SPATIAL AND TEMPORAL DISTRIBUTION OF CONTAMINATED BASAL WATER IN SOUTHERN AND CENTRAL O'AHU AQUIFERS

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PREFACE

This report is part of the "Subsurface Water Quality: Pesticides Contamination" project authorized in Act 285, Section 38F, by the Twelfth Legislature, State of Hawaii, and supported by the Office of Environmental Quality Control with the cooperation of several data collecting agencies. Other project activities currently in progress focus on the following topics: geologic factors, mineralogic parameters, chronology of deep water percolation through pineapple fields, leaching properties of fumigants from soils, temporal and spatial distributions of contaminants in basal groundwaters, well and aquifer rehabilitation, and methods of contaminant removal. Forthcoming reports will present the results of these activities.

ABSTRACT

In recent years, several pesticide-related contaminants have been detected in the basal waters of southern and central O'ahu aquifers. Dibromochloropropane (DBCP) and ethylene dibromide (EDB), two soil fumigants which were previously used by pineapple growers in southern and central O'ahu, have been discovered in several wells in the area. A third contaminant, trichloropropane (TCP), which is an impurity of the soil fumigant DD, has also been detected in a number of wells. DBCP, EDB, and TCP are of particular concern to state public health officials due to the known and possible unknown health effects associated with these compounds. This is especially true for the Pearl Harbor Aquifer, which is the major potable water source for Honolulu. Thus, it is imperative to have an understanding of the extent and movement of the contamination.

The locations of the contaminated well sites appear to be correlated with the areas of past and present pineapple cultivation when the ambient groundwater flow pattern is taken into consideration. In addition, several significant pipeline leaks of petroleum products (aviation fuels) in the vicinity may have contributed to the EDB contamination. An analysis of the temporal variation of contamination in selected wells indicates no significant fluctuation in contaminant levels over a one-year study period from 1 September 1983 to 1 September 1984.

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INTRODUCTION

Over the past several decades, large amounts of pesticides have been used by the pineapple industry in the southern and central portion of O'ahu, Hawai'i (Fig. 1). During that time, application of pesticides continued under the belief that the great distance (hundreds of meters) between the ground surface and the basal lens of the aquifer was adequate to protect the groundwater body from pesticide residue leachate. It was further argued that if any residues did reach the basal aquifer, the concentrations would be so dilute as to be undetectable and presumably harmless.

In recent years, however, several pesticide-related contaminants have been detected in the basal waters of southern and central O'ahu aquifers. Dibromochloropropane (DBCP) and ethylene dibromide (EDB), two soil fumigants which were previously used by pineapple growers in southern and central O'ahu, have been discovered in several wells in the area. In fact, 10 wells were closed by the Hawaii State Department of Health in the central O'ahu area as a result of DBCP or EDB contamination (Fig. 2). A third contaminant, trichloropropane (TCP), which is an impurity of the soil fumigant DD, has also been detected in a number of wells. DBCP, EDB, and TCP have been of particular concern because of their associated health effects, both known and unknown. This is especially true for the Pearl Harbor Aquifer, which is the major potable water source for Honolulu. Thus, it is imperative to have an understanding of the extent and movement of the contamination.

Southern and Central O'ahu Study Area

GEOLOGY AND HYDROLOGY. The island of O'ahu is formed primarily from the lavas of the Koolau and Waianae shield volcanoes. The Koolau dome and the lower portion of the Waianae dome consist mainly of thin basaltic flows (generally less than 3 m [10 ft] in thickness). The Schofield Plateau, which lies between the two volcanoes, consists of lavas from the younger Koolau volcano ponded against the eroded lower slopes of the Waianae volcanoe. Terrestrial and marine sedimentary deposits created coastal plains during the quiescent period following the formation of the two volcanoes. The permeability of the coastal plain sediments is considerably lower than the permeability of the underlying basalt aquifers. Thus, the sedimentary deposits act as a caprock restraining the seaward movement of the fresh groundwaters. The cap-

