.9	92	19	62	0.07	0.46	----	3.7		0.35	112	39	269	7.6	22
		11/13/69	35	20	17	31	1.2	98	19	54	0.58	0.24	----	3.8	0.27		120	40	230	7.7	22.5
		1/20/70	47	25	11	38	1.2	110	13	60	0.28	0.88	----	3.2	0.24		106	18	254	7.5	23
362-1 PUMP 6		2/6/69	61	14	13	51	1.0	106	16	58	0.90	0.5	0.01	5.0	0.44	0.0	88	2	273	7.4	25
		5/1/69	61	14	11	40	1.2	86	12	57	0.056	0.7	----	3.4	0.24	0.5	80	9	243	7.4	22.5
		8/12/69	96	16	15	39	1.1	86	19	61	0.07	0.56	----	4.2	0.16	0.3	106	31	294	7.4	23.6
		11/13/69	40	15	16	45	1.2	88	29	68	0.64	0.32	----	4.8	0.3		102	31	265	7.6	23
		1/20/70	47	19	12	41	1.6	102	13	56	0.4	0.62	----	4.4	0.4		97	13	246	7.5	23
362-AF PUMP 3		10/31/68	54	40	24	42	1.9	86	19	140	0.11	0.2	0.02	1.1	0.22	0.0	200	128	364	7.3	23
		2/6/69	13	29	9.6	25	3.5	66	12	73	0.74	0.5	0.00	0.6	0.10	0.0	112	58	200	8.3	23
		5/1/69	56	30	26	43	1.7	88	18	124	0.035	1.25	----	3.4	0.19	0.6	180	110	347	7.4	22
		8/12/69	72	34	26	42	1.5	90	29	128	0.11	1.2	----	3.2	0.04		190	118	383	7.4	24
		11/13/69	36	41	35	43	1.8	86	40	166	0.52	0.82	----	4.2	0.15		246	226	411	7.6	23.5
		1/20/70	25	22	15	29	3.2	62	13	86	0.2	0.86	----	1.2	0.29		118	66	227	7.4	23
363 PUMP 7		9/4/68	40	55	47	50	2.8	63	24	242	0.60	2.4	0.01	0.4	0.11	0.5	330	279	496	7.8	25
		10/31/68	42	52	35	51	2.9	60	23	230	0.02	0.9	0.01	1.1	0.00	0.1	272	225	468	7.5	25
		1/30/69	45	48	39	44	2.5	65	24	208	0.28	0.1	0.00	1.4	0.09	0.0	282	227	444	7.2	22
		5/1/69	42	51	35	53	3.3	65	23	208	0.02	2.3	----	0.9	0.05		270	217	450	7.5	22
		8/12/69	59	53	33	45	4.1	64	23	200	0.05	1	----	1.8	0		266	220	452	7.7	22
		11/13/69	31	48	37	48	3	64	22	214	0.2	0.86	----	1.4	0.1		270	218	438	7.8	22.5
		1/20/70	42	60	29	44	3.2	66	21	205	0.2	2.2	----	2.8	0.13		270	215	442	7.7	22
365 LAIE		9/4/68	46	17	14	30	1.1	93	13	52	1.5	0.2	0.01	2.0	0.27	0.4	100	24	223	7.7	23
		10/31/68	50	16	13	32	1.3	91	13	50	0.95	0.0	0.02	3.4	0.16	0.5	94	19	225	7.5	22.5
		1/30/69	43	17	13	29	1.3	91	13	58	1.3	0.1	0.02	3.0	0.28	0.1	95	21	224	7.0	22
		5/1/69	52	17	14	30	1.7	91	12	49	0.048	0.57	----	2.3	0.24		98	23	224	7.5	22
		8/12/69	74	16	15	26	1.5	92	12	49	0.07	0.26	----	1.4	0.01		100	26	241	7.5	22.2
		11/13/69	35	17	14	31	1.2	90	11	54	0.15	0.29	----	3.8	0.24	0.1	98	24	212	7.7	22
		1/20/70	48	20	25	27	1.2	90	13	51	0.18	0.58	----	3.8	0.24		110	38	224	7.5	22
367 LAIE		9/4/68	46	17	17	28	1.2	96	13	50	0.76	0.2	0.01	2.3	0.27	1.0	112	34	226	7.6	22
		10/31/68	50	18	11	31	1.3	88	13	51	0.09	0.0	0.02	2.8	0.12	0.2	90	18	222	7.4	22
