A STUDY OF THE EFFECTS OF SECONDARY EFFLUENT ON WAIMANO AND WAIAWA STREAMS

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ABSTRACT

A field study was made between September 1972 to May 1973 to assess the water quality changes in Waiawa and Waimano Streams, particularly the effect of chlorinated effluent from the Pacific Palisades Sewage Treatment Plant on the receiving stream waters. Some changes were very apparent, especially those of an aesthetic nature, the visible change in the color and turbidity of the water and the sulfurous odor of septic sewage. These obvious changes were indications of changes in water quality which could only be determined in the laboratory by chemical analysis.

The actual degree of change in stream quality and amount of recovery cannot be determined until Palisades treatment plant ceases operation, and sewage effluent is no longer discharged into the stream.

Waiawa Stream is an intermittent stream with a large drainage area. The developed areas within the Waiawa basin represent 20-25 percent of the total drainage area, but the sewage flow from one such developed area, Pacific Palisades, is the source of perennial flow for the lower section of Waiawa Stream. However, even with the large drainage area and intermittent streamflow, self-purification takes place in the short distance from the point of sewage effluent discharge to Pearl Harbor.

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INTRODUCTION

Discharging raw sewage or treated sewage effluent into a nearby stream is a time-tested convenient method of waste disposal. However, many problems are created by this continuing practice with respect to aesthetics malodor, and situations of sanitary significance and public health. There is also the legal aspect to consider in light of public concern of the environment and resulting pollution control legislation, such as the Federal Water Quality Act of 1965.

In some situations, there is no other feasible method for the disposal of sewage due to location, economics, or both, than discharge into a stream. Such a case exists at the Pacific Palisades Sewage Treatment Plant, located above Pearl City, Oahu, Hawaii (Figs. 1 and 2).

The plant commenced operations on January 12, 1962 and treats an average of 0.69 million gallons per day, mgd (2611.65 cu m/day) of sewage from the Pacific Palisades subdivision (Chun et al. 1972). The plant (Fig. 3) is a two-stage high-rate trickling filter treatment operation. The digester is situated underground beneath the primary clarifier, and sludge beds are used to dewater the treated sludge.

The plant is scheduled to cease operations at some indefinite date in the near future. The sewage from Pacific Palisades will then be pumped from the present plant site to the Pearl City sewage treatment plant located on Pearl City peninsula. The Palisades plant presently discharges its chlorinated secondary effluent into Waimano Stream.

Waimano Stream has its source in the Ewa Forest Reserve on the slopes of the Koolau mountain range, and has a drainage area of approximately 1.5 square miles (3.885 sq kms). The lower portion of Waimano is an intermittent stream, flowing only when sufficient rainfall and runoff occurs. At times, the only flow of Waimano Stream is the effluent from the Pacific Palisades sewage treatment plant and whatever springs discharge into the stream bed.

Waimano Stream merges with Waiawa Stream at a point approximately one-half mile (.805 km) below the Palisades treatment plant. From this confluence, Waiawa Stream flows past the Pearl City treatment plant into the Middle Loch of Pearl Harbor.