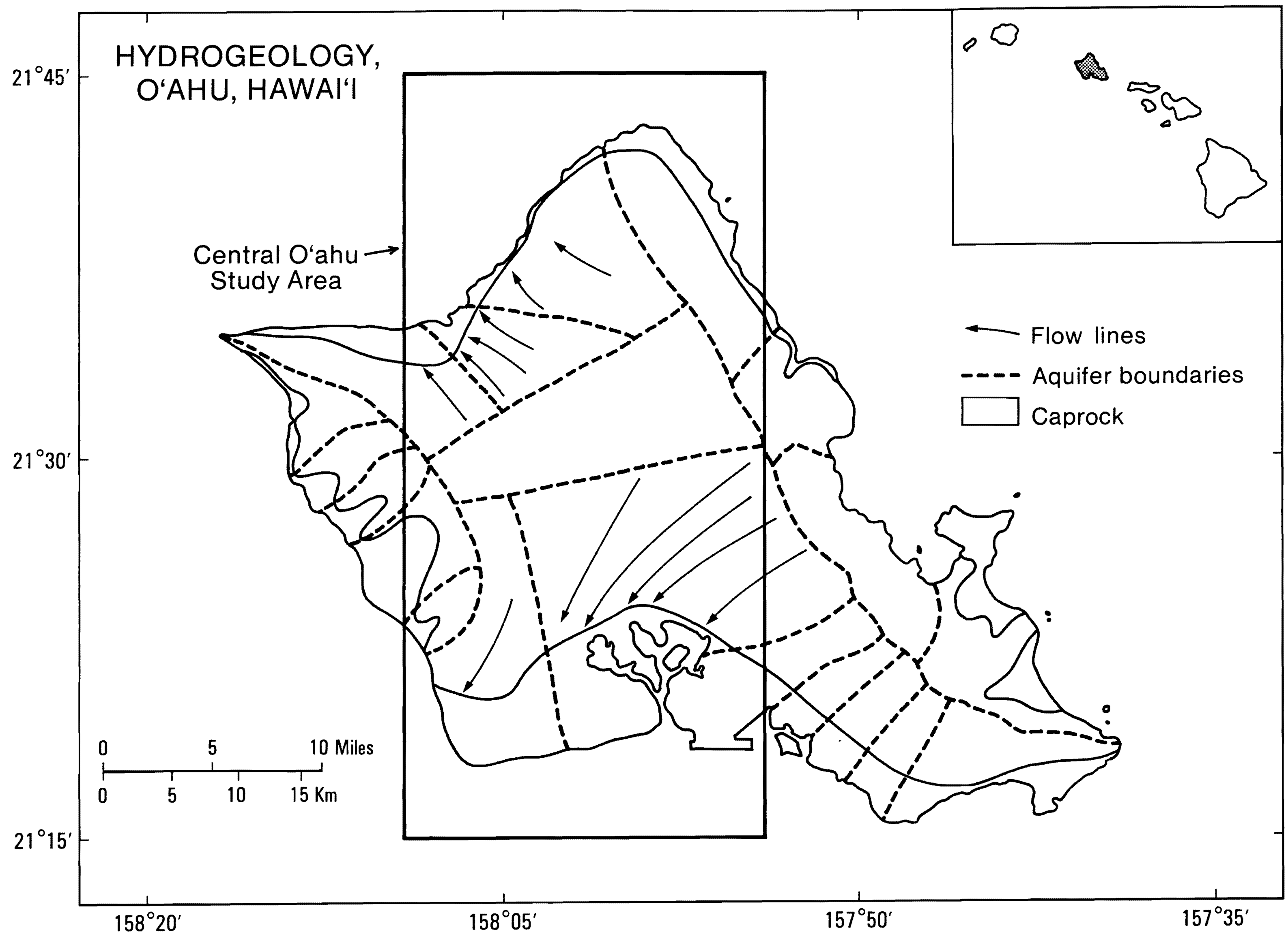


Figure 1. Aquifer and caprock boundaries for O'ahu, Hawai'i

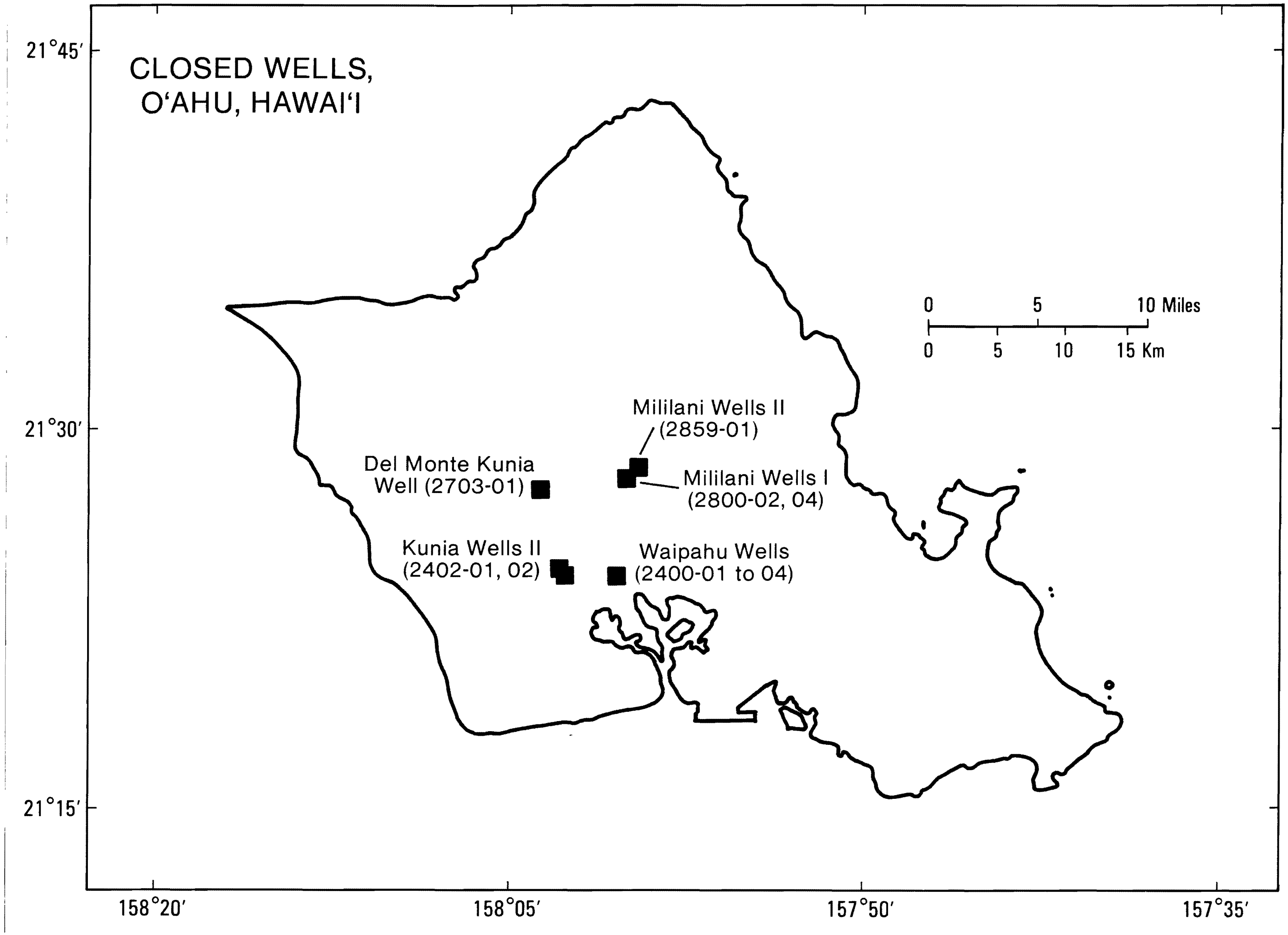


Figure 2. Closed well sites on O'ahu, Hawai'i

rock boundaries for O'ahu are presented in Figure 1.

The basal aquifers of O'ahu (Fig. 1) consist of a body of fresh water floating on seawater. Based on the Ghyben-Herzberg principle, the depth of the basal lens below sea level is approximately 40 times the freshwater head above sea level. The permeability of the unweathered rock that forms the basal aquifers of O'ahu is generally high. The high permeability is a result of the presence of clinker layers, lava tubes, irregular openings within and between the surface of flows, and contraction joints that formed on solidification (Visher and Mink 1964). The hydraulic conductivity of the Koolau lava flows is on the order of 3.40 to 13.58 $m^3/s/m^2$ (5,000-20,000 gpd/ft^2) in the Meinzer index. The gross porosity may range from 10 to 25% (Wentworth 1951).

Rainfall is the principal source of recharge to the basal waters. Water for recharge also occurs as a result of inflow from dike compartments at higher elevations, inflow from streams, and deep percolation of irrigation return water. Discharge from the aquifers occurs as a result of well withdrawals and the natural discharge of fresh water to the ocean. In the absence of external influences such as pumping, groundwater flows from areas of high hydraulic head to areas of lower head. The general flow patterns for selected aquifers within the study area are presented in Figure 1.

LAND USE. Land use is a critical factor affecting recharge. On agricultural lands, irrigation and suppressed evapotranspiration (pineapple) can contribute significantly to recharge (Giambelluca 1983). The leaching of pesticide residues may be accelerated as a result of high percolation rates in agricultural areas. The compound DBCP, EDB, and TCP have all been associated with the cultivation of pineapples. Areas of past and present pineapple cultivation (1940-1985) are shown in Figure 3 (p. 7). It should be noted that some of these areas were converted from pineapple cultivation to sugarcane cultivation. This change in land use would enhance the opportunity for leaching of pesticide residues because of the large amount of water used for sugarcane irrigation.

Plantation Practices

Dole Company and Del Monte Corporation are now the two pineapple growers on O'ahu. A third company, Libby, was involved with pineapple cultivation prior to the early 1960s but is presently not involved with pineapple growing on O'ahu.

1,2-DIBROMO-3-CHLOROPROPANE (DBCP). DBCP is a soil fumigant introduced in 1955 by the Dow Chemical Company and the Shell Development Company. This fumigant, which is used to control nematodes that attack the roots of pineapple crops, is effective in controlling a particularly hardy strain of rootworm called the reniform nematode. DBCP is injected into the soil at a depth of approximately 203 to 254 mm (8-10 in.) beneath a polyethylene film prior to planting. The application rate is approximately 0.028 to 0.037 m^3/ha (3-4 gal/acre). It is generally applied with another fumigant, such as DD (a dichloropropane-dichloropropene mixture) or Telone (a dichloropropene mixture). The volumetric application ratio of DBCP to DD or Telone is about 1:10 (Yim and Dugan 1975).

Records are not available to indicate the precise date on which DBCP was first used on a commercial basis by pineapple growers on O'ahu; however, the pesticide was probably first used between 1955 and 1964 on O'ahu pineapple fields. Dole Co. phased out the use of DBCP in the 1977 planting season. Del Monte Corp. has not used DBCP on O'ahu except on an experimental basis (Dept. of Agriculture 1983).

1,2-DIBROMOETHANE (EDB). The use of EDB as a fumigant was first reported in 1925. It was later introduced by the Dow Chemical Co. in 1946 (Worthing 1979). The Environmental Protection Agency (EPA) reported in 1983 that over 20 million pounds (9.07 million kg) of ethylene dibromide were being used in this country every year with soil fumigation accounting for 90% of the volume used (EPA 1983). Although EDB has been used as a quarantine fumigant for papayas in Hawai'i, its major use in the state has been for the soil fumigation of pineapple fields to control nematodes. As a soil fumigant for pineapple fields, EDB is injected into the ground at a depth of approximately 203 to 254 mm (8-10 in.) prior to planting. It is applied at a rate of 0.094 to 0.112 m^3/ha (10-12 gal/acre). A polyethylene film is placed over the soil at the time of application to retain the volatile fumigant and thereby improve nematode control. The film also helps to retain moisture and to increase soil temperature which improve early plant growth. Planting generally takes place 48 hr or more after fumigation (Dept. of Agriculture 1983).

On O'ahu, EDB was the primary soil fumigant of Del Monte Corp. for approximately 35 years prior to the EPA notice of cancellation and emergency suspension of registrations in September 1983. Dole Co. only began using EDB on O'ahu in 1978 after it phased out use of DBCP in 1977 (Dept. of Agriculture

1983). By the terms of the cancellation order, the use of EDB on pineapple fields in Hawai'i was allowed until 1 September 1984. Dole Co. chose not to use up its remaining stocks and discontinued use of EDB at the time of the order. Del Monte Corp. continued use of EDB until its remaining supply was completely depleted by the end of 1983.*