		1/30/69	44	16	14	28	1.2	92	13	58	0.80	0.9	0.02	3.2	0.24	0.3	98	23	225	6.8	22
		5/1/69	50	17	12	30	1.2	92	12	46	0.07	0.7	----	2.8	0.22	0.2	92	17	217	7.6	22
		8/12/69	72	16	11	30	1	92	13	48	0.06	0.34	----	3	0.01		85	10	671	7.6	22
		11/13/69	35	25	7.2	30	1.1	90	11	54	0.23	0.26	----	3	0.24	0.1	92	18	211	7.7	22
		1/20/70	48	20	12	27	1.2	92	12	49	0.17	0.6	----	4.8	0.26		100	23	220	7.5	22
373 PUMP 25		2/6/69	47	12	13	32	1.0	102	10	48	0.38	0.7	0.00	3.0	0.24	0.0	85	1	217	7.5	24
		5/1/69	56	12	13	35	1	92	9	50	0.038	0.47	----	1.2	0.19	0.8	84	9	224	7.5	22.5
		8/12/69	84	13	11	31	0.85	88	15	38	0.07	0.34	----	1.8	0.13		78	6	238	7.6	22.5
		11/13/69	36	11	13	33	9	92	22	49	0.28	0.2	----	0.8	0.3		80	6	220	7.7	22.5
		1/20/70	51	19	7.9	31	1.1	92	11	40	0.3	0.42	----	3.1	0.29		80	5	210	7.3	23

APPENDIX B. CHEMICAL ANALYSES OF PIONEER MILL WATER SAMPLES.

SAMPLE	DEPTH	DATE OF COLLECTION	SiO_2	Ca	Mg	Na	K	HCO_3	SO_4	Cl	F	Br	I	NO_3	PO_4	B	TOTAL HARDNESS	NON-CARB. HARDNESS	CALC. SOLIDS	pH	T,°C
			PPM																		
PIONEER MILL		2/13/70																			
A			60	140	109	170	15	246	120	600	0.20	11	----	15	0.15	1.5	800	597	1487	7.2	---
C			55	130	111	430	25	194	190	980	0.30	12	----	22	0.2	0.5	830	622	2150	7.2	---
D			50	80	56	440	20	172	100	850	0.40	9	----	13	0.5	----	430	289	1791	7.1	---
F			50	45	70	550	20	118	100	975	0.20	8	----	4.3	0.4	----	400	304	1941	7.7	---
L			45	70	62	150	10	150	60	410	0.15	5	----	14	0.20	----	430	307	977	7.4	---
M			40	30	30	130	5	76	30	280	0.65	2	----	6.6	0.30	4.0	200	136	635	7.7	---
N			45	70	62	170	6	120	40	480	0.35	2.5	----	7.7	0.15	1.0	380	332	1006	7.8	---
O			45	90	67	150	5	120	70	460	0.15	4	----	5.9	0.10	----	500	402	1017	7.6	---
P			60	85	29	180	15	130	50	400	1.25	6.0	----	11	0.05	2.0	330	225	969	7.5	---
R			55	40	17	120	6	64	26	260	0.9	5.0	----	7.7	0.80	1.5	158	117	610	7.8	---
9-A	25'	4/23/68	48	120	66	225	19	224	113	582	0.30	5.4	0.25	14	0.10	0.0	570	388	1333	7.2	---
		7/1/68	90	30	158	795	16	324	160	993	0.36	13	0.11	0.8	340	0.0	725	460	2756	6.3	---
9-A	25'	1/22/69	51	116	100	240	10	278	85	630	0.17	7.2	0.04	16	0.13	2.3	700	473	1395	6.8	25
		4/9/69	52	153	136	410	17	240	107	1040	0.13	10	----	15	0.14	0.0	940	744	2058	7.3	29
		8/11/69	47	135	105	340	6.8	232	100	853	0.3	5.6		14	0.1	0.2	770	565	1722	7.7	---
		10/31/69	46	135	98	396	9.4	232	65	909	0.9	2.1	----	13	0.02	0.1	742	550	1788	7.3	28
HONOKOWAI INTAKE			15	6	3.7	7.0	2.0	42	1.0	10	0.05	0	----	1.2	0.03	----	30	0	118	7.3	---
