TRITIUM MEASUREMENT OF NATURAL WATERS ON OAHU, HAWAII: A PRELIMINARY INTERPRETATION (SAMPLING PERIOD: JULY 1969 TO JUNE 1970)

by

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ABSTRACT

Water samples collected from various surface and sub-surface sources on the island of Oahu were analyzed for tritium levels. Tritium activity levels in twenty-five monthly rainwater samples show a seasonal dependence with a maximum in the summer (18.5 to 23 TU) and a minimum in the winter (12 TU). Samples from two surface-water reservoirs had activities of 13.2 and 19.7 TU reflecting contemporary rainwater which is their major source of recharge. Four streams in the Pearl Harbor area showed "rainwater" tritium levels when sampled at high flow. At low flow, two of the streams had low tritium levels indicating ground-water discharge into the stream, while the tritium activity of the other two streams was comparable to rainwater. Tritium activity higher than that of contemporary rainwater (22-38 TU) was exhibited by samples from two springs which discharge perched water, while samples from three wells and two shafts in the Honolulu area showed very little or no tritium activity. Multiple-depth samples obtained from wells in the Pearl Harbor area showed correlations between tritium activities, depths of sampling, and chloride concentrations.

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INTRODUCTION

Atmospheric precipitation contains a minute concentration of tritiated water molecules (H - O - T). These molecules differ from ordinary water molecules in that a tritium atom occupies the position of one of the two hydrogen atoms, but tritiated water molecules have nearly identical physical and chemical properties as ordinary water molecules (H - O - H). It is therefore generally assumed that they act alike during natural hydrological processes, such as precipitation, evaporation, or infiltration. Tritium atoms are radioactive isotopes of hydrogen with a half life of 12.26 years. The concentration of tritiated water molecules in a water sample can thus be assessed through radiochemical analysis.

At present, two major sources of tritium atoms (in short tritium) can be identified: natural and man-made. Natural tritium is produced in the upper atmosphere when cosmic rays and nitrogen atoms collide. Man-made tritium mainly comes from the detonation of nuclear bombs. Tritium from natural sources is small in contemporary precipitation compared to that from "man-made" sources. Measurements of the natural abundance of tritium in Hawaiian rain was made in 1953 by von Buttlar and Libby. The results of their analyses are listed below:

SAMPLE	COLLECTED	TU
UPPER NUUANU	3-26-53	0.61 ± 0.10
HICKAM FIELD	7-17-53	0.59 ± 0.08
TANTALUS	11-13-53	0.73 ± 0.11
MANOA VALLEY (SINGLE RAINFALL)	12----53	1.53 ± 0.11
COMPOSITE OF SEVERAL RAIN-GAGES KOOLAU RANGE	------53	0.67 ± 0.14

The effects of the explosion of nuclear weapons upon the tritium activity in precipitation, monitored during the early sixties by the International Atomic Energy Agency, indicated that between February 1962 and June 1965, tritium activity levels in Hawaiian rain varied between a minimum of 21 TU and a maximum of 373 TU. Since that time there has been a gradual decrease in atmospheric tritum. At present, the activity level of tritium in Hawaiian rain is between 10.5 and 23.1 TU which is still considerably higher than the natural levels measured by von Buttlar and Libby in 1953.

It is possible to utilize the man-made tritium spike as a tracer to

study the infiltration, flow, and storage of ground water. For this application, it is necessary to analyze ground-water samples for their tritium content. A comparison of the possible differences in tritium activities can then be made between samples from different regions or depths. As a working basis for the preliminary study reported here, it is assumed that any ground water containing tritium levels above the natural abundance level (~ 0.5 TU, decay corrected) must contain man-made tritium. The latter implies that such ground water, or at least a part of it, must have been recharged less than 17 years ago since major testing of nuclear weapons started in 1954. Thus, tritium activity levels consistently below about 0.5 TU indicate that no recharge from rainwater has taken place within the last 17 years. For a more sophisticated approach it will be necessary to obtain all available rainwater-tritum data taken during the last twenty years and construct decay corrected tritium input functions. Current efforts at the Water Resources Research Center are geared towards the implementation of this approach for future studies.

The objectives of the study herein reported are as follows:

1. Determine the present activity levels of Hawaiian rain and surface waters.

2. To make a pilot investigation of the tritium levels of the various types of ground water on the island of Oahu.

3. To identify those ground-water bodies or systems which would be most suitable for tritium analysis because of its capability to indicate differences between recently recharged waters and waters having long residence times.

Included in the data discussed in this report are those listed in a previous report (Hufen, *et al.*, 1969).

ANALYTIC PROCEDURE

Instrumentation and procedures used for the tritium analysis were essentially the same as described in a previous report (Hufen, *et al.*, 1969). In view of this, only a brief outline of the analytic procedure will be given here. Any changes or improvements made during this period of research will be pointed out.

Tritium analysis consists of electrolytic enrichment and liquid scintil-

lation counting. To enrich water samples, the "periodic addition electrolysis" method is used (Ostlund and Werner, 1962) with some minor modifications. Samples of 500 ml are electrolyzed in three stages:

500 ml - 50 ml at 6.0 amps
50 ml - 25 ml at 3.0 amps
25 ml - ~ 5 ml at 0.6 amps

During the first stage of the electrolysis (6.0 amps), the volume of water in the cells is maintained between 100 and 50 ml. Every 24 hours, the cells are refilled with 50 ml of sample water from mounted storage funnels (Fig.1). When the funnels are empty and the remaining water volume in the cells is 50 ml, the current is lowered to 3.0 amps for the second stage. When 25 ml remains the current is lowered to 0.6 amps. The electrolysis is stopped when the smallest residual sample reaches the 5 ml mark. All samples are then vacuum distilled and prepared for counting. The current for the electrolysis is provided by a constant D.C. power supply. The electrodes consist of nickel anodes and soft-iron cathodes. Each cell contains 3.0 ml of a 30-percent NaOH solution to serve as the electrolyte. A plastic T-connector attached to the head of each cell provides a gas-tight inlet for the wires and at the same time serves as a vent for the reaction gases (Fig. 1). During the electrolysis, the cells stand in a water bath maintained at 2.0 ± 0.5°C.

To count the enriched samples, a toluene-based scintillation solution of the following composition is used:

1000 ml Toluene
8.0 g Butyl PBD[1]
0.5 g PBBO[1]
450 ml Solubilizer BBS-3[1]

From each enriched sample, 2 ml is measured out and mixed with 15 ml of the scintillation solution. Counting is performed with plastic counting vials in a Beckman CPM 100 liquid scintillation counter. Enrichment factors and counting efficiences are calculated from standards which are analyzed along with the samples. Final data and error levels are computed with the use of

[1]See Appendix A for further information.

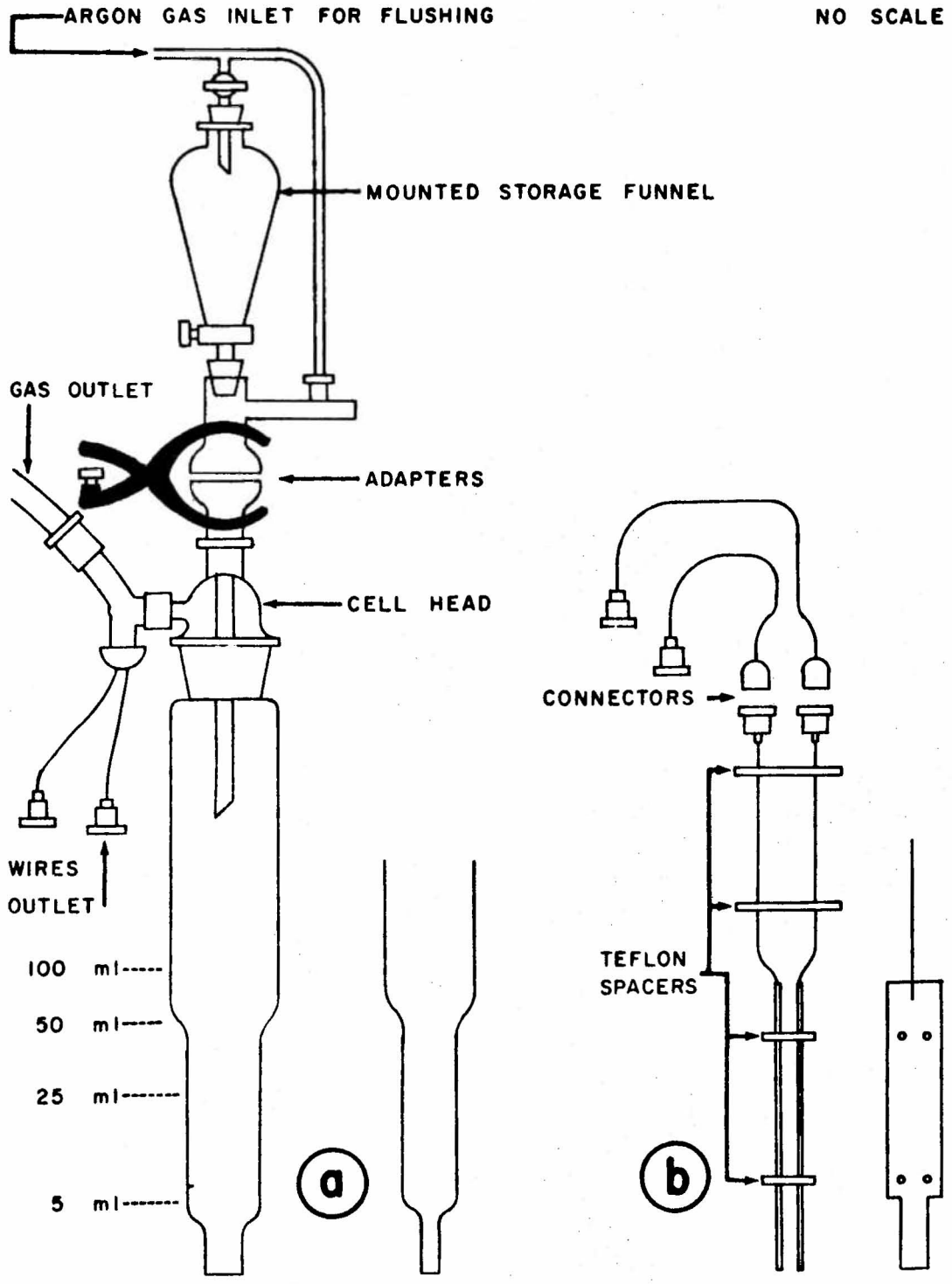


FIGURE 1. ASSEMBLY OF ELECTROLYSIS CELLS AND ADDITIVE FUNNEL, ELECTRODES, AND WIRING.

a programmable electronic calculator.

The very low tritium activity levels of most ground-water samples from Oahu has prompted the optimization of the analysis. To obtain enriched samples of higher specific activity, the electrolytic enrichment was scaled up using larger samples and higher currents. Samples in quantities of 500 ml were electrolyzed at 6.0/3.0/0.6 amps with an enrichment factor of about 16.4. A set of samples analyzed by this procedure will yield enriched samples of higher activity than could be obtained by the earlier method which was used. Previously, samples in quantities of 375 ml were electrolyzed at 4.5/2.25/0.45 amps with an enrichment factor of about 17.4 (Hufen, *et al.*, 1969).

A toluene-based scintillation solution is used for preparing the enriched samples for counting because they are more stable than those prepared with the dioxane solutions which were used earlier. The solubility of water in toluene is very limited. Even with an appropriate solubilizer only 2 ml of sample can be incorporated into 15 ml of toluene solution, whereas, with the dioxane system 4 ml can be used. Fortunately, the greater counting efficiency of the toluene mixtures (37 percent), as compared to that of the dioxane mixtures (20 percent), makes up for its limited solubility.