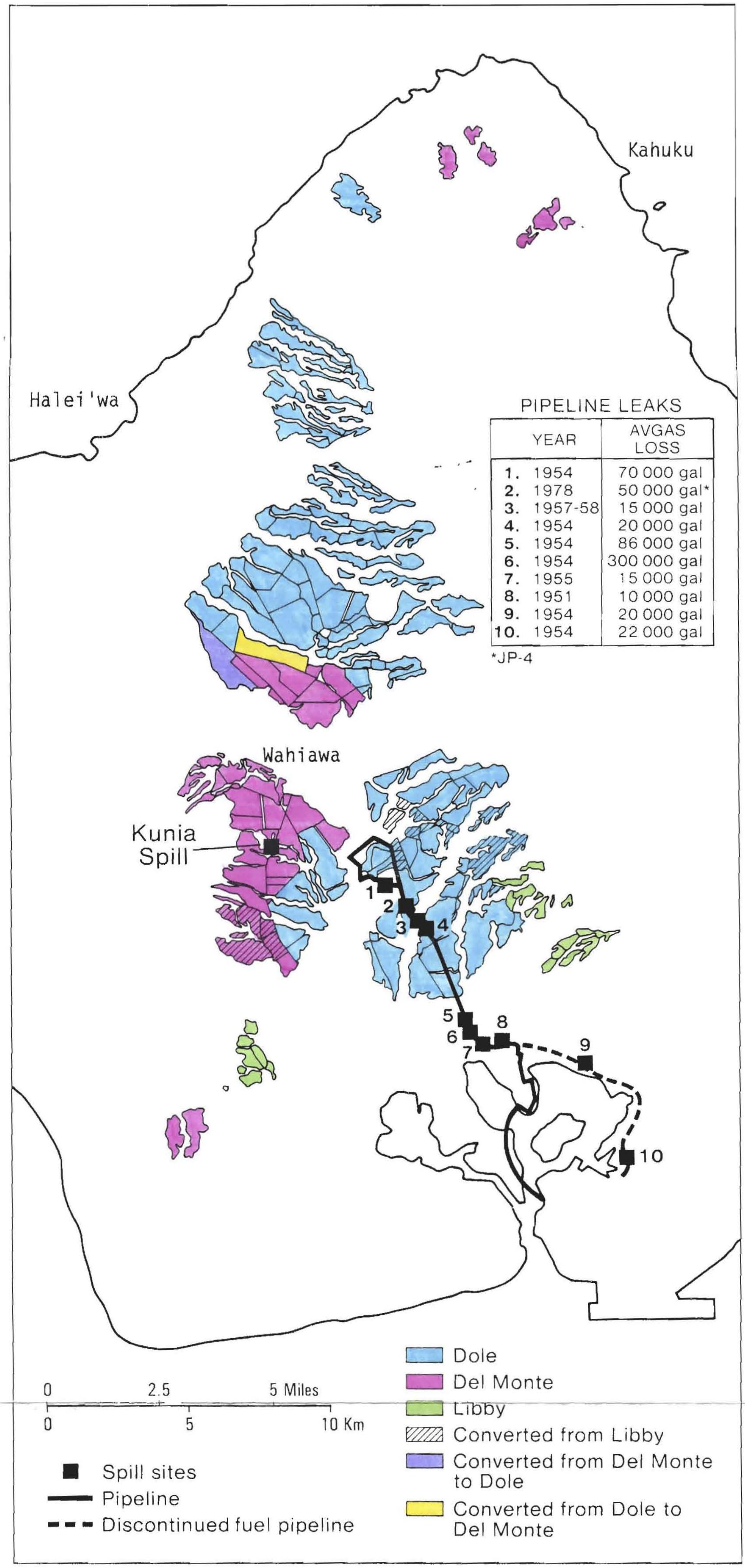
1,2,3-TRICHLOROPROPANE (TCP). TCP is used as a paint and varnish remover, a solvent, and a degreasing agent (EPA 1980). It also occurs as an impurity during the manufacturing process of the Shell Chemical Co. product DD which was introduced in 1942. The first use of DD as a soil fumigant was described in 1943 (Worthing 1979). Estimates of the amount of trichloropropanes in the DD mixture vary from 0.4% by weight (Dept. of Agriculture 1984) to 6-7% by weight (Carter 1954). The actual amount of trichloropropanes in the mixture, however, may have deviated greatly from these values at times.

The soil fumigant DD was commonly used in conjunction with DBCP by Dole Co. on O'ahu. It is also believed that Libby used a DD formulation with a high TCP content on its fields. Where the reniform nematode was not present, DD (or Telone) was used alone at the rate of 0.374 to 0.561 m^3/ha (40-60 gal/acre) (Yim and Dugan 1975). Records are not available to determine when DD was first used on a commercial basis; however, it was most likely first used on O'ahu in the 1940s or 1950s. It has not been used on pineapple fields on O'ahu since 1977.†

OBJECTIVES

The objective of this report is to examine available groundwater quality data to identify spatial and temporal patterns of DBCP, EDB, and TCP contamination. In addition, possible sources of DBCP, EDB, and TCP will be identified to establish the relationship between the spatial distribution of contamination and the potential sources of contamination.

*"Pine Growers Drop Fight for EDB," Hono. Star-Bull., 13 Feb. 1984, pp. A-10.
†"EDB May Be in Mililani's Water Wells," Hono. Adv., 6 Oct. 1983, pp. A-1, -4.



YEAR		AVGAS LOSS
1.	1954	70 000 gal
2.	1978	50 000 gal*
3.	1957-58	15 000 gal
4.	1954	20 000 gal
5.	1954	86 000 gal
6.	1954	300 000 gal
7.	1955	15 000 gal
8.	1951	10 000 gal
9.	1954	20 000 gal
10.	1954	22 000 gal

*JP-4

Figure 3. Spill sites and areas previously and presently under pineapple cultivation, central O'ahu, Hawai'i

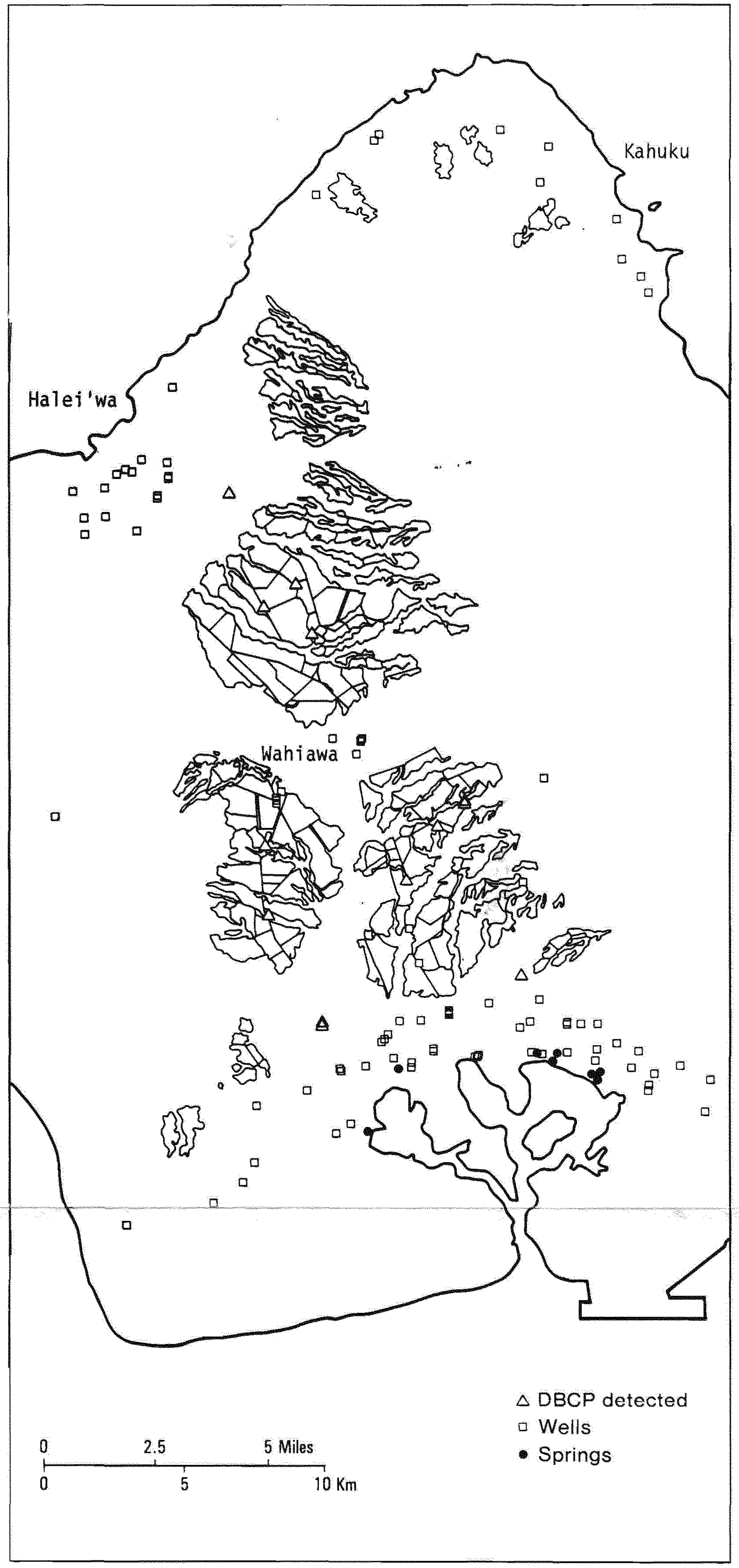


Figure 4. Well and spring sites tested for DBCP contamination in relation to areas of pineapple cultivation, central O'ahu, Hawai'i