Waiawa Stream has its origin in the Ewa Forest Reserve, and flow

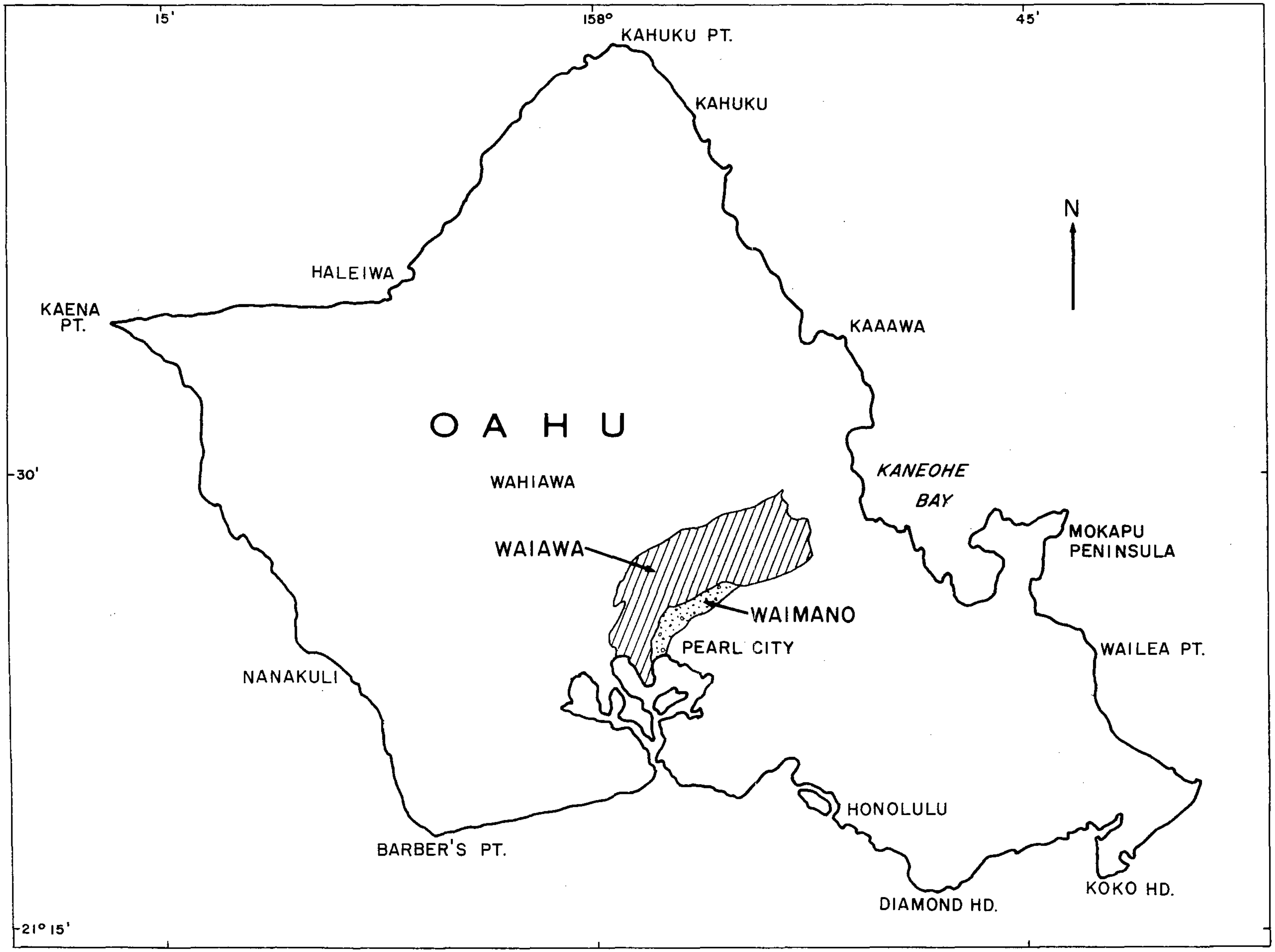

FIGURE 1. WAIMANO AND WAIAWA DRAINAGE AREAS.