Background counting rates have been lowered significantly by using plastic counting vials. Typical background rates obtained at present are around 6.0 CPM/ml (Counts Per Minute/ml of H_2O) compared with 10 to 10.5 CPM/ml for the glass vials used before. An undesirable feature of the plastic vials is their permeability to toluene. On standing, a toluene-based mixture contained in a plastic vial gradually reduces in volume due to diffusion of the toluene through the walls of the vial. This diffusion causes a change in the composition of the scintillation mixture and, hence, a change in its counting efficiency. To avoid counting errors, the following procedure is used. All enriched samples from one electrolysis run along with blanks and counting standards are mixed with the scintillation solution and stored in glass vials. The samples are transferred to plastic counting vials and dark-adapted in the counter for 12 hours before it is counted. Each sample is counted several times for certain pre-set periods (usually 200 min.). This procedure, although somewhat cumbersome, has given reproducable results.

RESULTS AND INTERPRETATION

Rainwater at Koolau Mountain Range near Honolulu

Rainwater samples were collected from eight stations located in high rainfall areas on the Koolau Range near Honolulu from July 1969 to June 1970 (Fig. 2) and analyzed for tritium activity levels. Laboratory analyses were done within 10 days after the sample was collected and tritium activity levels were averaged with the following formula:

$$\bar{Y} = \left[\frac{\Sigma_i \left(\frac{Y_i}{\sigma_i} \right)^2}{\Sigma_i \left(\frac{1}{\sigma_i} \right)^2} \right]^{1/2}$$

where: Y_i = individual tritium activity level

σ_i = error on Y_i

The error on $\bar{Y}$ was computed using the formula:

$$\sigma_{\bar{y}} = \left[\frac{\Sigma_i (\sigma_i)^2}{n_i} \right]^{1/2}$$

where: n_i = number of Y_i values

In Figure 3, the averaged tritium activities ($\bar{y}$) are plotted against time. The $\sigma_{\bar{y}}$ values are indicated by the shaded area. Seasonal fluctuation is evident, being high (23 TU) in June 1969, low (12 TU) in December 1969, and high (18.5) again in June 1970. This fluctuation has been also known to exist elsewhere. Since there were no known thermonuclear detonations adding artificial tritium to the atmosphere during the months just prior to the report period, the tritium fallout during this period was provided by the tritium already existing in the atmosphere. The periodic and attenuating pattern can be represented by a mathematical function which will be used as an input function of tritium by way of rainwater to ground water.

Average monthly rainfall was computed from records of twenty-four rain-

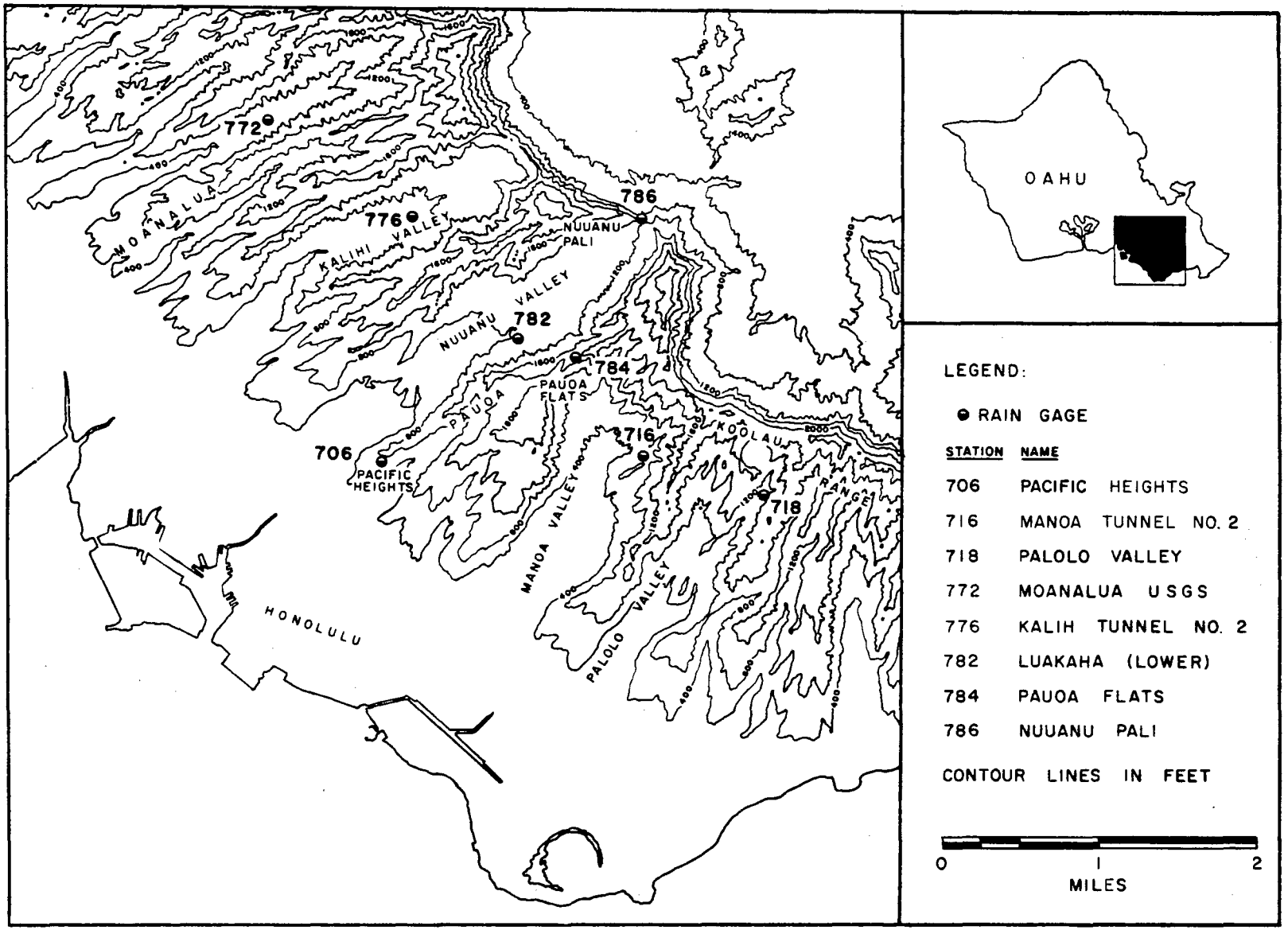


FIGURE 2. RAINWATER SAMPLING STATIONS ON THE KOOLAU RANGE, OAHU.

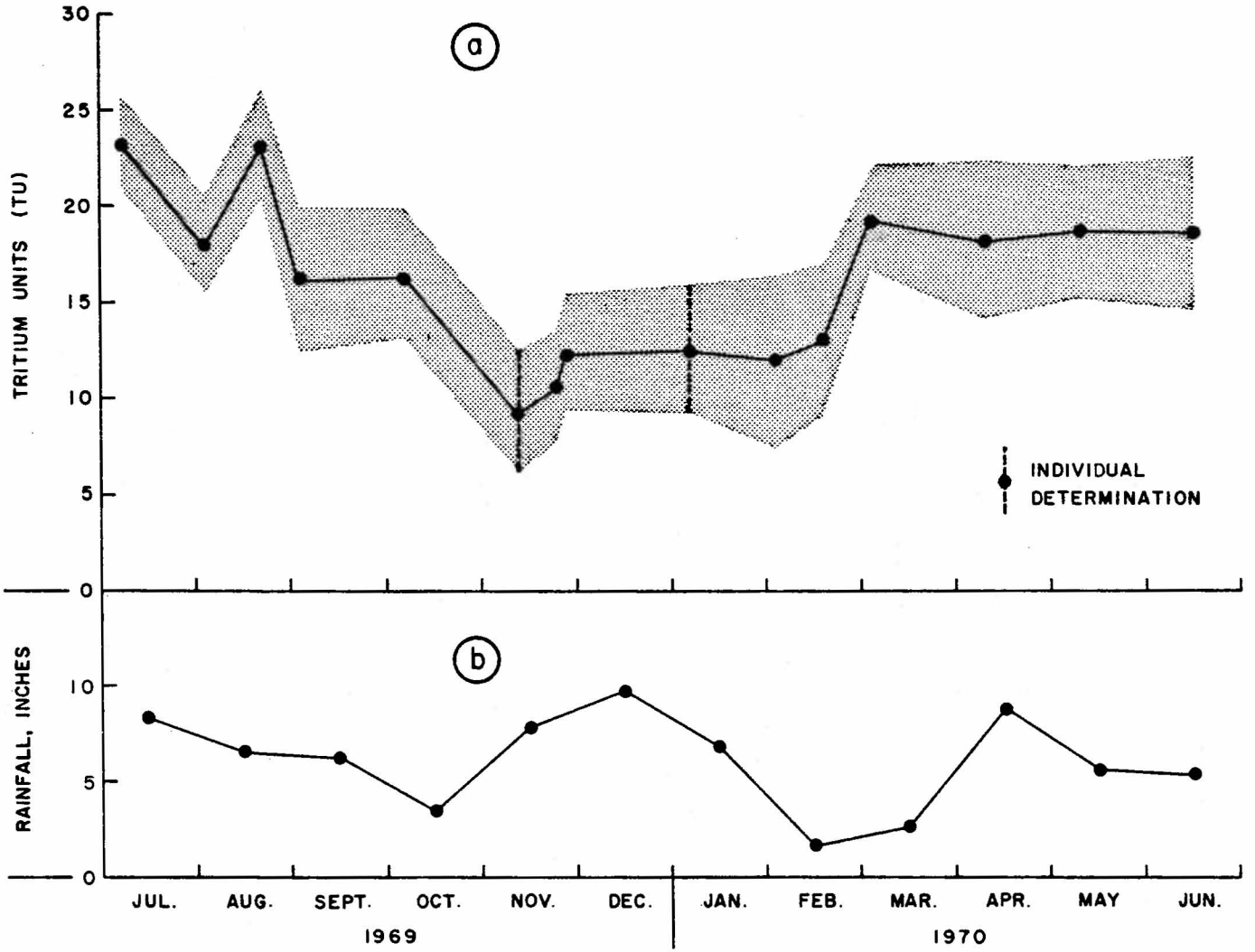


FIGURE 3. TRITIUM ACTIVITY IN RAINWATER COLLECTED ON OAHU, HAWAII.

gages located in the sampled areas. The eight gages providing the rainwater for tritium analysis are among them. The average values are also plotted in Figure 3. Apparently no relationship exists between the tritium in the rainwater and the average rainfall over the study area.

Reservoir Water

Water samples collected on November 12 and 13, 1969 from two surface reservoirs had the following tritium activity levels:

Nuuanu Reservoir	13.2 ± 4.1 TU
Wahiawa Reservoir	19.7 ± 3.1 TU

The data generally reflect tritium in contemporary rainwater, circa 1969-1970.

Surface reservoirs are not common in Hawaii for several reasons: lack of sites having large capacity, excessive seepage, limited land resources, and the dependence on ground water rather than surface water sources for water supplies.

The Nuuanu Reservoir sampled is properly identified as Nuuanu Reservoir No. 4 under the jurisdiction of the Honolulu Board of Water Supply. It has a storage capacity of 531.9 million gallons and its release is now geared principally to flood control and, to a very minor extent, diverted to sand filters to augment the domestic water supply. About five years ago, the Honolulu Board of Water Supply began to open the reservoir to fishing but on a very limited schedule. Ground-water recharge probably occurs through seepage from the bottom and sides of the reservoir but the quantity is uncertain.