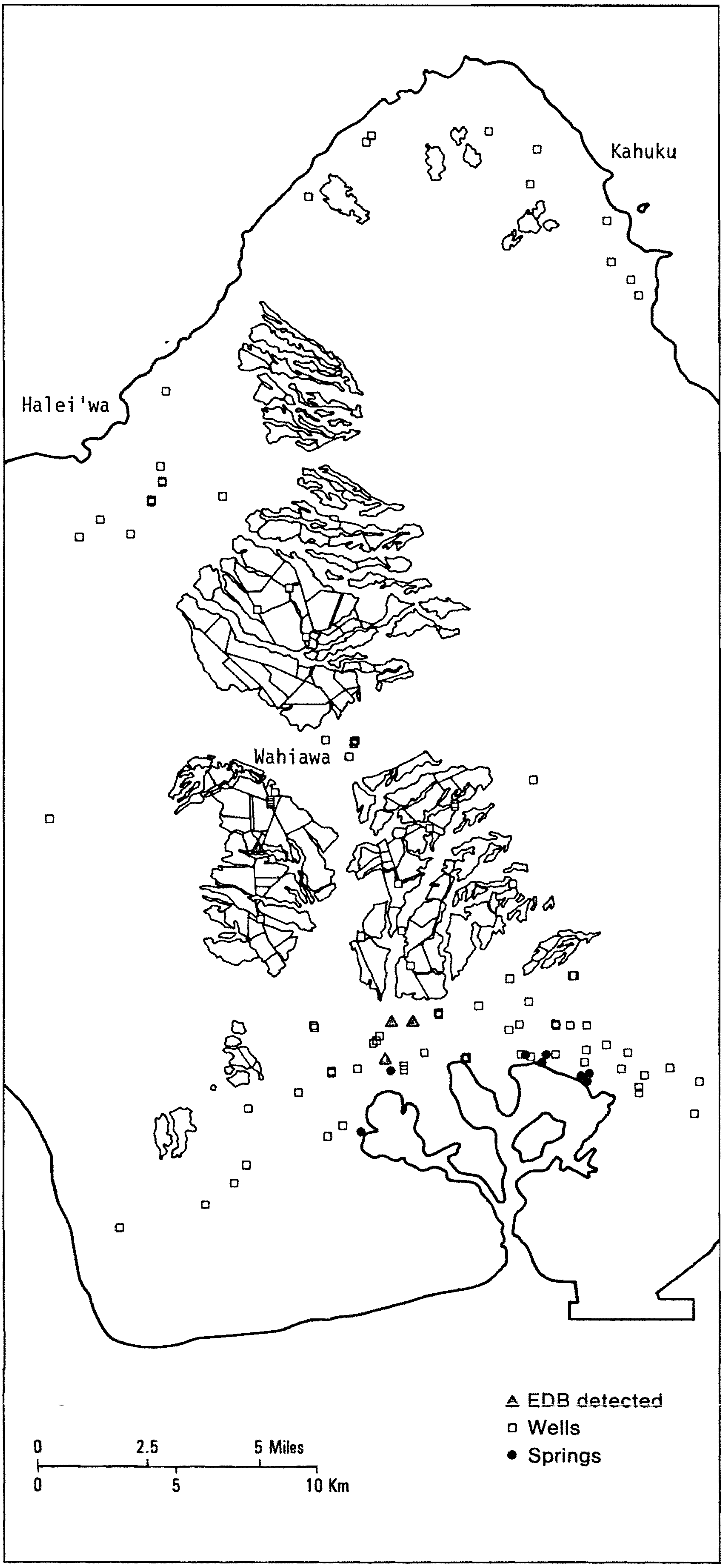


Figure 5. Well and spring sites tested for EDB contamination in relation to areas of pineapple cultivation, central O'ahu, Hawai'i

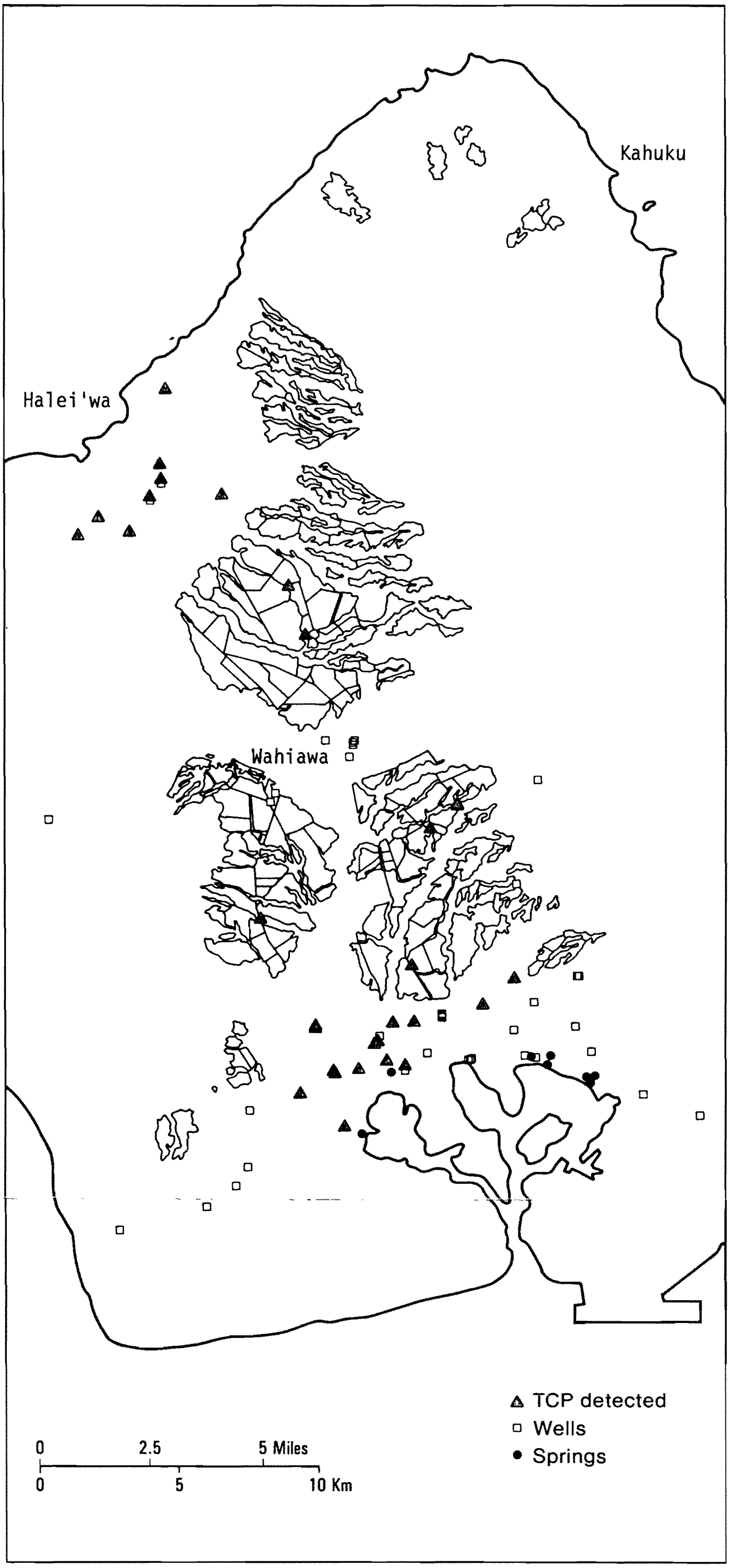


Figure 6. Well and spring sites tested for TCP contamination in relation to areas of pineapple cultivation, central O'ahu, Hawai'i

METHODOLOGY

Water quality data compiled by the Water Resources Research Center (Oki and Giambelluca 1985) were utilized to determine the extent of the contamination in southern and central O'ahu aquifers. Additional results from recent analysis performed by the University of Hawaii were utilized to supplement the existing WRRC Data Base. Separate maps were drawn to depict spatial distributions of DBCP, EDB, and TCP contamination. On each map, all well sites tested for the particular compound of interest are shown. The contaminated well sites are identified on these maps. In addition, those contaminated well sites with sufficient available data were analyzed for temporal variations in contaminant levels from 1 September 1983 to 1 September 1984.

RESULTS AND CONCLUSIONS

Spatial Distribution of Contamination

Well and spring sites tested for DBCP, EDB, and TCP contamination in relation to areas of pineapple cultivation are respectively presented in Figures 4, 5, and 6. The locations of the contaminated well sites appear to be correlated with the areas of past and present pineapple cultivation when the ambient groundwater flow patterns (Fig. 1) are taken into consideration. That is, the contaminated well sites are located directly within or hydraulically downgradient from areas of pineapple cultivation. The Del Monte Kunia Well No. 2703-01 is not downgradient from any fields which received regular applications of DBCP. DBCP contamination at that well site has been attributed to a spill of 1.87 m^3 (495 gal) of EDB occurring on 7 April 1977 (it was believed that the EDB contained a small amount of DBCP as an impurity) (Mink 1981). All other sites contaminated with either DBCP or TCP are within or hydraulically downgradient from fields which received applications of DBCP or DD. The EDB contamination occurring in the Waipahu area of southern O'ahu may be the result of soil fumigation on upgradient Dole Co. fields. In addition, several significant pipeline leaks of petroleum products (aviation fuels) in the vicinity may have contributed to the EDB contamination (Fig. 3).