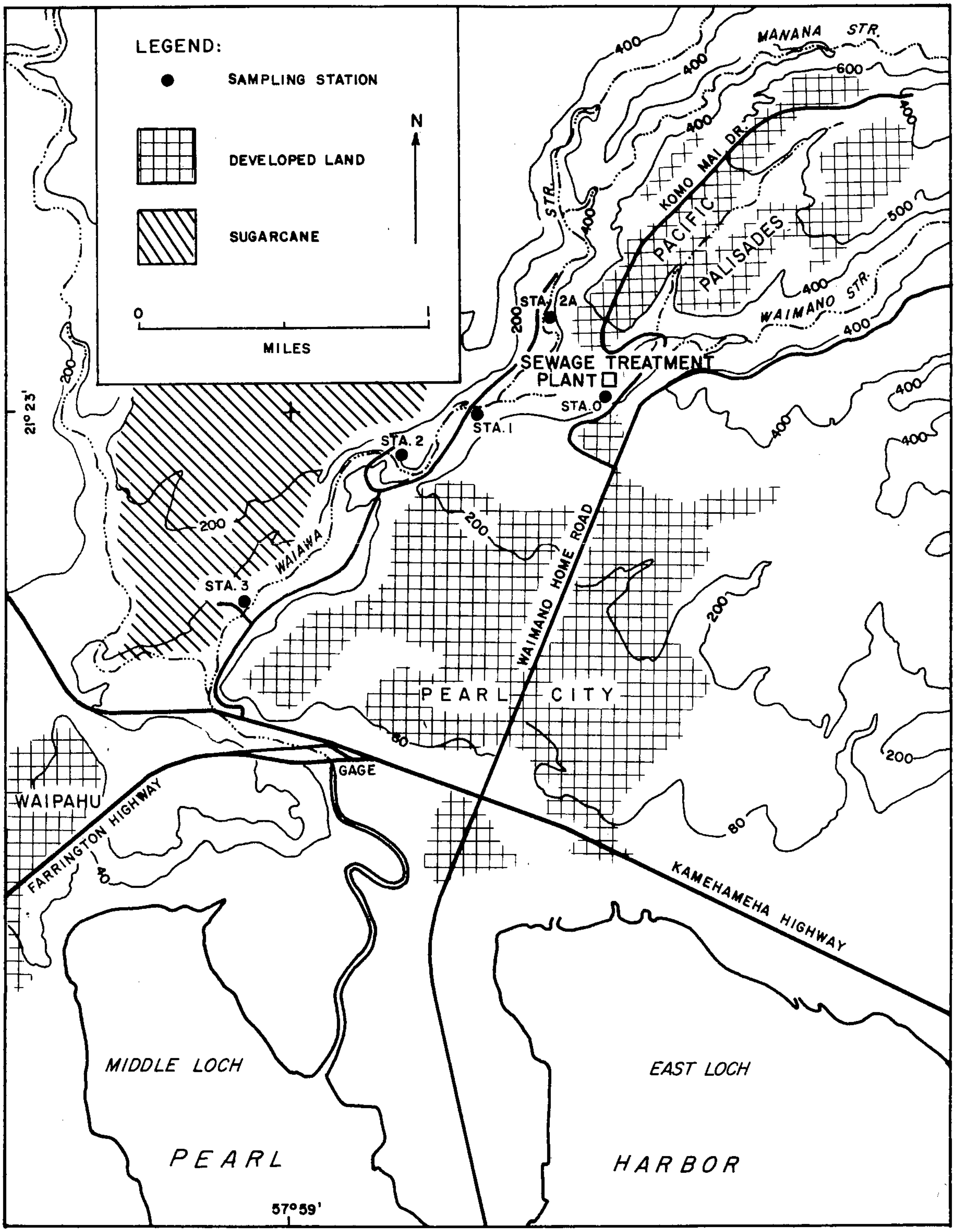

FIGURE 2. WAIAWA - WAIMANO.

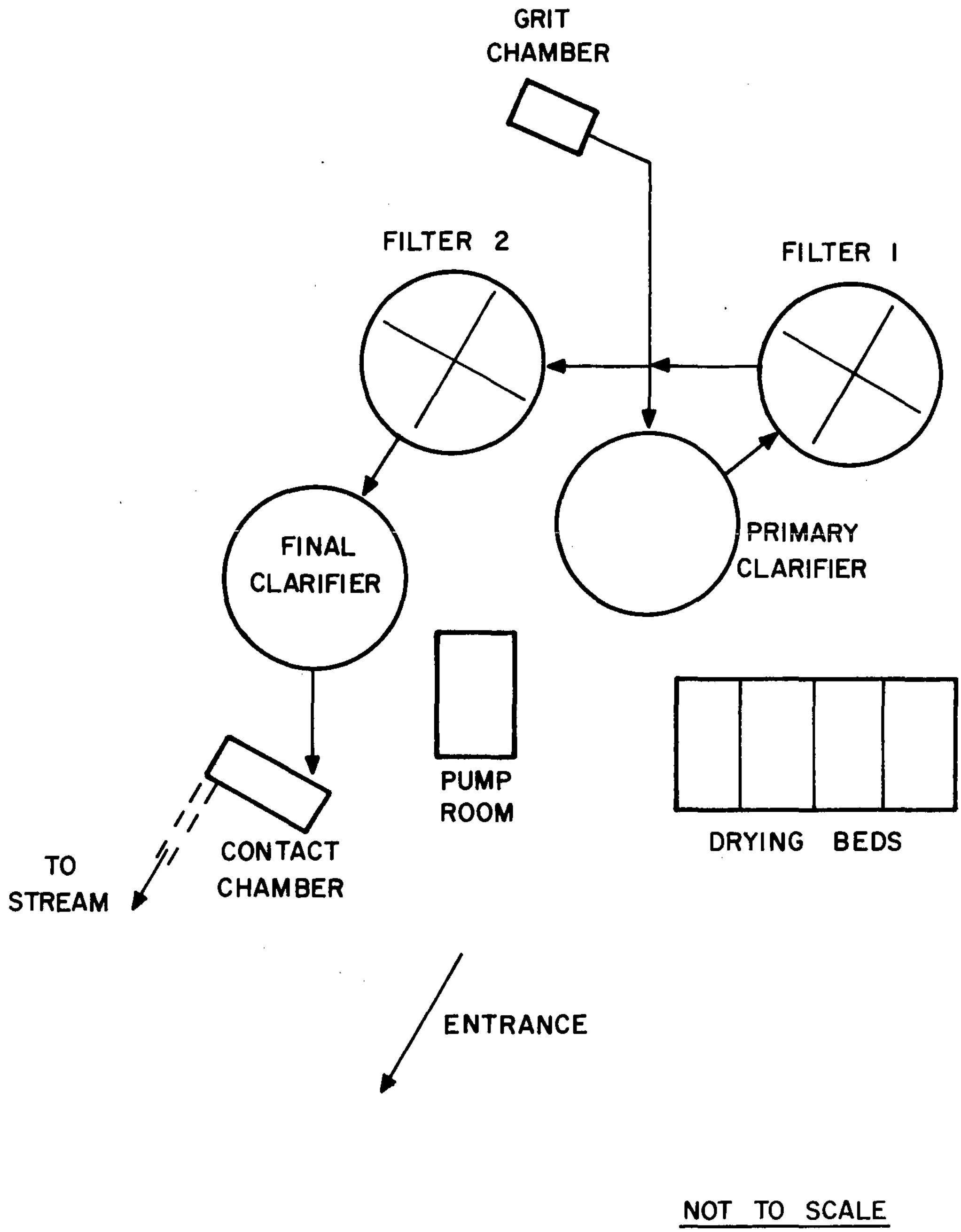

FIGURE 3. SCHEMATIC OF PACIFIC PALISADES SEWAGE TREATMENT PLANT.

above the confluence with Waimano Stream is intermittent. Above the confluence of Waimano and Waiawa Streams, Waiawa Stream is generally dry unless rainfall and runoff are sufficient. The portion of Waiawa from the confluence to the ocean is perennial due to the effluent from the treatment plant and flow from brackish springs which contribute to the flow in this portion of the stream as indicated by increased chloride values. Irrigation runoff from nearby sugarcane fields occasionally contributes to the flow. The U.S. Geological Survey (USGS) has a gaging station located at Waiawa Stream where Farrington Highway crosses the stream.