Wahiawa Reservoir situated at an elevation of about 800 feet is located within the geologic boundary that creates a high-level water in central Oahu. The elevation of the water table there varies between 270-285 feet above sea level, whereas, the basal water table outside the geologic boundary is only about 25 feet.

Wahiawa Reservoir which has a storage capacity of 2.9 billion gallons and a maximum depth of 85 feet was constructed to catch and store surface runoff from Kaukonahua Stream for irrigation water by Waialua Sugar Company. It also receives sewage effluent from nearby sewage treatment plants. With-

drawal of reservoir water is principally dictated by irrigation requirements. It is open to fishing all year round under the management of the State Fish and Games Division. The fish yield is probably the best in the state.

Stream Water and Spring Water

The stream mouths of four streams draining the Pearl Harbor-Waipahu area and the nearby spring areas were sampled (Figs. 4 and 5). The tritium content of these samples are presented below in Table 1.

TABLE 1. TRITIUM ACTIVITY OF STREAM WATER, SPRING WATER AND RAINWATER, OAHU, HAWAII: 1969-1970.

STREAM WATER

STREAM GAGING STATION	DRAINAGE AREA SQ. MI.	MAY 6, 1969 WET WEATHER TRITIUM ACTIVITY TU	MAY 6, 1969 WET WEATHER MEAN DAILY FLOW CFS	DECEMBER 17, 1969 DRY WEATHER TRITIUM ACTIVITY TU	DECEMBER 17, 1969 DRY WEATHER MEAN DAILY FLOW CFS	AVERAGE DAILY FLOW YEAR 1968 CFS
KALAUAO	2.59	21.3 ± 2.9	11	4.7 ± 4.0	0.2	6.0
WAIMALU	6.07	20.8 ± 2.6	30	17.4 ± 4.1	----	14.7
WAIAU	26.4	14.5 ± 2.4	112	3.6 ± 2.4	5	80.5
WAIKELE	45.7	18.5 ± 2.3	141	13.7 ± 3.0	24	77.3

SPRING WATER

SPRING	MAY 6, 1969 TRITIUM ACTIVITY TU	DECEMBER 17, 1969 TRITIUM ACTIVITY TU
KALAUAO	-----	0.4 ± 2.7
WAIAU	0.3 ± 2.8	1.1 ± 2.4
WAIAWA	0.3 ± 2.1	1.0 ± 3.0

RAINWATER

RAIN GAGE	MAY 5, 1969 TRITIUM ACTIVITY TU	NOVEMBER 1969 TRITIUM ACTIVITY TU
PACIFIC HEIGHTS NO. 706	18.8 ± 2.6	10.5 ± 2.9
LOWER LAUKAHA NO. 782	23.6 ± 2.9	12.3 ± 3.0
NUUANU PALI NO. 786	21.5 ± 3.1	12.5 ± 3.4

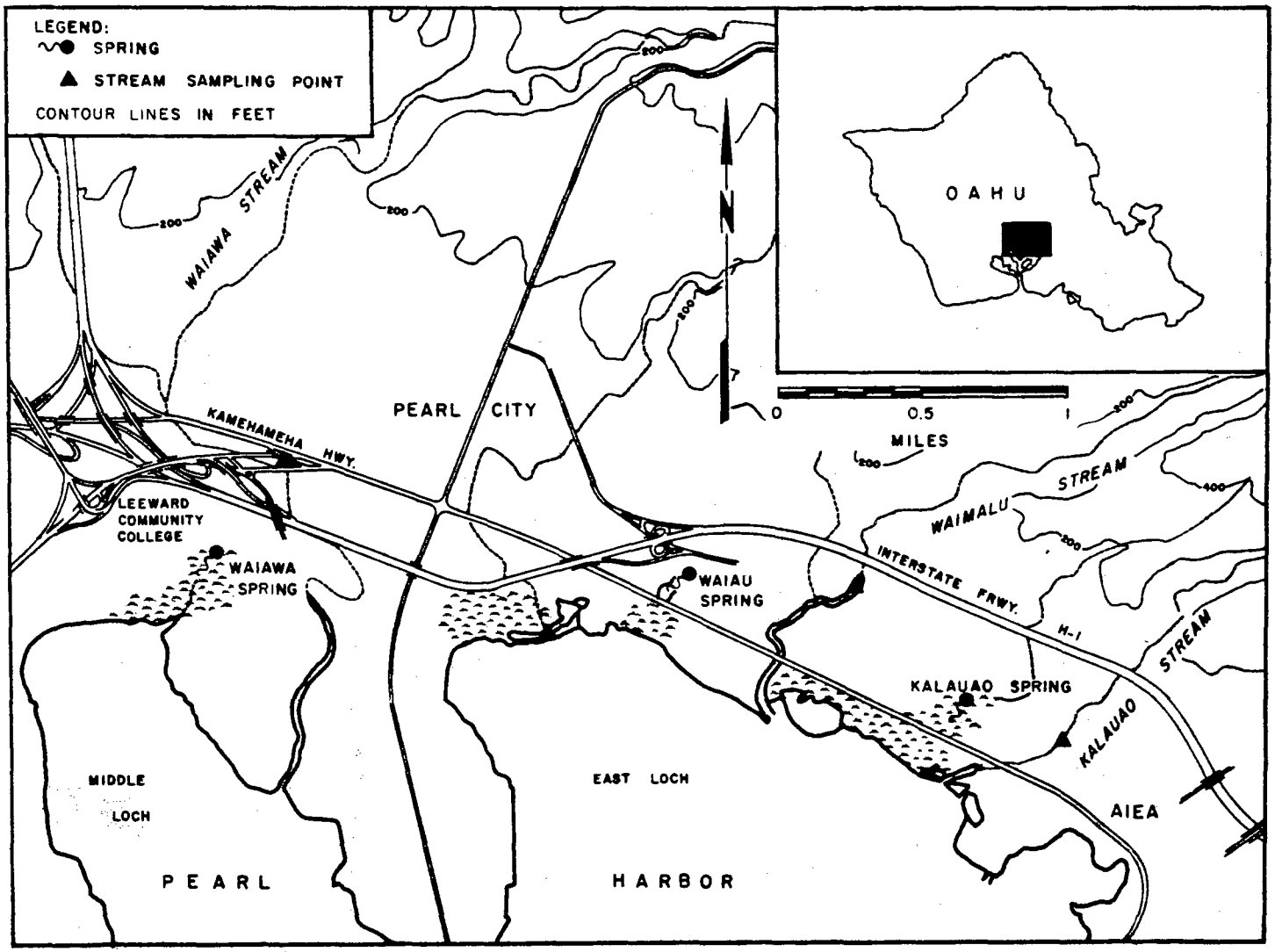


FIGURE 4. STREAM AND SPRING SAMPLING POINTS, PEARL HARBOR AREA, OAHU.

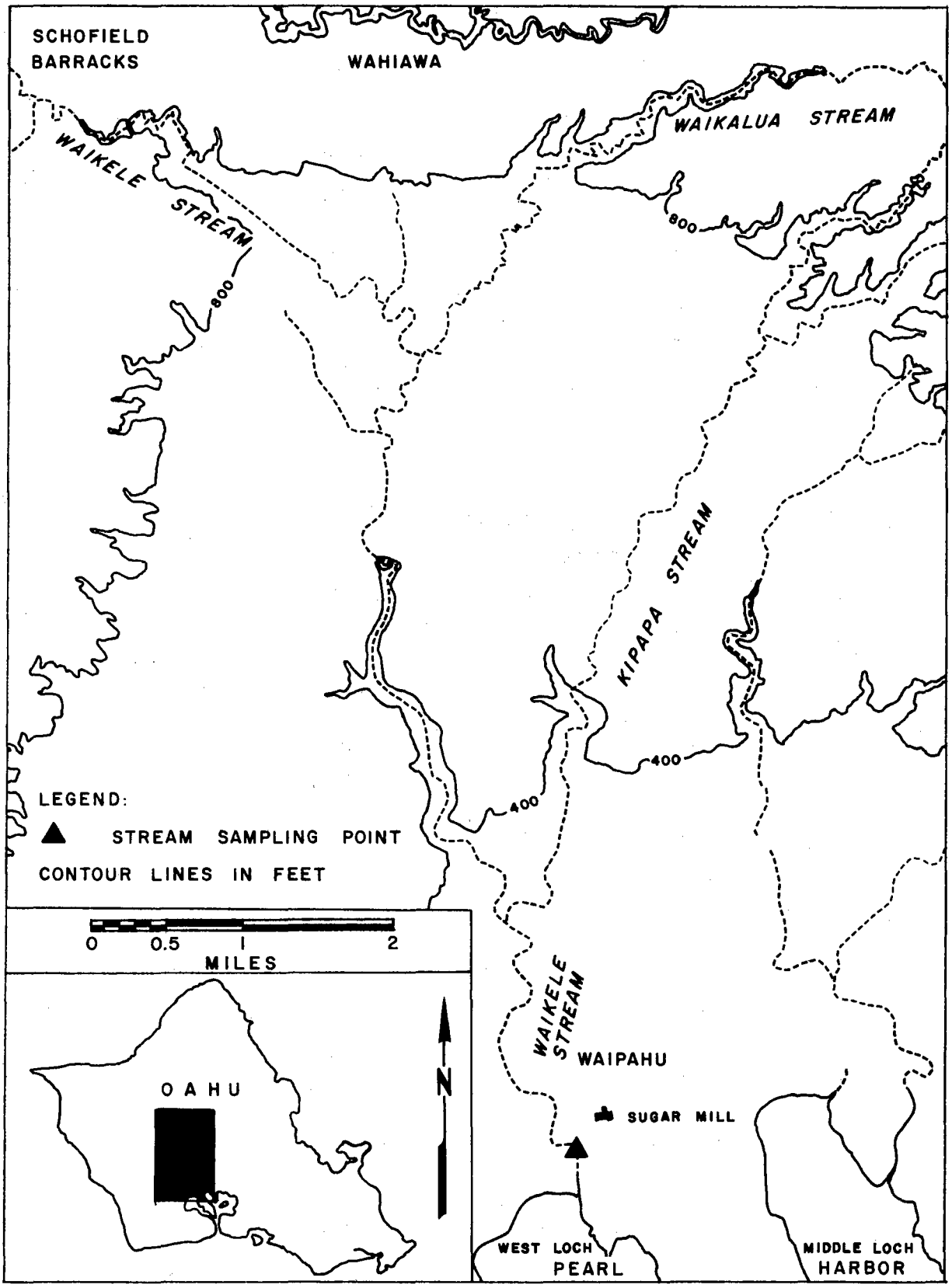


FIGURE 5. STREAM SAMPLING POINT, WAIPAHU AREA, OAHU.

It should be pointed out that Hawaiian stream discharge is extremely flashy. Streams are very sensitive and rise and fall in response to storms in a matter of hours, carrying that portion of rainwater not lost principally to infiltration out to sea. Because of the high permeability of Hawaiian soils, much of the infiltrated water percolates downward to contribute to ground water and normally does not reappear on the ground. The only exceptions occur when water is perched by tight materials such as ash or hardpan below the ground.

Dry weather flow in Hawaiian streams in the mountains comes principally from orographic tradewind showers or ground-water discharge of diked water. Unless these water sources are large enough, streams leaving the high rainfall areas can lose their content and become dry. However, there are also streams which gain water as they progress downstream. Near the coast streams, whether dry or wet enroute, can pick up water from basal discharges and become perennial.