HONOKOWAI		4/24/68	10	3.0	0.0	7.0	0.8	14	2.0	7.0	0.07	0.0	0.01	0.8	0.05	0.0	6	0	38	7.4	---
TUNNEL INTAKE		7/28/68	26	5.5	6.4	6.0	0.9	32	0.0	15	0.40	0.0	0.00	2.2	0.10	0.0	40	14	79	7.8	---
20-A		2/19/68	26	6.0	4.1	7.0	0.7	30	2.0	13	0.17	2.2	0.00	0.0	0.04	0.0	32	7	76	7.2	---
		5/1/69	17	5.0	1.8	5.0	0.4	22	1.0	5.0	0.02	0.0	----	0.0	0.02	0.6	20	0	47	7.3	---
		8/11/69	34	8	2.9	4	0.7	30	5	7	0.05	0.1	----	0.9	0	----	32	7	78	7.45	--
		10/31/69	21	6	14	5.5	0.7	35	30	15	0.3	0	----	1.4	0.17	----	72	44	121	7.5	16
HONOKOWAI	65'	4/23/68	51	27	35	280	19	105	86	473	0.40	3.7	0.11	11	0.52	0.0	212	125	1038	7.5	---
2-F		7/2/68	52	38	53	430	19	103	120	780	1.0	8.6	0.04	11	0.44	0.0	310	229	1563	7.9	---
		1/22/69	52	42	58	335	14	130	90	625	0.37	8.4	0.04	9.2	0.52	2.3	345	237	1301	6.7	22
		11/9/69	22	24	34	240	9.5	92	64	390	0.14	6.0	----	3.2	3.3	0.0	198	124	841	8.1	23
36-R	320'	4/22/68	55	8.0	6.9	83	5.1	71	23	106	0.20	1.0	0.08	8.8	0.70	0.0	49	0	333	7.4	---
		7/2/68	49	19	44	250	12	77	66	455	0.76	4.4	0.02	7.6	0.50	1.0	230	165	947	8.1	---
		1/22/69	92	7.0	7.4	61	3.0	61	14	85	0.27	1.2	0.03	7.2	0.75	3.2	48	0	312	7.1	20
		4/9/69	46	6.0	8.5	67	3.5	60	15	90	0.08	1.2	----	7.4	0.71	0.0	50	1	275	7.9	20
		8/11/69	58	13	15	158	9.7	66	55	235	0.15	2	----	6.5	0.44	----	92	40	586	7.45	----
		10/31/69	51	24	57	170	26	83	34	400	1	2.3	----	9.1	0.6	----	296	228	793	7.7	20
KAANAPALI																					
3-D	20'	4/23/68	39	33	39	265	23	124	130	430	0.30	3.7	0.11	15	1.10	0.5	244	141	1040	7.4	----
		7/2/68	56	43	59	465	20	157	124	840	1.00	8.8	0.03	13	0.48	0.0	350	221	1708	7.1	----
		1/22/69	44	18	26	195	8.8	106	80	300	0.32	4.6	0.04	10	0.38	2.8	150	65	742	7.0	21.5
		4/9/69	52	36	66	385	17	128	107	660	0.20	8.8	----	16	0.51	0.0	362	257	14.2	7.5	22
		8/11/69	61	40	61	475	24	150	100	808	0.29	5.4	----	13	0.06	----	350	228	1661	7.65	----
		10/31/69	50	59	13	440	12	406	95	880	0.56	3.8	----	0	0.32	0.4	666	335	1867	7.4	22.5
KAHOMA																					
5-M	320'	1/22/69	36	14	15	63	3.7	56	17	115	0.19	1.5	0.03	4.0	0.29	2.5	95	51	300	7.1	22
		4/9/69	40	12	10	82	4.2	58	20	125	0.66	1.9	----	4.8	0.50	5.4	72	24	335	7.8	22.5
		8/11/69	44	16	15	110	5.9	74	47	177	0.08	1.3	----	3.6	0.23	----	100	41	457	7.5	----
		10/31/69	46	28	37	220	10	144	34	400	0.82	1.7	----	3.9	0.24	----	224	104	853	7.3	25
LAHAINA MILL																					
7-C	30'	4/23/68	57	90	85	435	26	193	134	890	0.30	7.6	0.20	11	0.22	0.0	575	416	1831	7.2	----
		7/2/68	56	120	124	700	24	193	178	1440	0.56	9.0	0.08	0.0	0.74	0.0	810	652	2746	7.2	----