The Waiawa drainage basin encompasses 26.4 square miles (68.376 km^2), most of which is in forest reserve. The developed areas within the basin amount to a small portion of the total drainage area. The sugarcane and agricultural area is also a small percentage of the total area. The greater portion of the Waiawa drainage basin is undeveloped forest reserve reaching to the slopes of the Koolau Mountains.

The area from the confluence of Waiawa and Waimano Streams down to Kamehameha Highway is part of the U.S. Naval Reservation. As seen in Figure 2, Waiawa Stream forms a rough boundary separating the Naval Reservation to the east from the Oahu Sugar Company sugarcane fields to the west. The access road to the Reservation parallels Waiawa Stream in many places allowing the public access to the stream waters. The western edge of Manana Housing complex also borders the area. Children from Manana often play in Waiawa Stream and catch the fish which abound in many sections of the stream.

Since Waiawa Stream, with the Palisades effluent in some degree of dilution, flows into Pearl Harbor, the impact of the quality of the stream water on Pearl Harbor is of interest. Increased public concern over the condition and water quality of the waters in the Harbor, especially the destruction of oyster beds in the West Loch (FWPCA 1969), led to a study of Pearl Harbor by the U.S. Navy in April 1971 to locate the sources of water, air, noise, solid wastes, and pollution. The results of the Navy study stimulated the appointment of a State "Task Force" to recommend ways of abating the pollution of Pearl Harbor. The Task Force has been active in identifying and helping to overcome obstacles to the implementation of planned water pollution controls (FWPCA 1971). Influent sources which have in some way been altered from natural baseline conditions need to be studied to determine the impact of their waters on the quality of Pearl Harbor and the streams themselves.

The possible impact of the sewage effluent on both Waimano and Waiawa Streams and their flora and fauna from the point of discharge into Waimano Stream to the point where Waiawa Stream empties into the Middle Loch is of concern because of the short distance and usually low flows which limit dilution and assimilation of the effluent.[*] Springs contribute to the flow of Waiawa Stream; therefore, the infiltration of the sewage-water mixture into the groundwater table with resulting deterioration of the water quality is another source of concern.

When the water quality of streams are altered, the streams show some recovery in their flow from the mountain to the sea and tend to approach their baseline conditions.

The objective of this study was to determine the water quality changes occurring in Waiawa Stream and Waimano Stream, and particularly the effect of the addition of the chlorinated sewage effluent from the Pacific Palisades Sewage Treatment Plant.

The physical, chemical, and bacteriological characteristics indicative of the water quality of Waimano and Waiawa Streams were monitored over a period of 9 months at selected stations along each stream.

Previous surveys of Waiawa Stream were recent and very limited in scope. Table 1 lists the reported surveys and available data.

Tenorio, Young, and Whitehead (1969), while studying irrigation return water in the subsurface, determined that Waiawa Stream seemed to follow general patterns of dilution during high and low flow. It was also determined that the stream contained appreciable quantities of nitrates and phosphates and it was suggested that a comparison be made with samples from a location above possible sources of contamination.

The bacterial count in the study by Cox and Gordon (1970) was taken from a report made by the Division of Sewers listing indices of Pearl Harbor water samples. Cox indicated that coliform counts were generally highest at the stream mouths. The counts were of significant interest since some data was from 1957, prior to the construction of the Pacific Palisades Sewage Treatment Plant. Unfortunately, that was the extent of the data available for Waiawa Stream.

TABLE 1. PREVIOUS STUDIES OF WAIAWA STREAM.

PARAMETER	TENORIO[a] AT GAGE (1969)	FWPCA[b] (1969)	COX[c] (1970)	WQPO[d] (1972)
FLOW	WL = 1.65-3.20 FT (1967-1969)	74.2 MGD	2-16 MGD	--
SS	--	13	--	--
PO_4-P	0.039-1.18	0.430 (TP)	--	(AT MOUTH) 0.25
NO_3-N	0.09-4.74	--	--	0.56
Cl^-	31-271	--	--	--
pH	6.2-7.4	7.6	--	--
TEMP	20.5-27° C	20.5° C	--	--
TC/100 ml	--	5900	24,000 MPN/100 ml (NEAR MOUTH, 1957)	--
FC/100 ml	--	5000	--	--

NOTE: CONCENTRATIONS IN mg/l UNLESS OTHERWISE NOTED.

[a] TENORIO, YOUNG, AND WHITEHEAD 1969

[b] FWPCA 1969

[c] COX AND GORDON 1960

[d] ENGINEERING-SCIENCE, INC. et al. 1972.