Temporal Variation of Contamination

The temporal variation of the contamination can be seen with the formation of a time series. Such a time series was formed when sufficient data were available. Several contaminated well sites were not analyzed due to an insufficient amount of quantitated results at these sites. In general, the time series presented in Figures 7 through 15 do not indicate any distinct temporal variations of contaminant levels. The one year of record utilized may have been insufficient to reveal any significant trends. The one exception to this generalization is at Mililani Well II Pump 5 (2859-01). From October 1983 to April 1984, DBCP concentrations at this site rose steadily from 25 to 70 parts per trillion (ppt). This may have been due to the continual introduction of DBCP from some source or the aquifer response to variable well pumping rates.

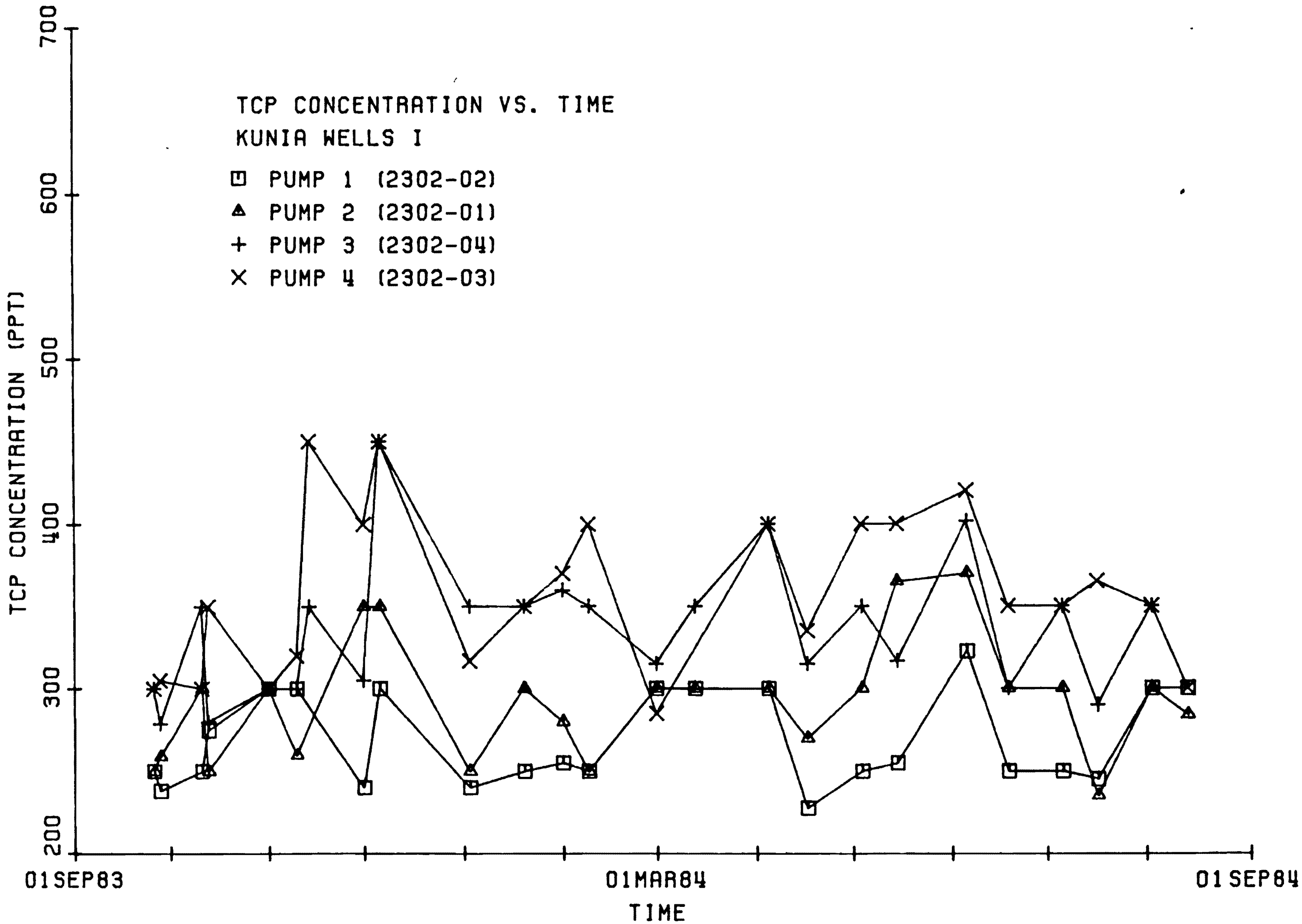


Figure 7. TCP concentration vs time, Kunia Wells I, O'ahu, Hawai'i