With this simplified general information, the following observations can be made:

1. On May 6, 1969, a wet weather day, all stream waters reflect contemporary rainwater in terms of tritium activity levels although Waiawa stream water had noticeably lower TU levels than rainwater.

2. On December 17, 1969, a dry weather day, the TU activity levels in Kalauao and Waiawa Stream waters were much lower than that in the contemporary rainwater. A possible explanation could be that the stream water came largely from a low-tritium source such as ground-water discharge. The fact that Waiawa Stream water has the lowest levels of TU could be taken to mean that ground-water flow into Waiawa Stream is disproportionately greater than that to other streams.

3. On December 17, 1969, a dry weather day, the activity levels of TU in the discharge from both Waimalu and Waikele Streams were anomalously higher than that in contemporary rainwater. The source of the high tritium water is unknown at present.

Stream Water

WAIKELE STREAM. Waikele Stream at Waipahu (Gaging Station 2130) drains one of the largest drainage basins, 45.7 square miles, on Oahu (Fig. 5). Its

upper reaches cuts into Koolau basalt in central Oahu and also into both consolidated and unconsolidated noncalcareous deposits in its lower reaches near Pearl Harbor (Stearns and Vaksvik, 1935).

At the gaging station where the water samples were taken, the stream channel bottom was not paved over. Waikele Stream is intermittent at its upper reaches, but at the gage site, the flow is perennial because Waikele Spring discharges into the stream channel. The average flow of Waikele Spring between 1953-1957 was 34 cfs (Visher and Mink, 1964). On the date of measurement, the discharge at the gage was 24 cfs and was nearly the lowest daily flow of the year.

The gage height on the sampling date was 2.13 feet (U.S. Geological Survey data) and the gage datum is 1.37 feet above the mean sea level. Hence, the water level in the channel was 3.50 feet. The ground-water head in this area is about 19 feet (Honolulu Board of Water Supply, 1964). Hence, it is clear that the stream is receiving ground-water seepage near the sampling site.

The stream-flow data reflected dry weather condition for at least twenty days prior to the day of sampling (U.S. Geological Survey, 1968). Hence, contemporary rainwater contribution to the stream-water sample was unlikely. Diversions above the gaging station for irrigating sugarcane in Waipahu have been documented (U.S. Geological Survey, 1969). It is believed that return water from Waipahu Sugar Mill probably flows into Waikele Stream above the sampling site.

The stream-water samples obtained from Waikele Stream consist of ground water, possibly mill return water, and seepage from unknown sources. The tritium levels of the samples were anomalously high (13.7 ± 3.0 TU), which is higher than contemporary rainwater and certainly higher than any known level in ground water. Further investigation is needed to determine the cause or causes of the anomaly.

WAIAWA STREAM. The geologic formations of the Waiawa basin are generally similar to that of Waikele basin (Stearns and Vaksvik, 1935).

Waiawa Stream at Gaging Station 2160 near Pearl City has a drainage area of 26.4 square miles. The stream starts at the high-rain area but runs dry at about the 400-foot level. At the gaging station site, basal ground water flows into the stream as its channel bed cuts into basalt at an elevation of about 15 to 20 feet. The low flow of the stream is affected by effluent discharge from a sewage treatment plant, occasional small

irrigation diversion, and return flows above the station (U.S. Geological Survey, 1969).

On December 18, 1969, the date of sampling, the stream discharge was 5.1 cfs, near the lowest daily flow. The gage height was 1.71 feet above datum which is 1.81 feet above mean sea level. Since the regional ground-water head is about 18 feet, which is considerably above the stream gage height of 3.52 feet, and since the channel material is natural and cuts into the basalt, the sampled water was mostly ground-water discharge.

Waiawa Springs are down gradient from the gaging station (See Fig. 4). It is interesting to compare tritium levels in Waiawa Stream and Waiawa Spring waters which were collected on the same day:

Waiawa Stream	3.6 ± 2.4 TU
Waiawa Spring No. 1	2.0 ± 3.1 TU
Waiawa Spring No. 2	0.0 ± 3.0 TU

WAIMALU STREAM. The Waimalu Stream basin is geologically similar to that of Waiawa and Waikele Streams and its drainage area at the gaging site is 6.07 square miles. The mean daily flow for Waimalu Stream averages 14.7 cfs for the water year. Under normal conditions, occasional small diversion for irrigation of truck farms is practiced above the station (U.S. Geological Survey, 1969). The tritium activity level (17.4 ± 4.1 TU) was not only the highest in the Pearl Harbor area but was higher than any ground water that had ever been sampled. It is even higher than contemporary rainwater. The sources of the high tritium water cannot be presently determined.

Construction of the H-3 interstate freeway has changed the landscape and stream channel considerably and resulted in a temporary cessation of stream gaging during the sampled period. However, since neighboring gaging stations showed dry weather flow during this period, the Waimalu Stream data in all probability also reflect dry weather flow.

KALAUAO STREAM. Kalauao Gaging Station 2245 at Moanalua Road in Aiea, located at an elevation of 12.75 feet above mean sea level, is the highest among the four stream gaging stations sampled. The low tritium activity level found in the stream water sample (December 17, 1969) indicates conclusively the absence of direct rainwater contribution to the stream flow on that day. This checks well with the rain record showing that period of time was indeed dry weather.

Perched Ground Water

Makiki and Booth Springs are located at an elevation well above the 800-foot contour. They are in a region close to the 100-inch annual isohyet where there is lush growth year round. The general area is covered by basalt and fire fountain deposits (black sand) of the Honolulu Volcanic Series, which are late deposits resting on the soil-covered surface of the much older Koolau basalt. The black sand is extremely permeable, friable, bedded, and, in places, cemented by secondary calcite. Percolating water is trapped by the soil and alluvium to form perched ground-water bodies. East Makiki Spring occurs at 954 feet and West Makiki at 976 feet. The average annual discharge from combined East and West Makiki Springs ranges from 0.62 to 0.12 mgd with highest flow occurring typically in the months of December and January as during the years 1968-1970 (Fig. 6).

Booth Spring is not in hydrological communication with Makiki Spring although they were probably created in the same geologic period. A late lava flow poured out from Tantalus and ran down Pauoa Valley for one and one-half miles and buried the alluvium and soil. The buried materials apparently prevent much of the recharge water from percolating downward into Koolau basalt and instead perch water which seeps to create several springs, the highest one being Booth Spring at 775 feet. The discharge from Booth Spring is considerably smaller than that from Makiki Spring, the average annual discharge ranging from 0.20 mgd to zero during the years 1968-1970. It occasionally ran dry.

Figure 6 shows the monthly discharge hydrograph for Makiki and Booth Springs. Similar seasonal fluctuations are clearly evident for both springs. Booth Spring has a smaller discharge than Makiki Spring and Booth Spring has run dry or nearly dry every year, indicating that it discharges the overflow from the smaller of the two perched ground-water bodies. There is about a two-month lag between discharge and rainfall fluctuations and the input-output relation between rainfall and discharge is unmistakable.

The tritium data on water samples collected from Makiki and Booth Springs are insufficient to demonstrate a definite seasonal fluctuation but they appear to correspond to the fluctuation in the activity level of tritium in rainwater as indicated in Table 2. Further, the tritium activity level is higher in the spring water than in contemporary rainwater. This would suggest the following:

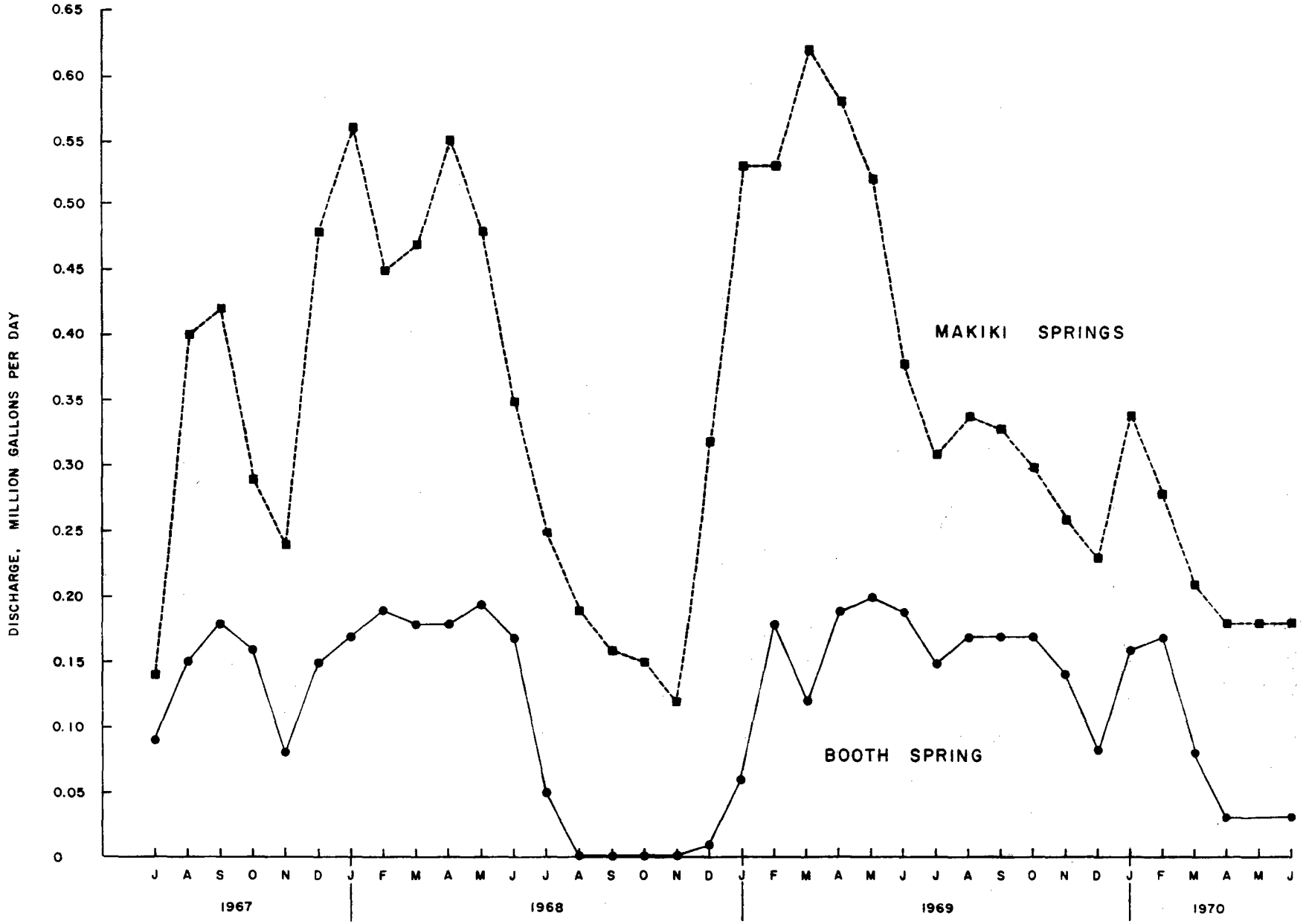


FIGURE 6. DISCHARGE FROM MAKIKI SPRING AND BOOTH SPRING: 1967-1970.

TABLE 2. TRITIUM AND CHEMICAL QUALITY OF MAKIKI SPRING AND BOOTH SPRING: 1969-1970.