In 1969, the Federal Water Pollution Control Association (FWPCA), now known as the Environmental Protection Agency (EPA), at the request of the State of Hawaii identified and documented the sources of pollution in Pearl Harbor and the effects upon the water quality and shellfish resources (FWPCA 1969). They concluded that the waste discharges from federal, municipal, and industrial sources, amounting to 11.1 mgd, were adversely affecting the water quality and jeopardizing the existence of the oyster beds in West Loch. Water quality standards for bacterial and nutrient levels exceeded state standards at numerous locations. The reported median coliform level was 610 organisms/100 ml, and Salmonella organisms were identified in the oysters. If Pearl Harbor were officially open to the public, according to the FWPCA, the high degree of bacterial concentration would make fishing, swimming, and collecting shellfish hazardous.

The FWPCA found that tributaries entering Pearl Harbor, including Waiawa Stream, also contain coliform and nutrient concentrations in excess of state standards. They recommended that the source of high nutrient load in Waiawa Stream and other streams be identified and minimized.

The FWPCA study period covered January to March 1969. Flow in Waiawa Stream averaged 74.2 mgd for the period. The median total and fecal coliform counts for Waiawa Stream were 5900 and 5000/100 ml, respectively. Median values of other parameters are listed in Table 1.

Waiawa Stream and Waimano Stream would be classified as Class 2 waters according to the criteria specified in Chapter 37-A Water Quality Standards of the Public Health Regulations, State of Hawaii (Dept. of Health 1968). Pearl Harbor, including Middle Loch which receives the flow of Waiawa Stream, has a Class A designation. The pertinent criteria for each class are summarized in the following paragraphs and in Table 2.

Class 2 waters include all waters used for "bathing, swimming, recreation, growth and propagation of fish and other aquatic life . . . agricultural and industrial water supply . . . shall not act as receiving waters for any effluent which has not received the best practicable treatment or control compatible with the standards established for this class . . . includes all fresh water streams and rivers not included in Class 1."

Class 2 waters must have a median coliform bacteria count less than

TABLE 2. SUMMARY OF WATER QUALITY STANDARDS.