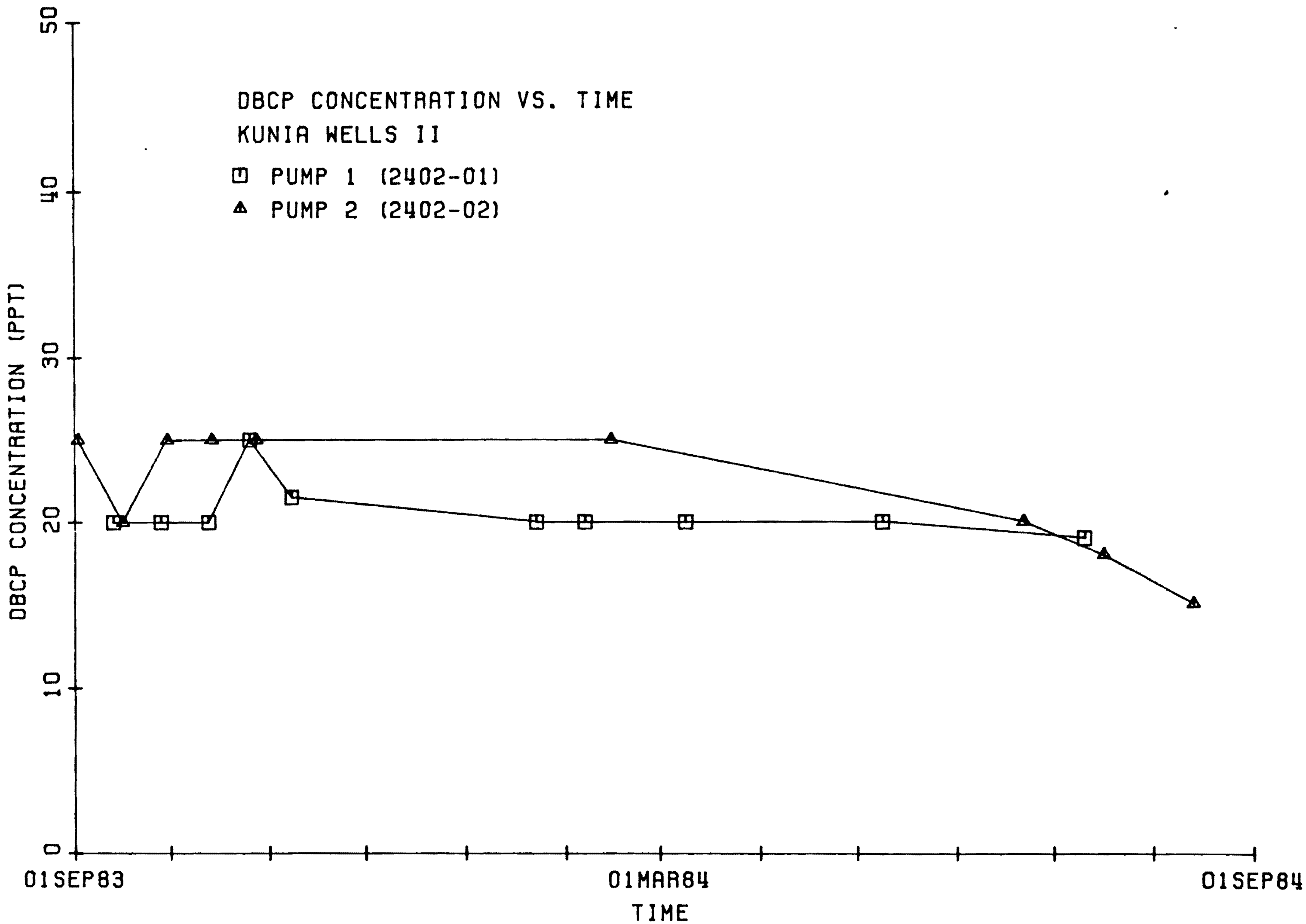


Figure 8. DBCP concentration vs. time, Kunia Wells II, O'ahu, Hawai'i

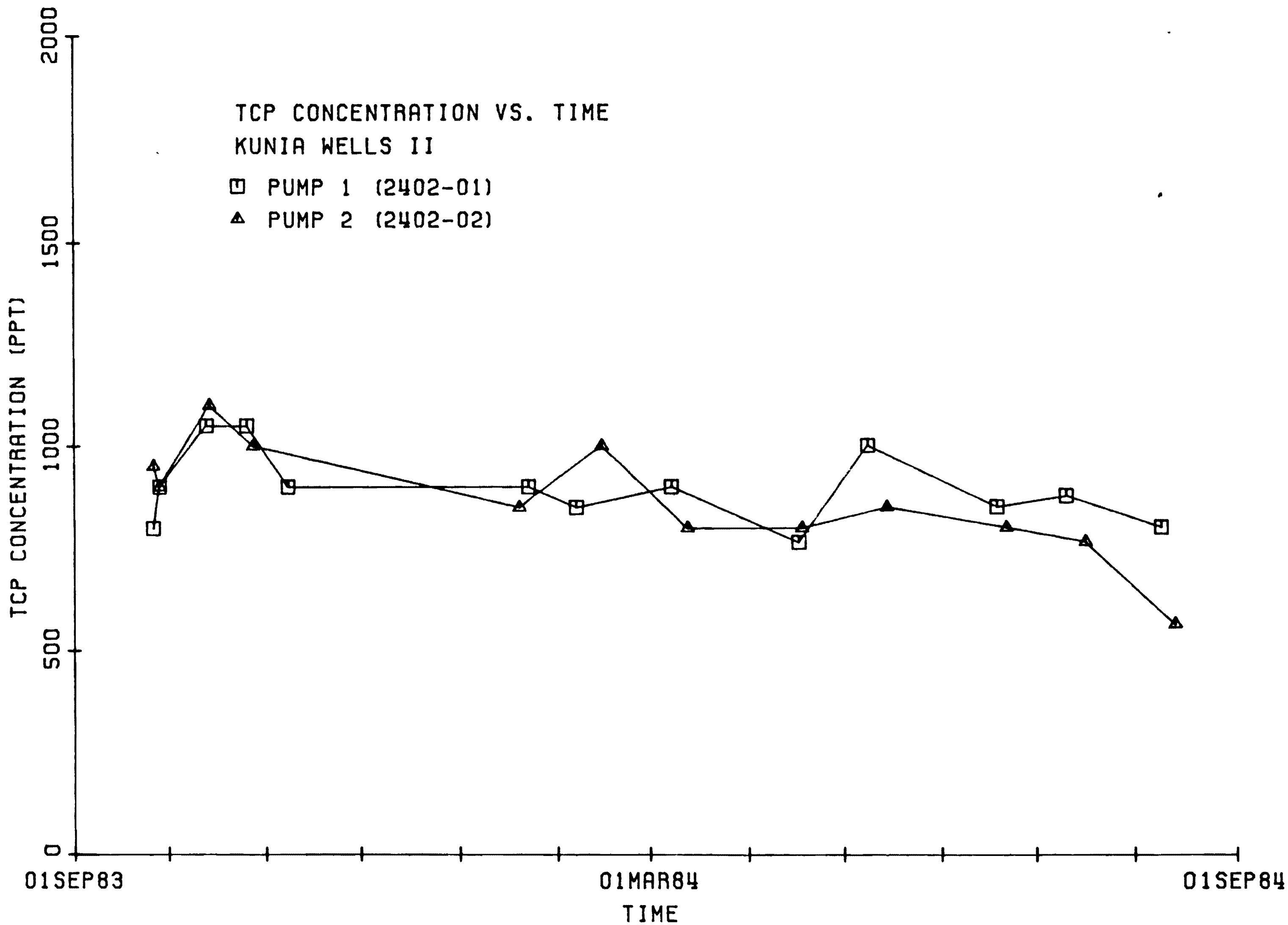


Figure 9. TCP concentration vs. time, Kunia Wells II, O'ahu, Hawai'i

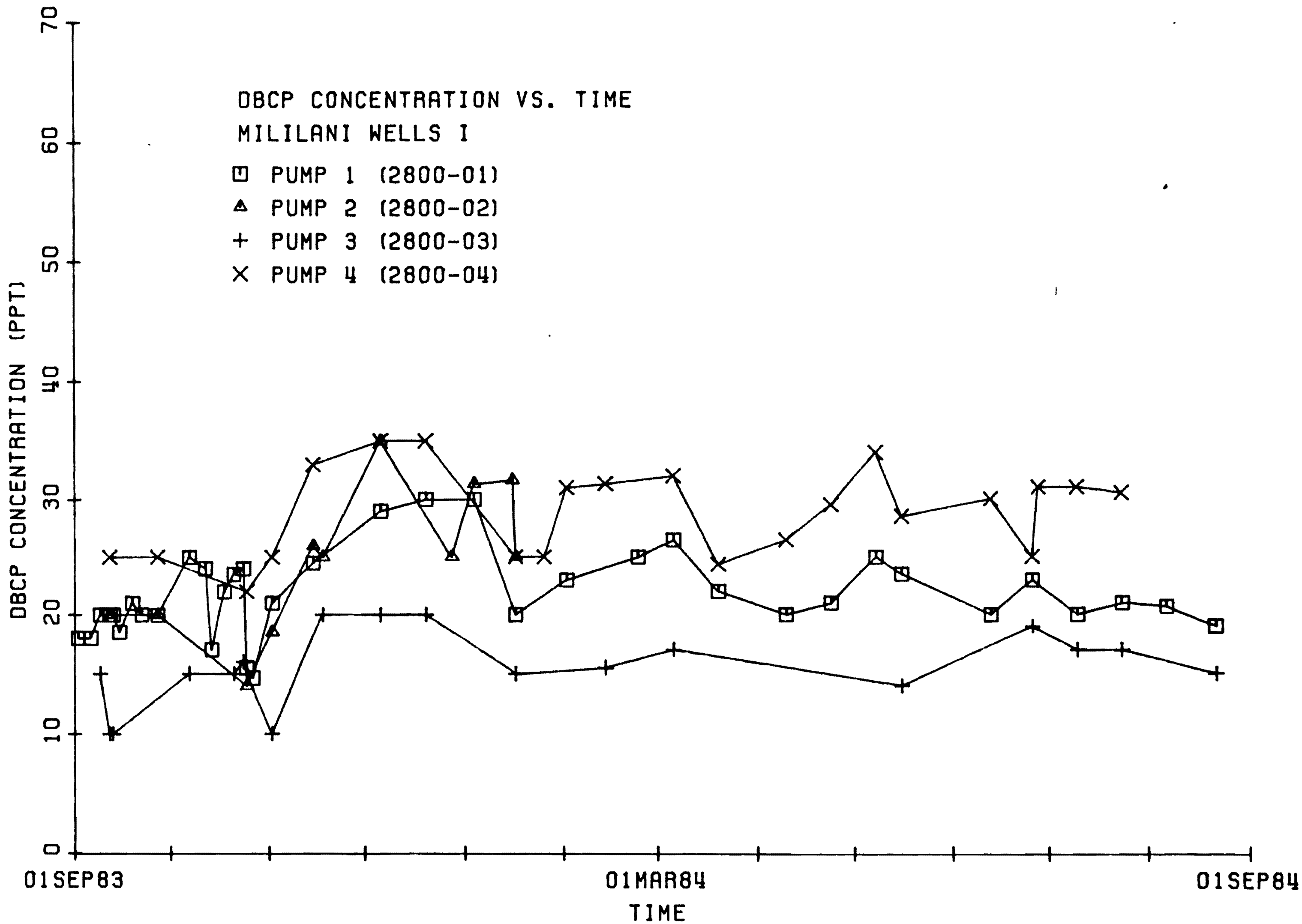


Figure 10. DBCP concentration vs. time, Mililani Wells I, O'ahu, Hawai'i

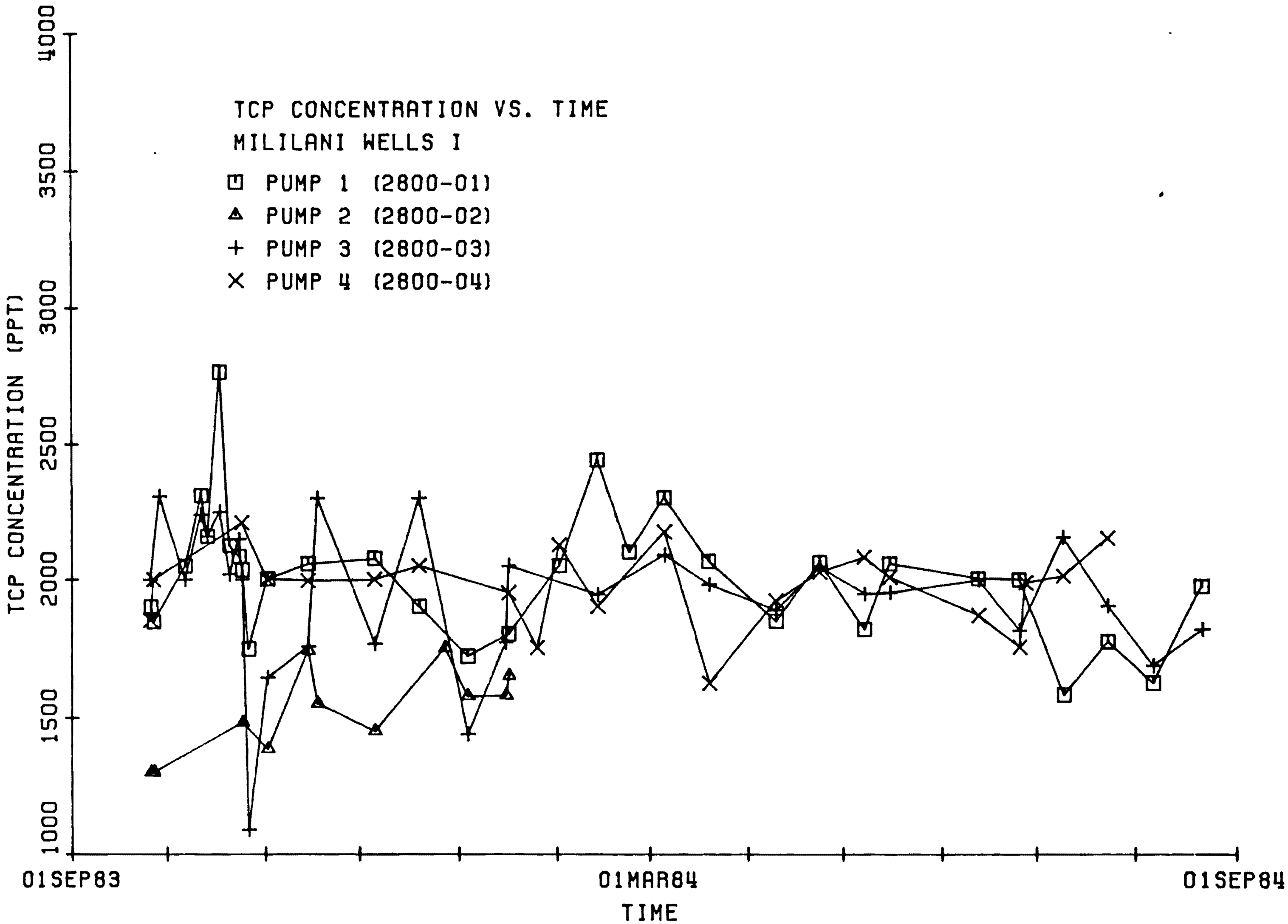


Figure 11. TCP concentration vs. time, Mililani Wells I, O'ahu, Hawai'i

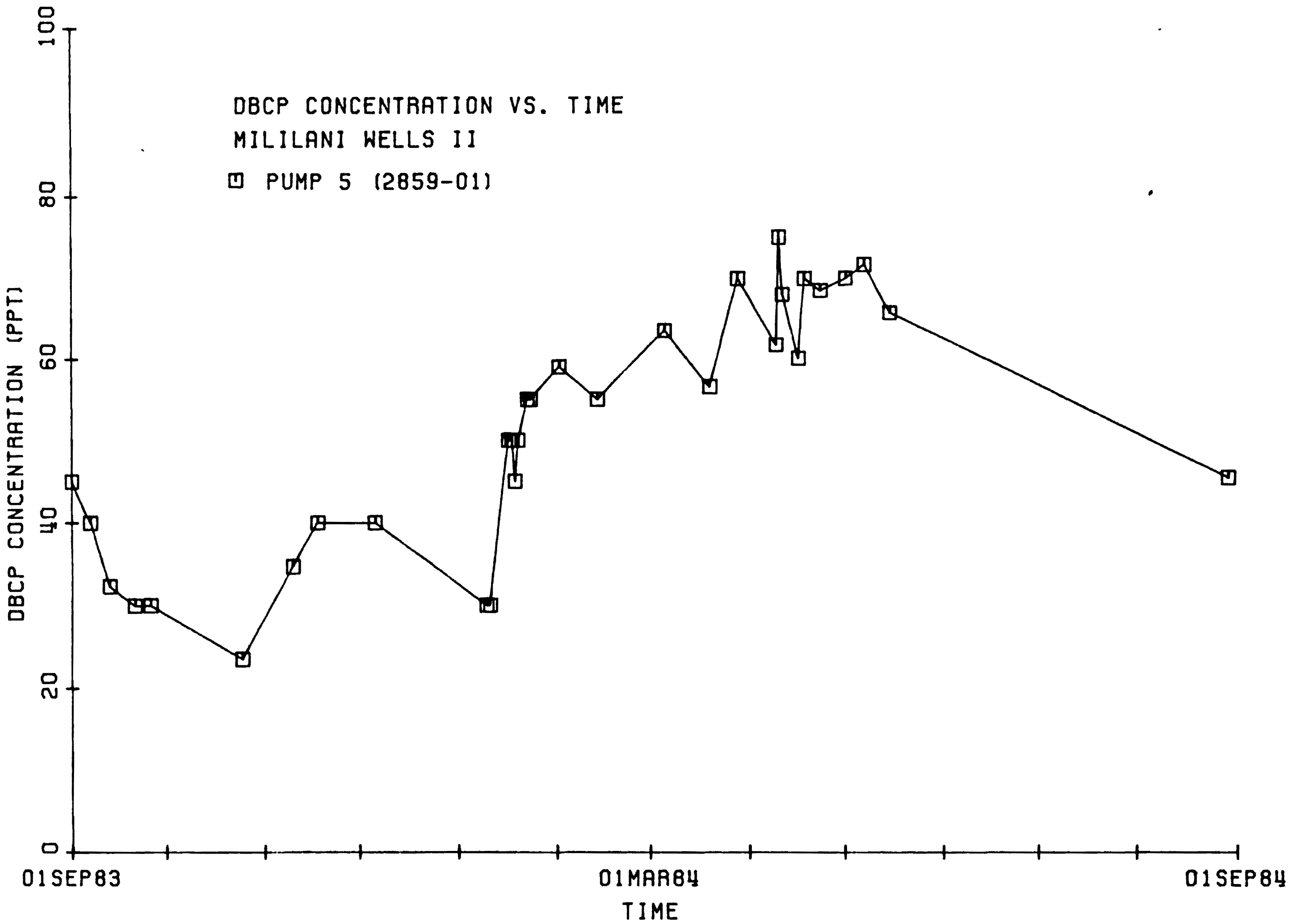