		1/22/69	34	25	21	62	4.0	129	25	102	0.09	1.6	0.30	2.0	0.04	2.5	150	43	343	6.6	23
		4/9/69	61	95	137	640	26	194	122	1325	0.11	11	----	17	0.20	1.0	800	641	2531	7.2	24.5
		8/11/69	56	86	167	660	37	194	100	1418	0.2	10	----	15.2	0	---	900	745	2645	7.3	----
		10/31/69	52	115	117	552	10	192	89	1280	1.15	3.1	----	8.3	0.36	0.1	770	610	2323	---	24.5
OLOWALU SHAFT																					
10-N		4/22/68	53	30	18	93	4.5	198	30	112	0.80	1.0	0.40	8.5	0.02	0.0	149	0	449	7.0	----
		7/1/68	46	45	29	146	5.7	172	41	275	1.6	2.7	0.04	5.6	0.06	1.6	230	91	684	8.4	----
		1/22/69	54	29	24	91	3.5	202	28	110	0.25	1.7	0.03	10	0.17	2.5	170	6	454	6.9	23
		4/9/69	54	37	31	127	4.8	220	38	191	0.17	2.7	----	12	0.20	7.3	220	40	613	7.3	25
		8/11/69	66	61	49	148	7.9	160	66	338	0.23	2.5	----	8.1	0	----	354	223	826	7.3	----
		10/31/69	52	135	84	228	8.8	77	21	780	0.54	2.6	----	3.8	0.05	----	682	620	1354	7.2	21
11-O	15'	4/23/68	32	15	6.5	17	2.3	75	11	22	0.15	0.1	0.06	2.2	0.01	0.0	64	3	143	7.8	----
		7/1/68	53	74	59	118	7.2	222	45	305	1.1	3.0	0.01	20	0.02	0.0	430	246	795	7.3	----
		1/22/69	57	69	48	115	5.8	196	42	270	0.13	3.8	0.02	16	0.10	1.9	370	209	726	6.4	25.5
		4/9/69	45	49	34	92	4.0	150	35	208	0.14	2.7	----	14	0.06	0.9	263	139	559	7.2	25
		8/11/69	58	51	35	93	5	140	57	223	0.13	1.6	----	10.4	0	----	270	157	603	7.2	----
		10/31/69	47	67	24	156	3	137	29	303	0.9	1.2	----	10.0	0.05	----	364	152	709	7.2	25.5
UKUMEHAME SHAFT																					
12-P		7/1/68	66	38	23	210	19	50	42	420	2.6	4.0	0.12	9.0	0.02	0.0	190	149	859	9.0	----
		1/22/69	71	68	24	205	16	111	40	400	0.26	5.6	0.04	14	0.03	3.0	270	178	902	7.3	33
		4/9/69	71	68	21	240	17	124	47	432	0.08	5.1	----	13	0.06	2.4	256	155	978	7.7	34
		8/11/69	58	60	17	198	36	132	66	373	0.12	3	----	10	0	----	220	112	886	7.5	----
		10/31/69	59	53	15	200	10	147	21	354	1.2	0.94	----	5.5	0	----	194	74	792	7.5	33
WAHIKULI																					
6-L	25'	4/22/68	32	29	22	97	6.9	114	26	186	0.06	1.3	0.01	3.6	0.00	0.0	164	70	460	6.6	----
		7/1/68	46	60	66	187	8.0	154	56	440	1.1	4.8	0.02	16	0.04	0.0	420	295	961	7.4	----
		1/22/69	45	61	53	190	8.0	148	51	400	0.12	5.2	0.02	20	0.22	2.5	380	249	909	6.7	25
		4/9/69	46	50	56	212	8.2	142	59	435	0.11	6.0	----	13	0.22	0.0	356	239	956	7.2	25.5
		8/11/69	31	7	4.5	7.5	1	38	7	11	0.07	0.13	----	0.4	0	----	36	5	89	7.5	----
		10/31/69	46	47	114	99	4.1	142	25	459	0.76	1.2	----	6.3	0.05	0.1	580	470	872	7.2	24.5

APPENDIX C. CHEMICAL ANALYSES OF HC&S AND WAILUKU WATER SAMPLES.