CLASSIFICATION OF WATER ACCORDING TO USES	MICROBIOLOGICAL REQUIREMENTS (COLIFORM COUNTS)	pH (UNITS)	NUTRIENTS mg/l TOTAL P	NUTRIENTS mg/l TOTAL N	DISSOLVED O_2 mg/l	TOTAL DISSOLVED SOLIDS (TDS) SALINITY AND CURRENTS	TEMPERATURE	TURBIDITY (SECCHI DISC OR EQUIVALENT AS "EXTINCTION COEFFICIENT")	RADIONUCLIDES
CLASS AA									
OCEANOGRAPHIC RESEARCH PROPAGATION OF SHELLFISH AND MARINE LIFE CONSERVATION OF CORAL REEFS AND WILDERNESS AREAS AESTHETIC ENJOYMENT NATURAL PRISTINE STATE, WILDERNESS CHARACTER, NO ZONES OF MIXING	MEDIAN COLIFORM BACTERIA: <70/100 ML ANY SAMPLE ≤ 230/100 ML	2.5 FROM "NATURAL CONDITIONS", BUT WITHIN 8.0 - 8.5 FROM OTHER THAN NATURAL CAUSES FRESH TIDAL WATER ≥ 7.0	≤0.020	≤0.10	>6.0	TDS ≥28,000 mg/l NO CHANGES IN CHANNELS, IN BASIN GEOMETRY OF THE AREA, OR IN FRESH WATER INFLUX SHALL BE MADE WHICH WOULD CAUSE PERMANENT CHANGES IN ISOHALINE PATTERNS OF MORE THAN ±10 PERCENT OF "NATURALLY OCCURING VARIATION" OR WHICH WOULD OTHERWISE AFFECT BIOLOGICAL AND SEDIMENTOLOGICAL SITUATION.	TEMPERATURE OF RECEIVING WATERS SHALL NOT CHANGE MORE THAN 1.5° F FROM "NATURAL CONDITIONS"	±5 PERCENT FROM "NATURAL CONDITIONS"	RADIOACTIVITY IN WATER SHALL NOT EXCEED 1/30TH OF THE HPC_W VALUES GIVEN FOR CONTINUOUS OCCUPATIONAL EXPOSURE IN NATIONAL BUREAU OF STANDARDS HANDBOOK NO. 69. NO RADIONUCLIDE OR MIXTURE OF RADIONUCLIDES SHALL BE PRESENT AT CONCENTRATIONS GREATER THAN THOSE SPECIFIED BY THE U.S. PUBLIC HEALTH SERVICE, PUBLICATION NO. 956, AS REVISED IN 1962, AS ACCEPTABLE DRINKING WATER.
CLASS A									
RECREATIONAL-(FISHING, SWIMMING, BATHING, OTHER WATER-CONTACT SPORTS.) AESTHETIC ENJOYMENT ...SHALL NOT ACT AS RECEIVING WATERS FOR ANY EFFLUENT WHICH HAS NOT RECEIVED THE BEST PRACTICABLE TREATMENT OR CONTROL COMPATIBLE WITH THE STANDARDS ESTABLISHED FOR THIS CLASS.	MEDIAN COLIFORM BACTERIA: ≤1000/100 ML, NOT MORE THAN 10 PERCENT OF SAMPLES >2400/100 ML FECAL COLIFORM: ARITHMETIC AVE. ≤200/100 ML (DURING ANY 30-DAY PERIOD) NOT MORE THAN 10 PERCENT OF SAMPLES >400/100 ML (IN PERIOD AS ABOVE)	±0.5 FROM "NATURAL CONDITIONS", BUT WITHIN 7.0 - 8.5 FROM OTHER THAN NATURAL CAUSES	≤0.025	≥0.15	≥5.0	---	TEMPERATURE OF RECEIVING WATERS SHALL NOT CHANGE MORE THAN 1.5° F FROM "NATURAL CONDITIONS"	±10 PERCENT FROM "NATURAL CONDITIONS"	THE CONCENTRATION OF RADIOACTIVE MATERIALS PRESENT IN FRESH, ESTUARINE, AND MARINE WATER, SHALL BE LESS THAN THOSE THAT WOULD REQUIRE RESTRICTIONS ON THE USE OF ORGANISMS HARVESTED FROM THE AREA IN ORDER TO MEET THE RADIATION PROTECTION GUIDES RECOMMENDED BY THE FEDERAL RADIATION COUNCIL.
CLASS B									
SMALL BOAT HARBORS-(COMMERCIAL AND INDUSTRIAL SHIPPING) BAIT FISHING AESTHETIC ENJOYMENT ...SHALL APPLY ONLY TO LIMITED AREA NEXT TO BOAT DOCKING FACILITIES IN BAYS AND HARBORS.	FECAL COLIFORM: ARITHMETIC AVE. ≤400/100 ML (DURING ANY 30-DAY PERIOD) NOT MORE THAN 10 PERCENT OF SAMPLES >1000/100 ML (IN SAME 30-DAY PERIOD AS ABOVE)	±0.5 FROM "NATURAL CONDITIONS", BUT WITHIN 7.0 - 8.5 FROM OTHER THAN NATURAL CAUSES	≤0.030	≥0.20	≥4.5	---	TEMPERATURE OF RECEIVING WATERS SHALL NOT CHANGE MORE THAN 1.5° F FROM "NATURAL CONDITIONS"	±20 PERCENT FROM "NATURAL CONDITIONS"	SEE NOTATION FOR CLASS AA AND A.
CLASS 1									
DRINKING WATER FOOD SUPPLY ABSOLUTE MINIMUM OF POLLUTION (ALL FRESH WATER STREAMS, WHETHER PUBLICLY OR PRIVATELY OWNED, USED FOR DOMESTIC, CULINARY, OR FOOD PROCESSING PURPOSES.)	FECAL COLIFORM: ARITHMETIC AVE. ≤20/100 ML, (DURING ANY CALENDAR MONTH)	---	---	---	---	---	---	---	SEE NOTATION FOR CLASS AA.
CLASS 2									
BATHING, SWIMMING, RECREATION GROWTH AND PROPAGATION OF FISH AND OTHER AQUATIC LIFE AGRICULTURAL AND INDUSTRIAL WATER SUPPLY ...SHALL NOT ACT AS RECEIVING WATERS FOR ANY EFFLUENT WHICH HAS NOT RECEIVED THE BEST PRACTICABLE TREATMENT OR CONTROL COMPATIBLE WITH THE STANDARDS ESTABLISHED FOR THIS CLASS (ALL FRESH WATER STREAMS AND RIVERS NOT INCLUDEDIN CLASS 1.)	MEDIAN COLIFORM BACTERIA: ≤1000/100 ML NOT MORE THAN 10 PERCENT OF SAMPLES >2,400/100 ML FECAL COLIFORM: ARITHMETIC AVE. <200/100 ML (DURING ANY 30-DAY PERIOD) NOT MORE THAN 10 PERCENT OF SAMPLES >1000/100 ML (IN SAME 30-DAY PERIOD AS ABOVE)	6.5 - 8.5	---	---	≥5.0	---	TEMPERATURE OF RECEIVING WATERS SHALL NOT CHANGE MORE THAN 1.5° F FROM "NATURAL CONDITIONS"	---	SEE NOTATION FOR CLASS AA AND A.

SOURCE: ADAPTED FROM CHAPTER 37-A WATER QUALITY STANDARDS, PUBLIC HEALTH REGULATIONS, DEPARTMENT OF HEALTH, STATE OF HAWAII.
NOTE: CHAPTER 37-A WATER QUALITY STANDARDS WERE REVISED AS OF MAY 25, 1974.

or equal to 1000/100 ml, and not more than 10 percent of the samples greater than 2400/100 ml. Fecal coliforms should have an arithmetic average less than or equal to 200/100 ml (during any 30-day period), not more than 10 percent of the samples greater than 1000/100 ml (in the same 30-day period as above). Other criteria are pH of 6.5-8.5, dissolved oxygen (DO) greater than or equal to 5.0, and no more than 1.5°F (16.9°C) change from "natural conditions" in the temperature of the receiving waters. There are no nutrient (nitrogen and phosphorus), total dissolved solids, or turbidity requirements.