SPRING	SAMPLING DATE	H-3	pH	Cl^-	HCO_3^-	SiO_2
MAKIKI SPRING	11-13-69	22.2 ± 4.2				
	6-17-70	32.7 ± 6.8	7.7	23	128	27
BOOTH SPRING	11-13-69	25.2 ± 5.6				
	6-17-70	37.9 ± 5.6	7.9	20	120	27

1. Rainwater that has infiltrated is not completely and immediately discharged as spring water.

2. The spring water is made up either in part or in entirety of ground water which has been in storage from past rainfalls having high tritium content. Despite an unknown period of storage and dilution by the more recent rainwater having low tritium, the spring discharge still has a tritium content higher than contemporary rainwater.

High-Level Ground Water

WAIHEE TUNNEL, KANEOHE. Waihee, an unusual high-level diked water, was documented by Hirashima (1965, see Fig. 7). As part of the current survey, a sample was collected on May 28, 1970 which showed tritium activity of 4.3 ± 2.6 TU. This activity level, although not very high, unmistakeably indicates the presence of "excess" tritium. The tunnel discharge thus consists at least in part of "young" water. In view of the findings by Hirashima, it is suspected that the tritium activity level of the tunnel water may reflect the mixing of waters from two different sources: 1) water in dike compartments located behind the ones penetrated by the tunnel (low in tritium ?). 2) Stream water and rainwater infiltrating through the surface of the overlying material (high in tritium). Additional sampling and analyses are under way as part of a detailed study on water stored in Koolau dike compartments.

WAHIAWA WELL 330-9. High-level ground water has been known to occur in the Wahiawa area with water levels varying between 270 and 185 feet above sea level (Board of Water Supply, 1963). A sample taken from well 330-9 on

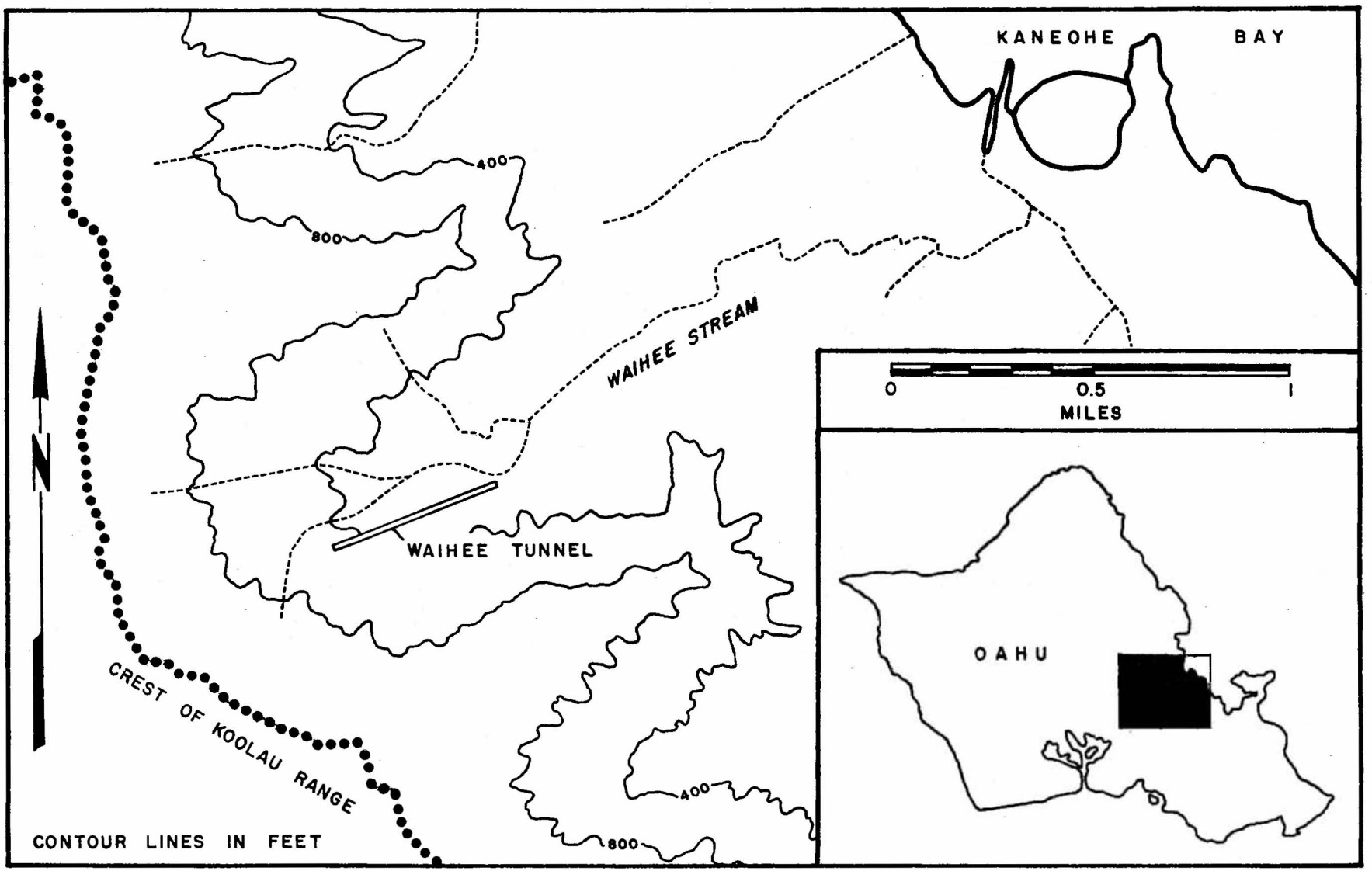


FIGURE 7. WAIHEE (FROM HIRASHIMA, 1965).

11-13-69 showed an activity of 1.7 ± 1.8 TU which is on the margin of detectability, hence meaningful interpretation is not possible until additional data become available.

Basal Ground Water

HONOLULU COASTAL PLAIN. The Honolulu coastal plain and the adjoining valleys are covered by a formation of terrestrial and marine sediments, known locally as "caprock," which is thinnest at its inland boundary and progressively increases in thickness toward the coastline. The permeability of the caprock, taken as a whole, is considered quite poor in comparison with the extremely permeable underlying basalt. Hence, the possibility for percolating water to pass through the caprock into the basalt is considered poor and, in terms of hydrologic significance, the recharge of rainwater through the caprock into the underlying ground water is considered nil. The natural recharge to the Honolulu coastal plain takes place inland in noncaprock areas. Furthermore, natural recharge is limited to areas where the annual rainfall exceeds the annual evapotranspiration. A second source of recharge of the ground water in the basaltic formation is from water caught and stored between the dikes in the marginal dike zone of the Koolau mountain range. The water, known as dike or high-level water because of the high elevation at which the water occurs, is lost as subsurface or surface flow over the dikes and leakage through openings or other imperfections of the otherwise water-tight dikes. The ground-water body receiving the dike water is known as basal water because of its relatively low water table of about 20 feet above sea level compared with that of the high-level water occurring at about 600 feet above sea level. Although difficult to estimate generally, basal-water storage is infinitely larger than diked-water storage. Figure 8 is a generalized map with two cross sections illustrating the gross occurrence of ground water in the Honolulu coastal plain.

The initial sampling program of the Honolulu coastal plain has been limited to the three major pumping stations, Kaimuki, Beretania, and Kalihi, and two shafts, Waialae and Kalihi. Their locations are shown in Figure 8. Each Station pumps a number of wells which penetrate the caprock and extend to various depths into the basalt and receive water only from basalt. The wells are connected to a common header and pump system. The shafts are

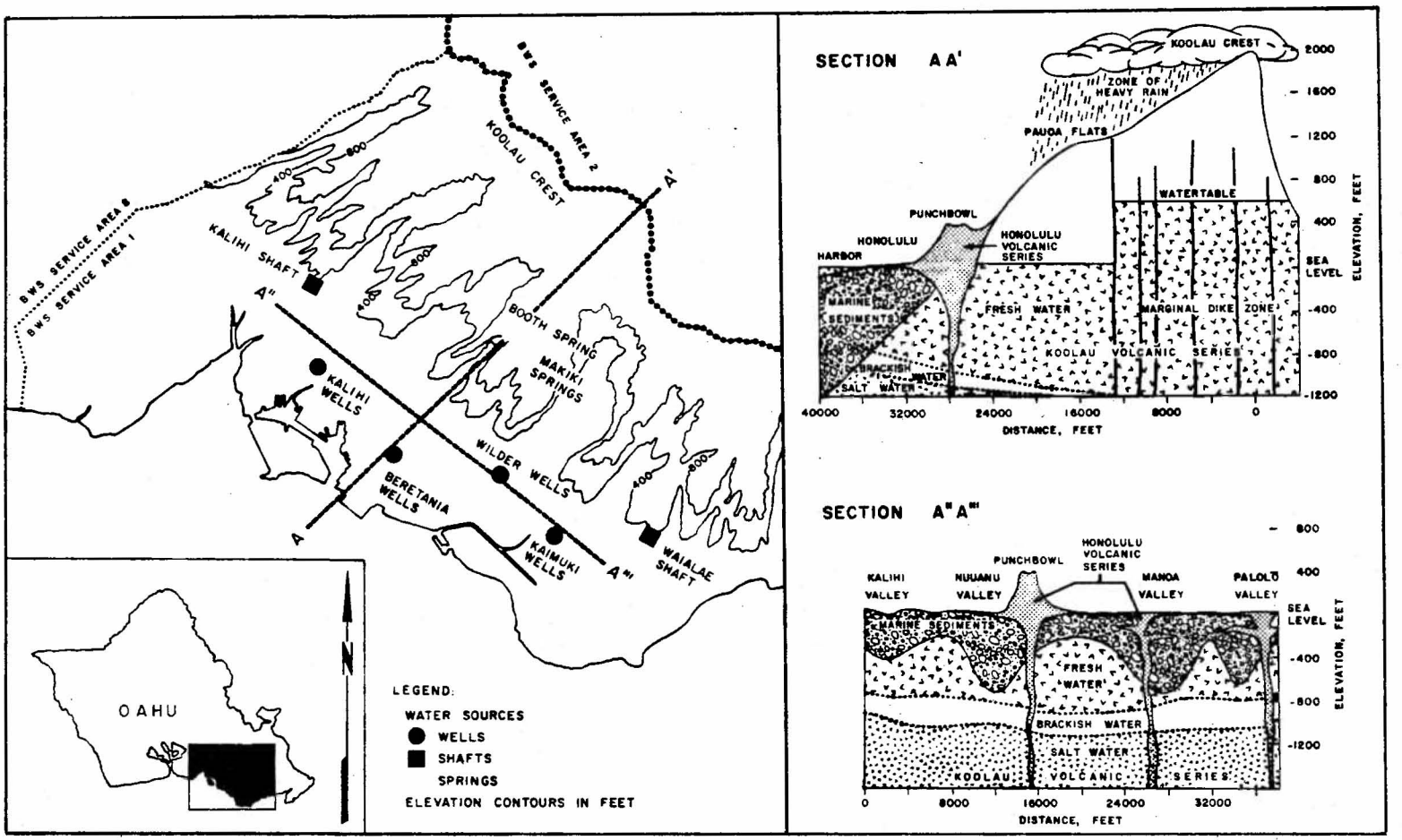


FIGURE 8. SAMPLING POINTS, HONOLULU COASTAL AREA.

essentially horizontal tunnels located at a shallow depth below the water table to permit infiltration of ground water into it. The tunnels are located to the side of the valley caprock. The table below gives some pertinent geohydrologic information:

STATION	TYPE	SUSTAINABLE[1] CAPACITY, mgd	1970[2] AVERAGE DRAFT, mgd	DEPTH[3] FT. BELOW msl	BOTTOM ELEV. OF CAPROCK FT. BELOW msl
KAIMUKI	WELLS	6.0	4.54	240	75
BERETANIA	WELLS	10.0	10.57	600	450
KALIHI	WELLS	8.0	8.0	400	300
WAIALAE	SHAFT	0.5	0.38	---	---
KALIHI	SHAFT	13.0	14.33	---	---

[1]BWS OAHU WATER PLAN
[2]BWS, 1970, ANNUAL REPORT SUPPLEMENT
[3]STEARNS AND VAKSVIK, 1938

The tritium levels in these initial samples are as follows:

LOCATION	SAMPLED WELLS	SAMPLED DEPTH	SAMPLED DATE	H-3	pH	Cl^-	HCO_3^-	SiO_2
KAIMUKI WELLS	7 E	85'	11-12-69	0.0 ± 1.6	8.1	76	77	37[1]
KAIMUKI WELLS	7 E	266'	11-12-69	0.0 ± 1.6				
BERETANIA WELLS	88 A, C-J	COMPOSITE	11-12-69	0.0 ± 1.6	8.3	59	78	38[1]
BERETANIA WELLS	88A, C-J	COMPOSITE	6-29-69	0.5 ± 1.2	7.8	80	82	39[2]
KALIHI WELLS	128 A-H	COMPOSITE	11-12-69	0.0 ± 2.3	8.2	69	71	37[1]
KALIHI SHAFT			11-12-69	3.3 ± 2.8	8.0	74	65	39[1]
WAIALAE SHAFT			11-12-69	1.9 ± 1.9	7.9	150	105	44[1]

[1]BWS OAHU WATER PLAN
[2]BWS, 1970, ANNUAL REPORT SUPPLEMENT

The data clearly suggest that the age of all basal water except near the top is older than can be measured by the present analytical capability of the Water Resources Research Center Tritium Laboratory. The data can mean that the first bomb-spiked tritium activity which occurred in 1954 has yet to reach the sample sites from the recharge area (Libby, 1963). Hence, a minimum age of 16 years may be inferred. This inference is based on the flow pattern of the recharge to the water wells and the dispersion of the spiked water in transit, both of which will cause dilution.

The shaft readings also suggest that the more recently recharged water occurs near the top of the basal water table. It is most likely that an age gradation of the basal water exists at different depths. Identical tritium readings at two different depths (85 feet and 266 feet) at 0.0 ± 1.6 TU merely means a common minimum age rather than the same age. Noting that both shafts are closer to the recharge area than the three pumping stations,

the higher tritium readings can also be taken to mean a spatial variation of the tritium distribution in the basal ground water. Much more data are needed from the same sampling sites extending over a longer period and from different depths together with other sampling sites both near the recharge area and the coast before meaningful statements can be made regarding ground-water flow patterns.

PEARL HARBOR AREA. The land area around Pearl Harbor is used for agricultural, military, industrial, and urban purposes. Although the cultivation of sugarcane and pineapple has somewhat diminished over the last 35 years in this area, it still is the most important land use in terms of total acreage.

A large part of the Pearl Harbor area is underlain by an unconfined basal aquifer. Being unconfined, the aquifer is capable of receiving overland direct recharge unimpeded by such barriers as caprock formations which occur, generally along the inner shore of the harbor separating the aquifer from the ocean and the harbor water. At several inshore locations of the Harbor, the caprock is very thin and allows ground water to breach and escape on land through spring orifices and seeps. On the other hand, the caprock formation on the Ewa coastal plain is thick and acts as an aquiclude to the basalt as in the case of the Honolulu coastal plain.

The water in the basal aquifer extends to a considerable depth and consists of a layer of fresh water at the top, a zone of brackish water in the middle, and a layer of salt water, essentially like ocean water, at the bottom. This system, known as Ghyben-Herzberg lens, is characterized by certain hydrodynamic relations and a rough resemblence of the fresh water body to a lens.

The major recharge to the fresh-water lens occurs in the Koolau mountains and in part from the Waianae mountains and the connecting plateau. A secondary source is irrigation water which is not utilized by the plants and which returns through the soil to the aquifer. Fresh water from the lens is discharged both naturally and artificially. About 60 mgd of ground water is discharged mostly through five major spring areas along the innershore of the Harbor and to a minor extent into streambeds whose channels are below the water table. Some discharge can occur directly into the sea through openings in the caprock below sea level. Artificial discharge occurs when water is pumped from wells and shafts. Urban use of this water amounts to

about 50 mgd while sugarcane culture uses about 140 mgd.

Fresh water that recharges the basal lens through the infiltration of rain in the Koolau mountains is chemically quite pure. The chloride content of this water is about 20-25 mg/l and it has been referred to as uncontaminated water (Visher and Mink, 1964). Transition-zone water, on the other hand, has a composition anywhere between that of uncontaminated water and that of sea water. The chemical composition of the water used for irrigation is difficult to assess due to its complex origin. About 80 percent of it comes from wells, shafts, and springs, most of which are located relatively close to Pearl Harbor. The chloride content of water from some of these sources can be as high as 800 mg/l. This is caused by sea-water encroachment of the basal water by transition-zone water. The remaining 20 percent of the total applied irrigation water comes from streams and dike compartments located in Windward Oahu and is brought to the area by a ditch system. This ditch water is chemically as uncontaminated as basal water and can be regarded as such.

Several investigations have been carried out to study the chemical composition and distribution of the fresh water and transition zone water in the basal aquifer. Dale (1967) documented the changes in chloride concentration as a function of changes in land use and recharge-discharge pattern. Visher and Mink (1964) pointed out the effects of return irrigation water upon the quality of the basal water. A recent study by Tenorio, *et al.* (1969) attempted the identification of return irrigation water in the basal lens through repeated chemical analysis of water samples from several different sources.

The object of the current investigation was to explore the feasibility of using tritium analysis to study the origin and residence time of fresh water in the basal lens. Samples were collected and analyzed from one shaft, seven test wells, and six springs. The location of the sampling points are indicated in Figure 9. Multiple depth samples were taken from five of the test wells while single samples were taken from the other sources. Table 3 shows the available data on tritium activities, depth of sampling, and chloride concentrations. Most of the chloride data were taken from the report by Tenorio, *et al.* (1969). They constitute the average of at least six determinations made between August 1967 and May 1969. The tritium activities of the samples from the shaft and five of the wells are plotted vs. the

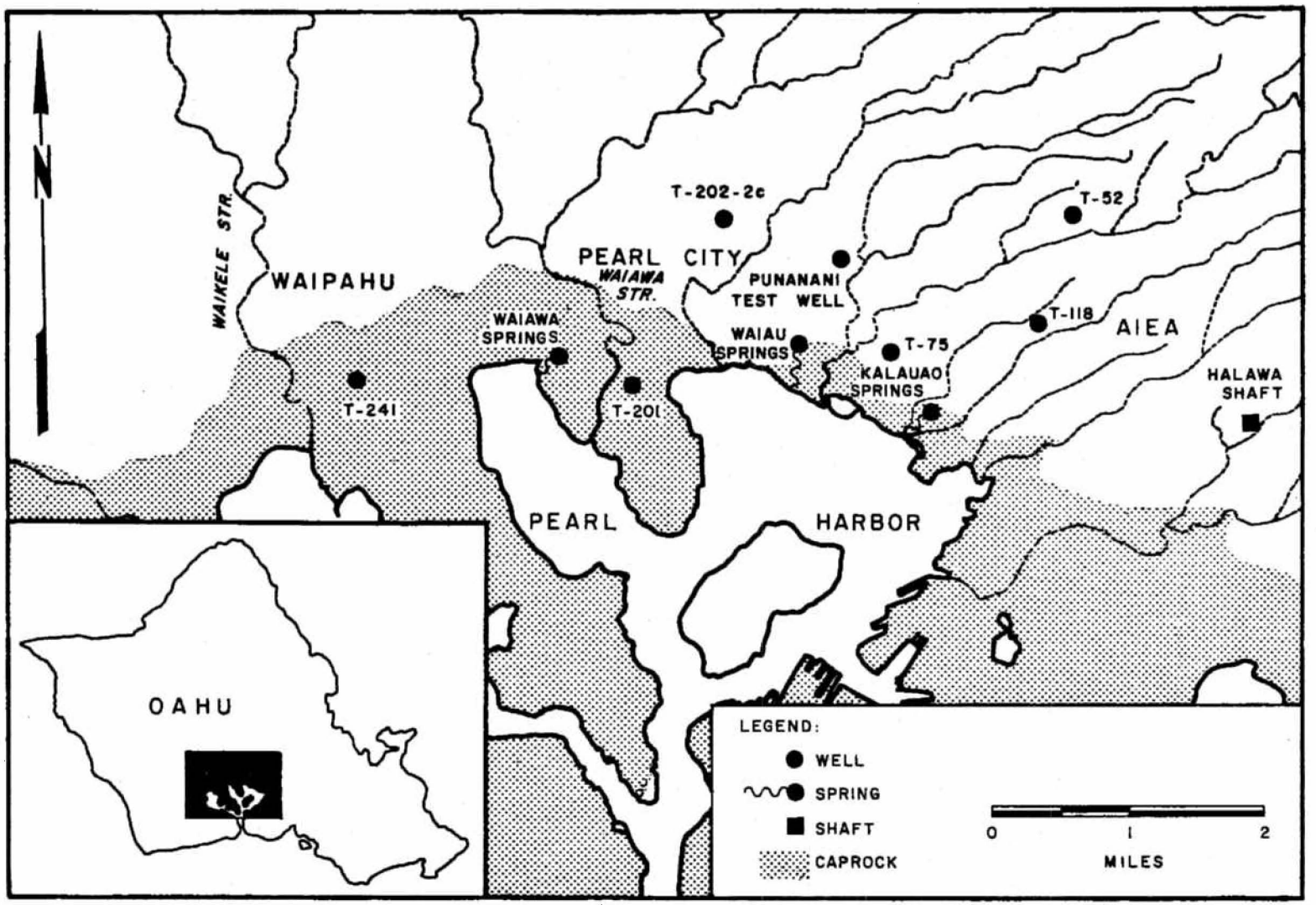


FIGURE 9. GROUND WATER SAMPLING POINTS, PEARL HARBOR-WAIPAHU AREA, OAHU.

TABLE 3. TRITIUM IN GROUND WATER, PEARL HARBOR-WAIPAHU AREA, OAHU.