SAMPLE	DEPTH	DATE OF COLLECTION	SiO_2	Ca	Mg	Na	K	HCO_3	SO_4	Cl	F	Br	I	NO_3	PO_4	B	TOTAL HARDNESS	NON-CARB. HARDNESS	CALC. SOLIDS	pH	T,°C
									PPM												
CAMP 2	120'	6/17/68	55	22	40	260	17	175	63	428	1.3	5.7	0.01	18	0.60	1.7	220	75	999	6.8	23
2 0		6/17/68	60	24	44	255	18	176	58	430	2.0	5.6	0.02	19	0.52	0.2	239	43	1003	6.8	23
		1/20/69	51	13	22	152	2.8	107	33	232	0.76	2.2	0.06	14	0.42	0.2	122	35	576	7.1	22
		4/8/69	71	20	41	245	16	180	49	385	0.72	2.7	----	18	0.74	0.0	220	72	938	7.4	23
		8/7/69	39	20	35	220	8.2	186	59	333	0.42	1.8	----	17	0.59	1.4	194	42	827	7.3	23
		10/30/69	63	22	50	270	10	180	67	450	1.5	1.5	----	14	0.56	0.1	260	113	1039	7.1	22
		1/13/70	56	25	46	250	14	140	36	448	2.7	3.3	----	14	0.68		250	137	964	7.2	22
HAIKU DITCH		6/17/68	58	17	31	220	18	196	47	318	1.08	4.8	0.01	18	0.30	1.3	170	0	830	6.9	23
9	180'	1/20/69	73	16	32	188	13	191	37	260	0.64	2.8	0.03	18	0.28	2.3	172	15	737	7.4	23
		4/8/69	52	21	30	220	17	204	44	300	1.3	2.7	----	17	0.33	0.0	176	9	805	7.5	23.5
		8/7/69	38	11	31	220	10	200	59	288	0.37	1.9	----	16	0.16		154	0	774	7.5	23.2
		10/30/69	59	18	34	208	6	204	18	340	1.1	1	----	13	0.24	0.1	186	19	800	7.3	23
		1/13/70	59	22	36	170	15	150	33	287	1.6	2.8	----	13	0.36		202	80	714	7.3	23
IAO STREAM		4/18/68	19	5.5	2.0	5.0	0.8	27	5.4	4.7	0.08	0.0	0.03	0.0	0.00	0.0	22	0	56	6.6	20
		6/19/68	18	7.0	2.6	6.6	0.7	28	10	6.0	0.20	0.1	0.01	0.0	0.20	1.5	28	5	67	6.6	21
		1/21/69	23	8.0	6.1	7.5	0.4	40	7.0	7.0	0.15	0.1	0.02	0.0	0.03	2.1	45	0	81	6.6	16
		4/7/69	12	4.0	1.7	4.7	0.3	18	2.0	5.0	0.03	0.0	----	2.7	0.04	0.0	17	2	41	7.3	16.5
		8/8/69	11	5	4.3	6.3	0.4	30	8	6.5	0.05	0.14	----	0.0	0.00	0.7	30	6	57	7.6	19.5
		10/29/69	23	5	6.2	7	2	26	15	12	0.25	0.12	----	1.5	0.05		38	17	85	7.4	20
		1/12/70	19	8	6.8	4.5	0.4	45	5	7	0.18	0.1	----	0.6	0.13		48	11	73	7.5	19
IAO TUNNEL		6/19/68	33	8.0	2.9	10	2.2	42	3.6	11	0.24	1.2	0.01	0.0	0.30	0.9	32	0	94	7.2	19
		1/21/69	37	9.0	2.9	10	1.4	46	4.0	10	0.20	0.2	0.03	0.1	0.16	1.8	37	0	100	7.1	20
		4/7/69	36	9.0	4.3	10	1.4	46	3.0	12	0.06	0.6	----	3.8	0.16	0.0	40	2	103	8.2	20
		8/8/69	32	7	3.5	11	2.1	48	4.5	10	0.07	0.15	----	0.8	0.00	0.7	32	0	96	7.9	20
		10/29/69	38	8	6.8	7.5	1.4	40	13	15	0.36	0.18	----	0.8	0.09		48	15	111	8.0	20
		1/12/70	31	9	4.3	6	1.4	40	4	12	0.25	0.15	----	0.8	0.78		40	8	90	7.9	20
KAHEKA	550'	6/17/68	48	38	46	425	22	84	112	750	0.84	9.6	0.02	10	0.68	2.4	286	215	1506	7.4	22