Class A waters are designated for recreational purposes and aesthetic enjoyment and should not receive waste discharges which have not received the best possible treatment. Median coliform and fecal coliform requirements are the same as for Class 2, except the corollary to the fecal coliform reads "...not more than 10 percent of samples greater than 400/100 ml" during any 30-day period. Other Class A standards are pH±0.5 from 'natural conditions' but within 7.0-8.5 from other than natural causes. Total phosphorus less than or equal to 0.025 mg/l, and total nitrogen less than or equal to 0.15 mg/l. The DO should be greater or equal to 5.0 mg/l, temperature change not more than 1.5°F from 'natural conditions,' and Secchi disc or equivalent turbidity ±10 percent from 'natural conditions'."

STUDY PLAN

The following sampling stations were selected (Fig. 2):

0 - Station 0 - Waimano Stream near Pacific Palisades Sewage Treatment Plant, upstream of effluent discharge.

E - Effluent - Pacific Palisades sewage treatment plant chlorinated effluent, taken at the effluent weir in chlorination chamber or from the effluent outfall before it mixes with Waimano Stream.

1 - Station 1 - Waiawa Stream at bridge below the confluence of Waiawa and Waimano Streams.

2A - Station 2A - Waiawa Stream at point above the confluence of Waiawa and Waimano Streams.

2 - Station 2 - Culvert where Waiawa Stream intersects access road near Navy warehouses.

3 - Station 3 - Culvert where stream intersects Oahu Sugar Company canefield access road.

G - Gage - Waiawa Stream at the USGS gaging station, sample collected at the weir.

Station 0 and Station 2A were the control stations, being above the point of effluent discharge. Streamflow was recorded at the two stations only when there was sufficient rainfall. At Station 2A a greater amount of rain was necessary for streamflow to occur, which accounts for the limited number of samples taken at that station. The effluent station was the point of waste discharge into the stream.

At Station 1 the combined flows of Waiawa and Waimano Streams were monitored. At this station, Waiawa Stream widens considerably and there is an abrupt change in direction, resulting in a sharp decrease in velocity and eddy currents. At times, the current was observed as moving upstream or in a large eddy. This area of the stream is a natural sedimentation basin where flow-through time is very long with the resulting odor and aesthetic problems. Samples were collected off the bridge by lowering a bucket with a rope.

Station 2 and 3 samples provided an indication of the location of springs which add to the flow of Waiawa Stream.

The gaging station was the only station on the stream where a measurement of flow was possible. The USGS has a recording gage at the station. The gage was the last station in this survey because tidal effects become significant farther downstream of that point. The weir at the gage prevents any effect of the tide on upstream flow.

Grab samples at each station were collected once each week from September 1972 through May 1973. Effluent samples with chlorine residual were neutralized with sodium thiosulfate immediately upon collection. Collected samples were chilled during the sampling period, which usually lasted 2 to 3 hours, until return to the laboratory where proper refrigerated storage could be provided. Samples were collected in the morning hours on five consecutive days in May 1973 to take advantage of a period of high flow.

On two dates, 10/13/72 and 12/20/72, irrigation runoff was observed at Station 2. On these occasions, two samples were collected, one above the point of mixing and one in the zone of mixing of the runoff and stream. All parameters relating to solids and mineral composition (suspended and total solids, chlorides, conductivity, and turbidity) showed an increase in the downstream sample. The volatile suspended solids increased in concentration for the downstream sample, but the percent volatile solids decreased, indicating dilution by a low organic content water. Other parameters showed some change but not significantly enough to draw conclusions.

Physical measurements of pH, temperature, and oxidation-reduction potential were made in the field and color and turbidity in the laboratory. Chemical tests included biochemical oxygen demand, ammonia-nitrogen, organic nitrogen, total Kjeldahl nitrogen, nitrate-nitrogen, nitrite-nitrogen, total phosphorus, orthophosphate, total and total volatile solids, suspended and volatile suspended solids, residual chlorine, chlorides, and specific conductivity. Bacteriological tests included total and fecal coliforms and fecal streptococcus.

The pH was measured in the field with a Photovolt Model 126A pH meter. ORP was measured with a Photovolt Model 126 pH meter. A YSI model 51A DO meter was used initially to measure DO in the field, but due to mechanical problems, a switch was made to the azide modification of the Winkler test as given in *Standard Methods* (1971).

Temperature was measured *in situ* where possible in the field with a laboratory thermometer. Residual chlorine was determined in the field with a Hach color comparator. The water level was read from the staff at the USGS gaging station, and visual reading compared favorably with the recorded measurements of the USGS.

Turbidity was determined with a Hach Model 2100A turbidimeter as Formazin Turbidity Units (FTU) which are equivalent to Jackson Turbidity Units (JTU). Conductivity measurements were made with an Industrial Instruments Model RC 16 B2 conductivity bridge.