Figure 12. DBCP concentration vs. time, Mililani Wells II Pump 5, O'ahu, Hawai'i

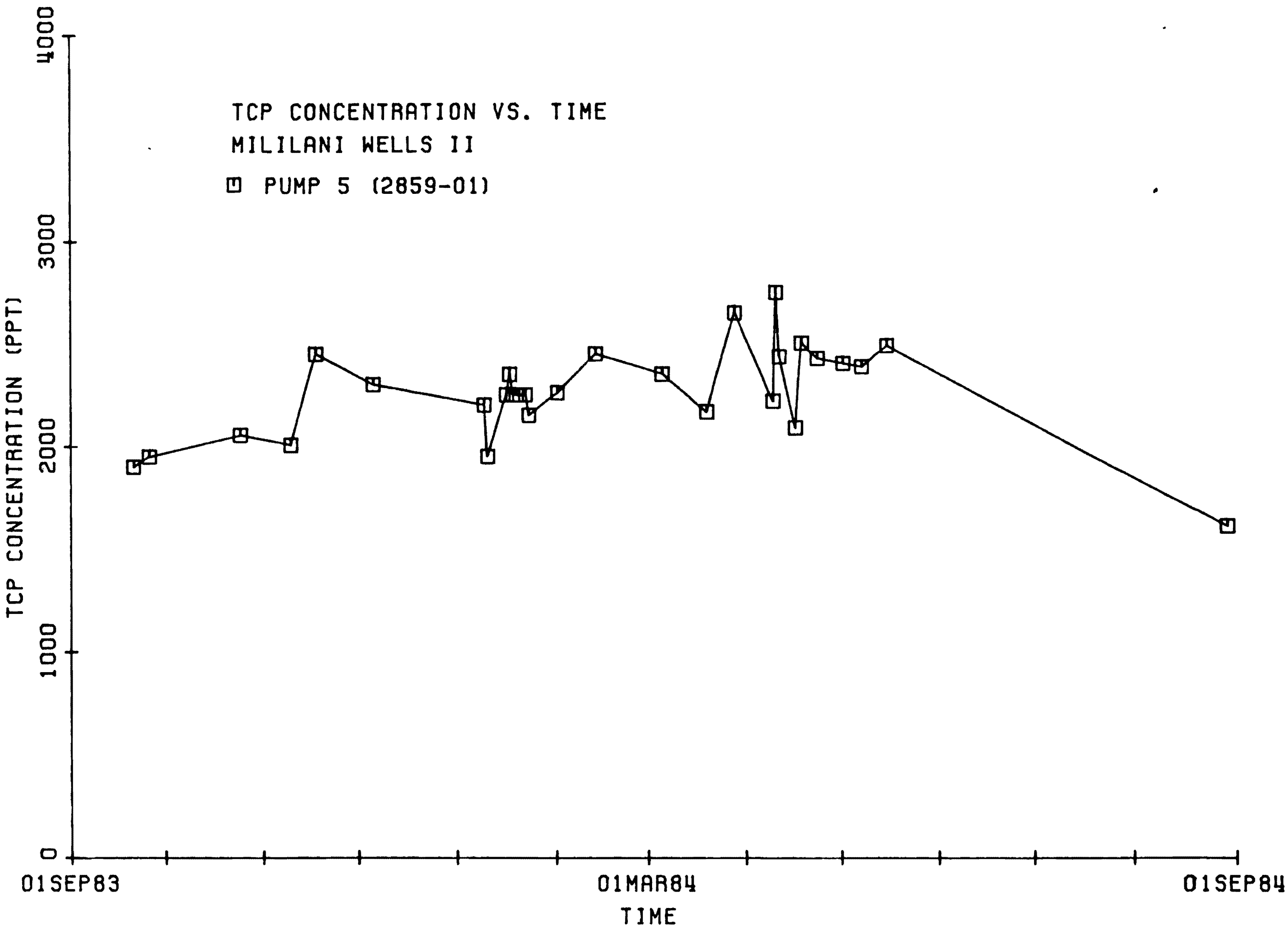


Figure 13. TCP concentration vs. time, Mililani Wells II Pump 5, O'ahu, Hawai'i

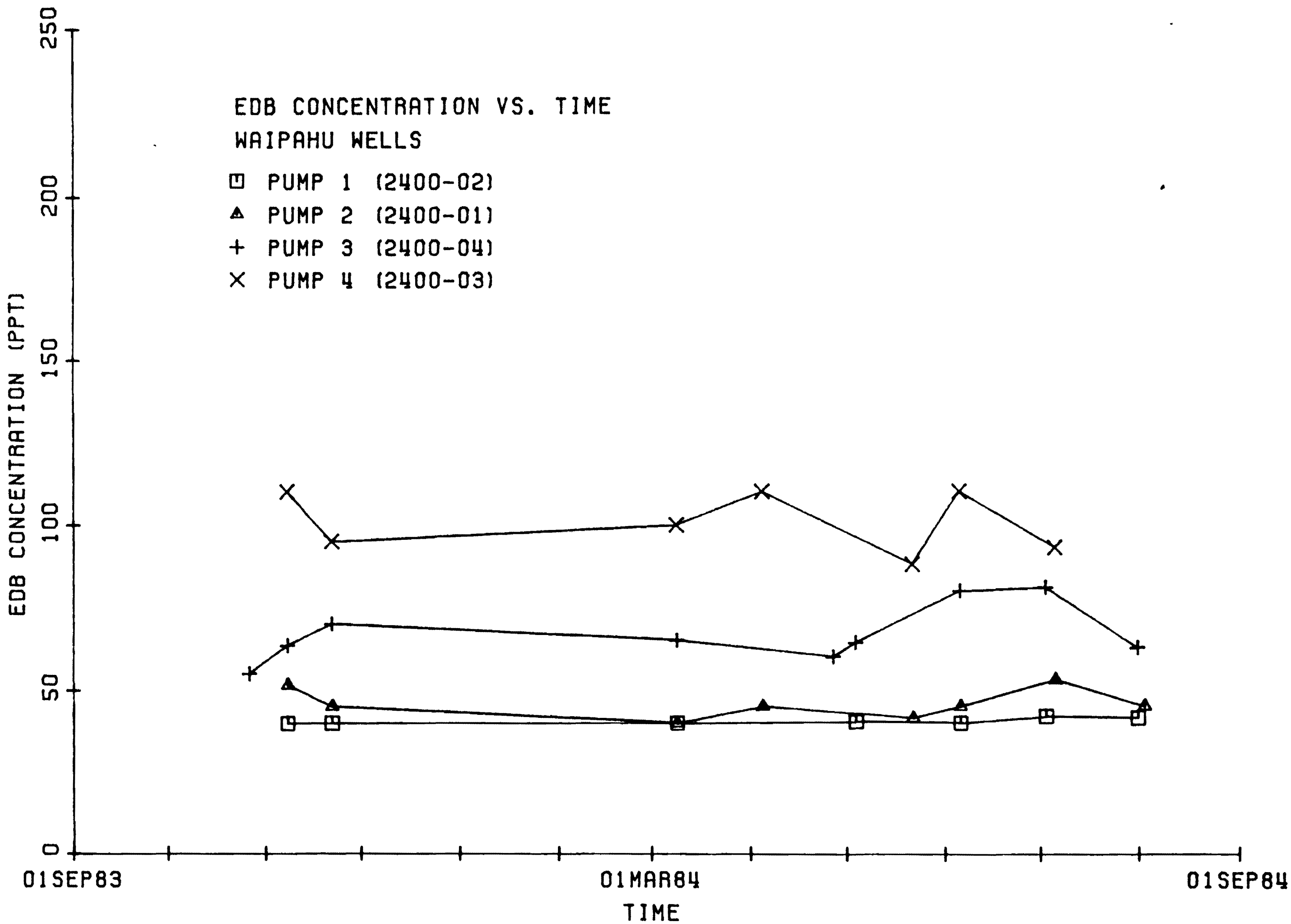


Figure 14. EDB concentration vs. time, Waipahu wells, O'ahu, Hawai'i

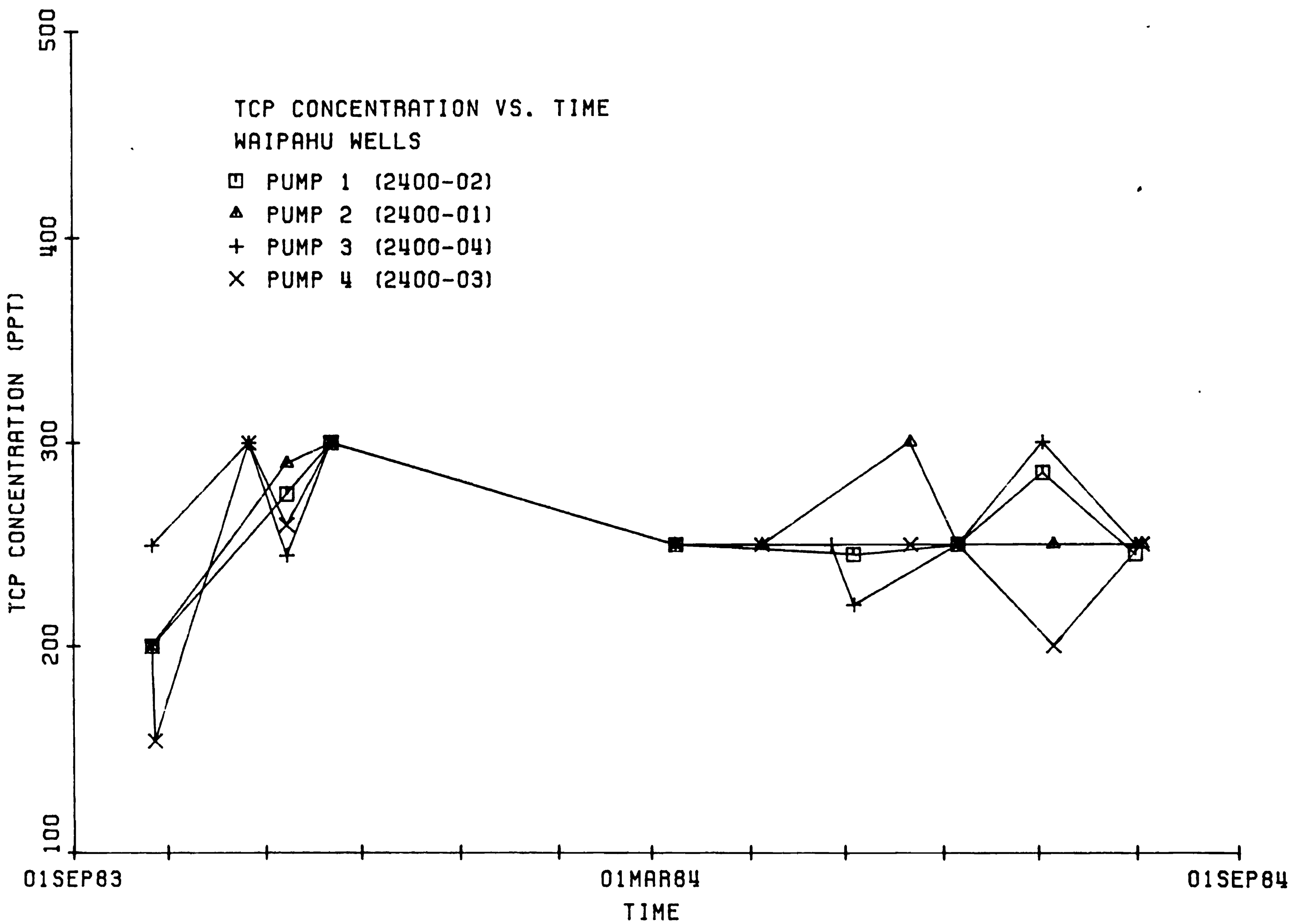


Figure 15. TCP concentration vs. time, Waipahu wells, O'ahu, Hawai'i

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