18		1/20/69	57	11	10	71	4.9	76	25	105	0.48	1.4	0.05	5.8	0.42	2.3	70	6	331	7.8	21.5
		4/8/69	66	13	18	93	6.6	106	33	119	0.30	1.3	----	15	0.99	0.0	106	19	418	7.7	22
		8/7/79	33	16	19	130	4.6	106	53	183	0.28	1.1	----	14	0.73	0.4	118	31	508	7.2	21.3
		10/30/69	57	24	35	150	7.4	100	24	300	1.1	1	----	14	0.56	0.1	204	122	662	7.5	21.5
		1/13/70	53	9	11	60	4.3	70	20	76	0.98	0.72	----	8.6	1.42		66	11	280	7.7	21
KAPUNA		4/19/68	16	3.0	1.1	12	1.7	20	5.0	13	0.10	0.1	0.01	0.2	0.05	0.0	12	0	62	6.2	23.5
E. MENDEZ		6/19/68	28	11	6.8	32	2.7	104	9.3	22	0.60	0.9	0.01	1.5	0.20	1.3	56	0	167	6.8	24
DOMESTIC WELL		1/21/69	36	13	7.1	28	2.2	106	16	17	0.26	0.4	0.03	1.4	0.13	1.9	61	0	175	7.2	23
		4/7/69	13	13	9.1	34	2.6	118	13	20	0.14	0.3	----	2.7	0.07	0.0	70	0	166	7.9	23.5
KIHEI	20'	6/18/68	45	36	39	343	20	452	75	460	2.8	6.2	0.05	21	0.16	1.8	250	0	1273	7.0	25
1		1/20/69	23	4.0	9.7	18	3.1	45	6.0	20	0.39	0.3	0.04	2.6	0.28	0.3	30	0	105	8.0	22
		4/8/69	48	21	37	260	18	286	50	340	0.90	2.6	----	16	0.22	0.0	204	0	935	8.1	24
		8/7/69	29	40	45	384	10	440	72	483	0.62	3.4	----	18	0.0	0.9	284	0	1303	7.5	24.5
		1/13/70	50	46	52	300	20	360	44	455	3.3	4.4	----	15	0.49		328	34	1167	7.5	24.3
KIHEI	300'	6/18/68	52	20	37	260	20	305	58	335	1.7	4.6	0.01	23	0.46	1.4	203	0	963	7.2	23.5
3		1/20/69	62	19	34	208	15	300	42	262	0.66	2.2	0.04	16	0.24	0.7	188	0	810	7.7	24
		4/8/69	66	20	41	250	20	312	50	315	0.90	2.6	----	17	0.22	0.1	220	0	937	7.7	24
		8/7/69	33	22	34	260	21	316	64	328	0.62	1.9	----	17	0.64	1.8	194	0	940	7.7	23.5
		10/30/69	59	21	41	260	8.6	320	55	340	2.2	1.1	----	14	0.12	0.2	220	0	960	7.5	23.5
		1/13/70	54	24	43	205	19	300	34	273	2.8	2.7	----	13	0.26		230	0	819	7.5	23
KUAU	120'	6/17/68	44	10	11	175	8.5	122	44	218	1.4	3.5	0.01	20	0.26	1.2	70	0	598	6.5	29.5
12		1/20/69	44	2.0	3.6	55	3.4	88	19	36	0.62	0.5	0.02	1.4	0.45	1.9	20	0	211	7.2	23
		4/8/69	42	7.0	8.4	86	6.4	134	7.0	82	0.26	1.3	----	2.7	0.45	0.0	52	0	309	7.2	22.5
		8/7/69	29	9	13	180	52	130	57	223	0.32	1.6	----	16	0.95	0.4	75	0	599	7.2	22
		10/30/69	61	10	28	160	13	122	50	235	0.9	0.74	----	14	0.95	0.1	140	40	633	7.2	22
		1/13/70	54	14	15	166	8	150	29	200	1.2	2.8	----	11	1.2		96	0	576	7.2	21.5
LOWER PAIA		6/17/68	55	31	69	520	28	176	126	938	0.8	12	0.03	18	0.30	1.2	360	217	1886	6.7	24
16	30'	1/20/69	62	25	42	228	14	188	55	348	0.39	4.0	0.02	16	0.31	1.9	235	81	889	6.7	24.3
		4/8/69	63	27	39	240	15	182	48	340	0.27	3.5	----	17	0.40	0.0	230	79	883	7.1	25