SAMPLING SITES	DEPTH FEET	TRITIUM IN TU		CHLORIDE[3] mg/l
		MAY 1969[1]	OCT.-DEC. 1969[2]	
HALAWA SHAFT 12	ABOUT SEA LEVEL	---	0.0 ± 1.6	47
KALAUAO T-118	- 40	2.4 ± 1.9	---	66
PUMPING	-120	1.5 ± 1.8	---	54
STATION	-210	---	0.0 ± 2.3	45
PUNANANI TEST WELL	COMPOSITE	---	1.4 ± 1.8	---
UPPER T-52	- 10	3.1 ± 1.9	---	42
WAIMALU	- 80	2.9 ± 1.9	---	28
LOWER T-75	- 55	1.3 ± 1.8	---	133
WAIMALU		1.0 ± 1.9	---	189
WAIMANO T-202-2C	+ 5	3.5 ± 3.3	---	95
PUMPING	- 75	---	2.6 ± 2.6	78
STATION	-151	0.5 ± 2.1	---	69
PEARL CITY T-201	COMPOSITE	---	1.3 ± 2.4	---
WAIPAHU T-241	- 27	1.1 ± 2.0	---	107
	-155	1.6 ± 2.1	2.2 ± 2.5	98
KALAUAO SPRING NO. 2		1.6 ± 2.1	---	66
KALAUAO SPRING NO. 3		2.3 ± 2.5	0.4 ± 2.7	55
WAIAU SPRING NO. 1		0.3 ± 2.8	1.2 ± 2.3	305
WAIAU SPRING NO. 2		2.2 ± 1.9	0.9 ± 2.4	316
WAIAWA SPRING NO. 1.		0.3 ± 2.1	2.0 ± 3.1	556
WAIAWA SPRING NO. 2		0.9 ± 2.2	0.0 ± 3.0	1328

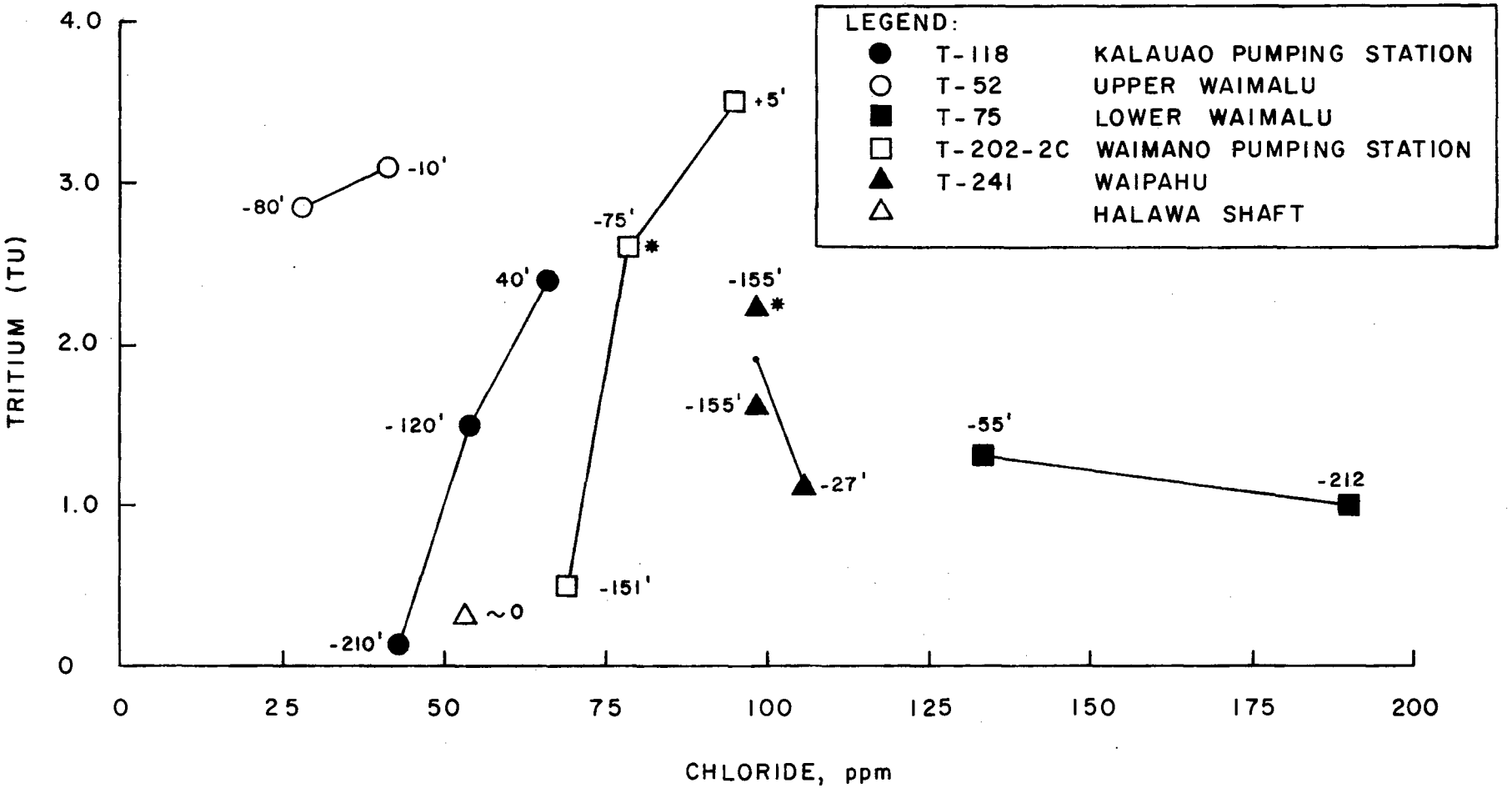
[1]T-52 AND T-202-2C WERE SAMPLED 5-8-69; ALL OTHERS 5-6-69.

[2]ALL SPRING SAMPLES 12-17-69; HALAWA 11-12-69; PUNANANI 11-13-69; T-202-2C 10-16-1969; ALL OTHER WELLS 10-13-69.

[3]WATER RESOURCES RESEARCH CENTER TECHNICAL REPORT NO. 33. HALAWA SHAFT, BOARD OF WATER SUPPLY ALL OTHERS.

chloride concentrations in Figure 10.

Correlation between tritium activity levels and chloride content is not readily apparent from the data in Figure 10. However, multiple depth samples from two wells (T-118 and T-202-2c) do show a correlation. For both wells, the tritium activity levels and the chloride content decrease with increasing depth. These results indicate that at the location of these wells, the upper portion of the basal lens contains water that was recharged more recently than that in the lower portion. The somewhat higher chloride content in the samples obtained from the upper portion compared with that of samples obtained from the bottom further suggests that recharge from irrigation return water has taken place. Due to the multiple sources of irrigation water and time-and-space variations of irrigation water application, the tritium input to the ground water is somewhat complicated and has yet to be characterized. Whether the higher tritium content of the samples from the



* OCTOBER - DECEMBER SAMPLES

FIGURE 10. RELATION OF TRITIUM ACTIVITY TO CHLORIDE CONCENTRATION AT SAMPLING DEPTH INDICATED FOR GROUND-WATER SAMPLES, PEARL HARBOR AREA.

upper portion reflect recent recharge from irrigation return water or some other type of recharge such as direct overland infiltration of rainwater from intense storm rain or some combination of the two is difficult to assess at this time and must await additional data.

The two samples from well T-52 taken at -10^1 and -80^1 msl both contain practically the same amount of tritium (2.9 - 3.1 TU) which is rather high when compared with most of the other samples from this area. The chloride concentration is slightly different for the two samples (20 and 25 mg/l) but both are low and indicate that the water is practically uncontaminated. On the basis of these observations, it can be stated that the aquifer at depths of -10^1 to -80^1 msl contains water derived mainly from the infiltration of rainwater. A significant fraction of this water or possibly most of it must have been recharged less than 15 years ago. These findings are not surprising considering the location of this well, which is relatively close to the mountains in comparison with the other sampling sites. Contamination from either transition-zone water or from irrigation return water is therefore very unlikely; whereas, the distance to the mountain recharge area is apparently short enough for tritium tracing purposes.

The results obtained from the T-241 and T-75 well samples are somewhat puzzling. A slight increase in tritium activity with increasing depth and practically no difference in chloride concentration are shown by the samples from well T-241. Two samples from well T-75, on the other hand, show no variation in tritium activity with depth while their chloride concentrations differ markedly. In comparison to the wells discussed before, these two wells are located close to Pearl Harbor and contain water which is higher in chloride content. Tenorio, *et al.* (1969) pointed out that the water from well T-241 could be contaminated by caprock water while that from well T-75 most likely contains transition-zone water. It appears, therefore, that the interpretation of tritium data becomes difficult when the samples contain mixtures of different types of water. The same applies to the interpretation of the data for the springs listed in Table 3. Tritium activity seems to be present in some of the samples but it can not be related to the chloride concentrations. Individual chloride concentrations show marked variations with time. For this report, the average concentrations were compared with the tritium activities of samples obtained at later dates. It is clear that periodic concurrent analysis for tritium and chloride performed on the same samples will be desirable.

In Figure 11, the tritium activities of the shaft and five wells are plotted against the depths at which the samples were taken. The figure indicates a definite trend for samples taken from shallower depths to have higher levels of tritium activity than those from deep depths. Notable exceptions are the samples from Halawa Shaft and well T-241. This type of "age stratification" is very interesting and important in determining regional flow distribution but needs to be confirmed through additional and more detailed sampling and analysis of water sources in the area.

Examination of Table 3 shows that the error levels in the tritium data are large compared to their absolute magnitude. These uncertainties in the data were kept in mind when the interpretations were made. Efforts are being made at present to reduce the error levels. From the data obtained so far, it seems clear, however, that tritium analysis can be used to study the freshwater lens in the Pearl Harbor area.

KAHUKU, PUNALUU AND WAIALEE. Tritium activity levels of well water samples collected from the northern and northeastern parts of Oahu, Kahuku, Waialee, and Punaluu have been determined. The data are presented in Appendix B, Table B-4. Interpretations will be made when additional analyses of samples are completed.

CONCLUSIONS

During the past twenty years large quantities of tritium have been, and still are being, released to the earth's atmosphere as a result of thermonuclear explosions. Most of this "excess" tritium becomes part of the atmospheric water vapor in the form of tritiated water molecules (HTO). The various processes contributing to the phenomenon of the "hydrologic cycle" result in a gradual removal of tritium from the atmosphere and its distribution into rainwater, ocean water, ground water, and other terrestrial waters. As a consequence, rainwater samples collected in Hawaii during the past twenty years have exhibited varying concentrations of tritium with maxima in the early nineteen sixties. Present tritium concentrations in rain are low but detectable and well in excess of the "naturally" (cosmic rays) produced concentrations that prevailed before the commencement of nuclear weapons testing.