		8/7/69	33	24	30	230	8.7	196	59	338	0.42	2.1	----	16	0.26	0.4	180	23	839	6.5	24.3
		10/30/69	61	37	76	400	19	170	71	800	1.6	2.6	----	14	0.71	0.25	406	268	1567	7.2	23
		1/13/70	51	27	40	185	14	140	37	342	1.3	2.2	----	12	0.4		230	117	780	7.2	25
MOKUHAU WELL		6/19/68	47	18	11	26	2.2	86	20	40	0.61	0.6	0.01	5.8	0.36	1.5	90	20	215	6.7	22
		1/21/69	45	18	15	28	2.0	97	17	50	0.50	1.0	0.04	4.0	0.20	2.5	106	27	231	6.7	22
		4/7/69	61	19	16	25	2.0	94	21	38	0.11	0.5	----	7.0	0.22	0.0	112	35	236	7.3	22
		8/8/69	32	18	13	26	2.3	92	22	39	0.12	0.41	----	4.6	0.03	0.9	99	23	203	7.5	22.2
		10/29/69	34	19	15	23	22	108	14	55	0.64	0.23	----	3.2	0.17		112	21	259	7.5	23
		1/12/70	31	23	10	24	23	75	21	45	0.32	0.5	----	4.6	0.52		98	37	174	7.5	21.8
PUUNENE		4/18/68	63	44	40	375	25	412	20	325	1.0	5.4	0.30	1.8	0.10	0.0	278	0	1303	6.7	26
5	60'	6/17/68	58	43	25	405	22	421	81	508	2.5	7.2	0.05	32	0.16	0.9	262	0	1392	6.9	26
		1/20/68	74	35	58	390	22	598	62	478	0.70	5.0	0.04	12	0.22	1.9	375	0	1454	7.2	26
		4/8/69	71	46	55	385	23	524	61	465	0.60	3.5	----	16	0.22	0.0	340	0	1384	7.3	26
		8/7/69	33	26	50	375	26	480	64	458	0.45	3	----	18	0.02	0.7	268	0	1291	7.2	26
		10/30/69	32	42	61	300	17	480	38	450	1.9	1.6	----	14	0.17	0.25	354	0	1215	7.2	26
		1/13/70	59	58	62	275	19	390	44	477	2.7	4.6	----	14	0.62		398	80	1208	7.3	26
PUUNENE		6/17/68	60	18	27	350	21	234	69	490	1.7	6.8	0.01	23	0.30	0.4	158	0	1182	6.9	23.5
6	140'	1/20/69	72	17	29	242	14	235	47	338	0.74	3.8	0.04	15	0.42	1.0	161	0	896	7.2	23
		4/8/69	71	18	33	335	20	248	57	435	0.60	3.5	----	17	0.33	0.0	180	0	1112	7.5	24
		8/7/69	38	20	33	300	19	200	68	468	0.47	2.9	----	16	0.15	0.5	182	22	1065	7.3	23.5
		10/30/69	59	15	70	158	12	240	24	305	1.25	1.0	----	4.4	0.4	0.1	326	130	768	7.3	23.5
		1/13/70	56	28	34	230	14	180	38	376	2.2	4.6	----	13	0.74		208	62	886	7.4	23.5
SPRECKLESVILLE		6/17/68	62	19	28	325	19	172	69	485	1.2	6.8	0.01	20	0.50	1.1	158	22	1122	6.9	24
4		1/20/69	72	16	35	250	15	172	52	392	0.66	6.2	0.03	19	0.45	0.8	182	43	944	7.0	22.5
		4/8/69	7.0	3.0	2.1	5.0	0.7	12	3.0	8.5	0.10	0.1	----	4.8	0.06	0.0	16	6	40	7.2	20
		8/7/69	39	19	39	325	9.7	176	74	488	0.45	3	----	18	0.34	0.9	208	64	1104	7.3	23
		10/30/69	66	24	40	270	15	176	72	430	1.3	1.5	----	16	0.4	0.3	226	80	1024	7.4	23
		1/13/70	-------------------NO SAMPLE-----------------																		

APPENDIX C. CHEMICAL ANALYSES OF HC&S AND WAILUKU WATER SAMPLES (CONT.).

SAMPLE	DEPTH	DATE OF COLLECTION	SiO_2	Ca	Mg	Na	K	HCO_3	SO_4	Cl	F	Br	I	NO_3	PO_4	B	TOTAL HARDNESS	NON-CARB. HARDNESS	CALC. SOLIDS	pH	T,°C
									PPM												
WAIEHU GOLF		4/18/68	42	30	11	90	3.8	306	23	30	0.80	0.4	0.2	11	0.60	0.0	127	0	394	7.6	26
CLUB POND		6/19/70	37	23	9.4	93	3.5	278	11	30	0.94	0.6	0.02	14	0.60	1.6	96	0	362	7.5	26
		1/21/69	46	11	33	95	3.0	332	22	38	0.18	0.7	0.02	15	0.45	3.0	162	0	421	7.4	21
		4/7/69	23	32	3.4	93	3.1	286	15	52	1.1	0.7	----	17	0.53	0.0	94	0	382	7.9	23.5
		8/7/69	25	20	16	110	3.7	270	26	50	0.56	0.6	----	16	0.26	1.2	112	0	403	8.7	33.3
		10/29/69	45	25	10	100	29	270	23	60	5.6	0.36	----	19	0.24	0.1	84	0	450	8.9	29
		1/12/70	31	28	14	93	3	300	15	46	1.3	1.6	----	5.8	0.21		126	0	387	8.8	22
WAIHEE	5'	4/18/68	27	25	26	495	35	1070	111	188	1.8	2.5	0.40	73	0.05	0.0	166	0	1512	7.1	25
DAIRY #2		6/19/68	26	192	0.6	540	38	1620	120	208	0.86	5.8	0.10	7.2	0.40	1.2	480	0	1938	7.1	26.5
		4/7/69	25	67	31	450	24	1400	54	95	0.41	2.0	----	3.8	0.30	0.0	295	0	1443	7.4	24
		8/7/69	20	18	42	430	20	1100	64	78	0.5	1.3	----	0.8	0.00	0.9	216	0	788	7.4	25
		10/29/69	25	36	66	250	27	930	69	98	0.64	5	----	6.3	1.41	0.6	360	0	1043	7.2	26
		1/12/70	33	24	12	480	36	1330	36	20	1.3	7.8	----	1.8	0.9		450	0	1303	7.7	24
WAIHEE	5'	4/18/68	6.5	20	12	50	5.8	194	6.0	36	0.30	0.6	0.20	0.4	0.05	0.0	100	0	233	7.2	24
DAIRY # 3		6/19/68	20	58	33	154	9.2	565	49	100	1.0	8.8	0.75	0.0	0.40	1.2	280	0	713	7.3	24.5
		4/7/69	34	95	76	170	20	1155	16	90	0.16	7.4	----	4.2	4.1	0.0	550	0	1086	7.3	24
		8/7/69	20	20	53	120	9.8	500	27	90	0.32	4.4	----	0.3	0.0	0.9	264	0	592	7.4	24.5
		10/29/69	NO SAMPLE																		
		1/12/70	28	31	116	152	16	968	15	40	1	6.2	----	3.4	0.49		556	0	886	7.6	24
WAIKAPU		4/18/68	52	29	27	265	18	324	86	304	0.80	2.3	0.30	1.6	0.20	0.0	182	0	946	6.7	24
7	125'	6/17/68	34	31	30	295	15	337	60	380	0.98	5.0	0.01	22	0.44	2.1	200	0	1040	6.7	23.5
		1/20/69	30	18	13	55	3.0	124	17	70	0.2	0.8	0.02	6.6	0.13	1.6	97	0	276	7.1	23.5
		4/8/69	59	30	39	280	14	352	51	330	0.52	2.7	----	17	0.33	0.0	234	0	1003	7.4	24
		8/7/69	30	32	41	245	7.7	356	64	300	0.23	2.7	----	17	0.15	0.9	249	0	916	7.3	23.5
		10/30/69	54	36	41	290	10	368	27	370	1.5	1.2	----	14	0.28	0.1	266	0	1026	7.3	23
		1/13/70	47	32	39	200	7	280	35	273	2.2	3.7	----	13	0.20		242	11	790	7.4	23