Excess concentrations of tritiated water molecules in Hawaiian rain can

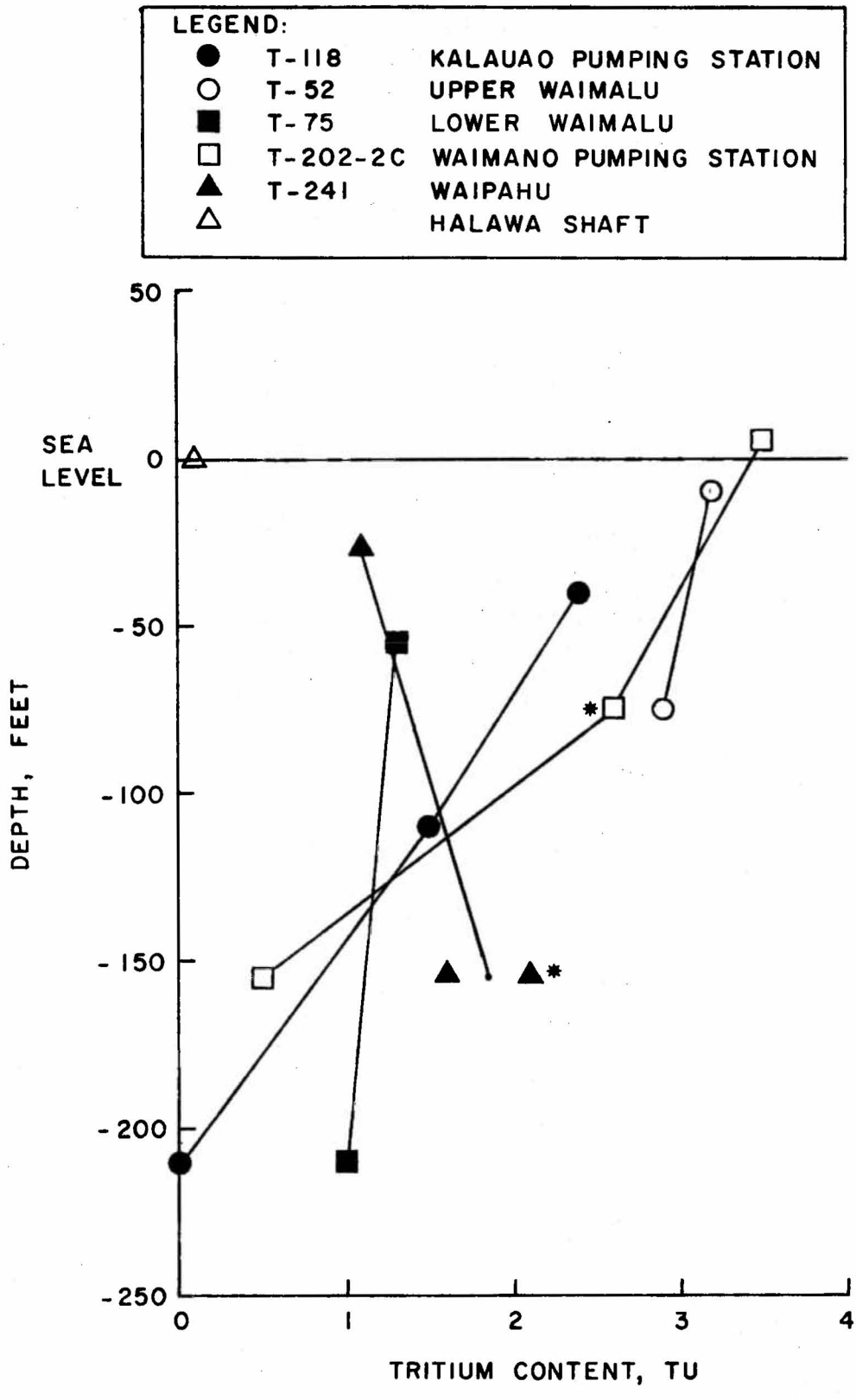


FIGURE 11. RELATION OF TRITIUM ACTIVITY IN GROUND-WATER SAMPLES TO SAMPLING DEPTH, PEARL HARBOR AREA, OAHU.

be regarded as a "continuous feed" tracer, bearing in mind that the tracer (tritium) input has not been uniform during the past 15 to 20 years and is subject to radioactive decay.

The major goal of the study the results of which have been described in the preceding pages was to determine whether this tritium tracer could be detected in various natural waters on Oahu and to what extent it could be utilized to obtain hydrologic information on surface or ground-water systems. Most promising in this regard appears to be the ability of tritium analyses to distinguish between ground waters having vastly different residence times. Two perched water springs (Makiki and Booth) for example show tritium activities comparable to those of rainwater indicating residence times on the order of a few months. On the other hand, wells discharging water from the Honolulu basal aquifers did not contain any detectable tritium, suggesting that the water being pumped up has a mean residence time of longer than 15 to 20 years.

Detection of "age" differences within a particular ground-water system is inherently more difficult due to the mixing processes. Tritium data on water samples from wells penetrating the Pearl Harbor basal aquifer clearly illustrate this. In some wells, water residing in the upper parts is higher in tritium that that residing in the lower parts indicating differences in residence times of the water as a function of depth. Hence, the top layers must have received recharge within the last 15 to 20 years. Samples from other wells, however, yield tritium data that are hard to interpret. The reason for this is attributed to mixing of water from various origins as suggested by chemical analyses. One well located relatively close to the main recharge area (Koolau mountains) contains small but distinct quantities of tritium in samples from two different depths suggesting recent recharge to the aquifer over the entire sampling depth.

Another promising application is identification of the sources contributing water to the flow in perennial streams and storage reservoirs. Stream discharge having high tritium levels reflect rainfall and bank storage sources, while stream water with low tritium content reflect basal water discharge. Tritium measurements on water samples from Pearl Harbor streams have indicated that this application is promising.

This study has shown that tritium analyses of Hawaiian natural waters has considerable potential as an additional hydrologic tool. At present only

qualitative interpretations are possible. However, it is expected that quantitative evaluations are possible through time studies of suitable systems.

ACKNOWLEDGEMENT

Dr. Robert W. Buddemeier has reviewed the report manuscript and made helpful suggestions.

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APPENDICES

APPENDIX A.

Abbreviations used for components of scintillation solution.

Butyl PBD = 2-(4'-t-Butylphenyl)-5-(4"-biphenyl)-1, 3, 4-oxiazole.

PBBO = 2-(4'-Biphenyl)-6-phenyl-benzoxazole.

BBS-3 = Toluene solubilizer marketed by Beckman Instruments, Inc.

APPENDIX B.

TABLE B-1. ANALYTICAL DATA OF RAINWATER ON OAHU.

STATION	SITE	DATE OF COLLECTION	ACTIVITY IN TU	$\bar{y} \pm \sigma_{\bar{y}}$
772	MOANALUA VALLEY	8-18-69	20.6 ± 2.9	23.1 ± 2.8
718	PALOLO VALLEY	8-26-69	25.1 ± 2.7	
706	PACIFIC HEIGHTS	9-02-69	16.5 ± 3.8	16.1 ± 3.8
782	LOWER LUAKAHA	9-02-69	15.7 ± 3.7	
706	PACIFIC HEIGHTS	10-06-69	16.1 ± 3.3	16.4 ± 3.4
782	LOWER LAUKAHA	10-06-69	16.8 ± 3.4	
782	LOWER LUAKAHA	11-11-69	9.3 ± 3.3	
786	NUUANA PALI	11-24-69	9.8 ± 2.6	10.5 ± 2.9
772	MOANALUA VALLEY	11-24-69	11.6 ± 2.5	
776	KALIHI TUNNEL	11-24-69	9.5 ± 3.5	
718	PALOLO VALLEY	11-25-69	13.6 ± 2.7	12.3 ± 3.0
716	MANOA VALLEY	11-25-69	11.6 ± 3.2	
784	PAUOA FLATS	11-28-69	11.0 ± 3.1	
782	LOWER LUAKAHA	1-05-70	12.5 ± 3.4	
786	NUUANU PALI	2-02-70	11.5 ± 3.7	12.0 ± 4.4
782	LOWER LUAKAHA	2-02-70	12.8 ± 5.0	
772	MOANALUA VALLEY	2-16-70	14.7 ± 4.9	13.0 ± 4.0
718	PALOLO VALLEY	2-18-70	12.5 ± 2.7	
706	PACIFIC HEIGHTS	3-02-70	18.5 ± 2.4	19.4 ± 2.8
782	LOWER LUAKAHA	3-02-70	21.0 ± 3.2	
786	NUUANU PALI	4-06-70	19.3 ± 4.0	18.2 ± 4.1
716	MANOA VALLEY	4-15-70	16.8 ± 4.2	
786	NUUANU PALI	5-04-70	21.1 ± 4.1	18.7 ± 3.5
706	PACIFIC HEIGHTS	5-04-70	24.8 ± 3.7	
772	MOANALUA VALLEY	5-12-70	13.3 ± 4.7	

TABLE B-2. ANALYTICAL DATA OF RESERVOIR AND STREAM WATER ON OAHU.

AREA	SITE	DATE OF COLLECTION	ACTIVITY IN TU
HONOLULU	NUUANU RESERVOIR	11-12-69	13.2 ± 4.1
WAHIAWA	WAHIAWA RESERVOIR	11-13-69	19.7 ± 3.1
PEARL HARBOR	WAIKELE STREAM	12-17-69	13.7 ± 3.0
PEARL HARBOR	WAIAWA STREAM	12-17-69	3.6 ± 2.4
PEARL HARBOR	WAIMALU STREAM	12-17-69	17.4 ± 4.1
PEARL HARBOR	KALAUAO STREAM	12-17-69	4.7 ± 4.0

APPENDIX B.

TABLE B-3. ANALYTICAL DATA OF PERCHED SPRING WATER ON OAHU.

AREA	SITE	DATE OF COLLECTION	ACTIVITY IN TU
HONOLULU	BOOTH SPRING	11-13-69	25.2 ± 5.7
		6-17-70	37.9 ± 5.6
	MAKIKI SPRING	11-13-69	22.2 ± 4.2
		6-16-70	32.7 ± 6.8

TABLE B-4. ANALYTICAL DATA OF HIGH LEVEL AND BASAL WATER ON OAHU.

AREA	SITE	DEPTH IN FEET	DATE OF COLLECTION	ACTIVITY IN TU
KANEOHE BAY	WAIHEE TUNNEL		5-28-70	4.3 ± 2.6
WAHIAWA	WELL 330-9	COMPOSITE	11-13-69	1.7 ± 1.8
HONOLULU	KALIHI SHAFT	COMPOSITE	11-12-69	3.3 + 2.8
HONOLULU	WAIALAE SHAFT	COMPOSITE	11-12-69	1.9 ± 1.9
HONOLULU	KALIHI WELLS 128 A-H	COMPOSITE	11-12-69	0.0 ± 2.3
HONOLULU	BERETANIA WELLS 88 A, C-J	COMPOSITE	11-12-69	0.0 ± 1.6
			6-29-70	0.5 ± 1.2
HONOLULU	KAIMUKI WELL 7-E	85	11-12-69	0.0 ± 1.6
HONOLULU	KAIMUKI WELL 7-E	266	11-12-69	0.0 ± 1.6
PEARL HARBOR	WAIAWA SPRING NO. 1	---	12-17-69	2.0 ± 3.1
PEARL HARBOR	WAIAWA SPRING NO. 2	---	12-17-69	0.0 ± 3.0
PEARL HARBOR	WAIAU SPRING NO. 1	---	12-17-69	1.2 ± 2.3
PEARL HARBOR	WAIAU SPRING NO. 2	---	12-17-69	0.9 ± 2.4
PEARL HARBOR	KALAUAO SPRING NO. 2	---	12-17-69	±
PEARL HARBOR	KALAUAO SPRING NO. 3	---	12-17-69	0.4 ±2.7
PEARL HARBOR	HALAWA SHAFT		11-12-69	0.0 ± 1.6
PEARL HARBOR	WELL T-118	390	10-13-69	0.0 ± 2.3
PEARL HARBOR	WELL T-241	180	10-13-69	2.2 ± 2.5
PEARL HARBOR	WELL 201	COMPOSITE	10-13-69	1.3 ± 2.4
PEARL HARBOR	WELL T-202-2C	360	10-16-69	2.6 ± 2.6
PEARL HARBOR	TEST WELL PUNANANI	COMPOSITE	11-13-69	1.4 ± 1.8
KAHUKU	341	COMPOSITE	11-13-69	1.4 ± 2.9
KAHUKU	348	COMPOSITE	11-13-69	0.1 ± 2.0
KAHUKU	358	COMPOSITE	11-13-69	0.1 ± 3.1
KAHUKU	365	COMPOSITE	11-13-69	0.0 ± 3.5
PUNALUU	T-143	COMPOSITE	3-03-70	0.5 ± 1.7
PUNALUU	402-2E	COMPOSITE	3-12-70	0.1 ± 1.7
PUNALUU	402-1	COMPOSITE	3-19-70	0.0 ± 1.4
PUNALUU	402	COMPOSITE	4-27-70	1.2 ± 1.9
WAIALEE	337-1	COMPOSITE	11-13-69	1.3 ± 2.3
WAIALEE	337-4	COMPOSITE	6-02-70	0.0 ± 1.3
WAIALEE	TEST WELL	COMPOSITE	4-30-70	0.0 ± 1.3