Phosphorus and orthophosphate determinations were accomplished with a Technicon Auto Analyzer II.

The remaining tests were determined using methods as specified in *Standard Methods*.

Bacterial tests were accomplished by the membrane filter method, also as noted in *Standard Methods*.

Many of the parametric concentrations at each station were flow dependent, being higher or lower as flow increased or decreased. Thus, a distinction between wet weather high streamflow and dry weather low streamflow was necessary.

Rainfall, runoff, and streamflow by themselves were not adequate to make the distinction, although Stations 0 and 2A had measurable flow only when there was sufficient runoff. The runoff flow was often insufficient to cause any noticeable dilution; therefore, a combination of chloride and dissolved oxygen concentrations along with the flow was utilized to differentiate high flow.

High flow conditions were based on the dissolved oxygen being close to saturation at Stations 0 and 1 and approximately 50 percent reduction of chloride between the effluent and Station 1. The minimum gage flow of these sampling dates was 8.53 cfs (14.5 cu m/min); therefore, any sampling date whose flow was greater or equal to 8.53 cfs (14.5 cu m/min) at the gage was considered wet weather flow. All other dates were considered to be representative of dry weather flow.

DISCUSSION OF RESULTS

In this stream survey, the period of investigation was not entirely representative because of low monthly rainfall. From interviews with USGS personnel, the three-year period of 1970-73 was very dry. Unfortunately, there is no rain gage in the Waiawa drainage basin. In 1969, the FWPCA reported an average annual rainfall of 160 inches (406.4 cm) at the 725-foot (221-m) elevation for Waiawa (FWPCA 1969). A National Oceanic and Atmospheric Administration (NOAA) rain gage located in Pacific Palisades accumulated 56.8 inches (144 cm) for 1972, and 38.56 inches (98 cm) of rain was collected from January through September 1973. The total rainfall during the 9 months of this study was 41.17 inches (104.6 cm).

Flow measurement was very difficult due to the "flashy" nature of the flow of Waiawa and Waimano Streams (Jones, Nakahara, and Chinn 1971). Fortunately, the USGS has an active gaging station on Waiawa Stream at Farrington Highway. Flow records of the Pacific Palisades Sewage Treatment Plant were available from the Sewers Division of the City and County of Honolulu. The gaging station and sewage plant records were the only direct measurements of flow available.

The average flow from the Palisades treatment plant during the time of sampling for all sampling dates was 0.65 mgd (2460 cu m/day). The mean flows at the gage during the sampling period were 2.9 mgd (10,976.5 cu m/day) dry weather flow and 28.1 mgd (106,358.5 cu m/day) wet weather flow. These values were calculated from the available data.

From the above, during dry weather, an average of 22 percent of the flow at the gage was contributed by the sewage treatment plant. In wet weather, only 2.2 percent of the gage flow was from the treatment plant.

The average flow at the gage for the calendar year 1970 was 36.3 cfs (61.71 cu m/min) and for the water year 1971, 50.2 cfs (85.34 cu m/min) (USGS 1973).

Data analyzed for the Pacific Palisades treatment plant effluent compared favorable with similar parameters analyzed by the City and County of Honolulu chemist (Table 3).

The DO content of the stream water exhibited the shape of the "spoon-shaped" dissolved oxygen sag curve (Fair, Geyer, and Okun 1968). The sag profile was especially evident during periods of dry weather and almost nonexistent during periods of high flow (Fig. 4).

The two control stations, 0 and 2A, which had flow only during periods of sufficient rainfall had DO at or very near saturation concentration during wet weather. During dry periods, the lowest DO at the control stations were 4.32 and 6.9 mg/l, respectively, while the mean concentrations were 7.4 and 8.7 mg/l, respectively.

The oxygen deficit at Station 1 was the lowest recorded during the investigation for the stations, and on several occasions the DO was zero. Station 1 was the lowest position on the sag curve, for as the stream flowed through Stations 2 and 3 and the gage, the DO increased by turbulent re-aeration during dry weather flow.

During wet weather, the DO was near saturation at the upper stream stations, but decreased at the gage (Fig. 4). One possibility was that the sag curve was moved to that point downstream by the increased flow.

The Class 2 Water Quality Standard of at least 5.0 mg/l DO was not met except during high flow and was probably not met overnight because of regular diurnal variation.

The BOD ranged from 0 mg/l at the control stations, 0 and 2A, to 55.2 mg/l for the effluent. The maximum concentration for the effluent occurred when the chlorination chamber was being aerated to resuspend settled solids carried over from the final clarifier, and the suspended solids were also at a maximum. The average BOD for the effluent was 26.2 mg/l (Fig. 5).

The general trend in the flow downstream was a decrease in the BOD

TABLE 3. CHEMICAL ANALYSIS OF PACIFIC PALISADES EFFLUENT.

DATE	TIME	FLOW (MGD)	pH UNITS	DO	BOD	SS	SET. SOL. (ml/l)	T-P	ORG-N	COMPOSITE NH_3-N	TS/TVS	TURB. (FTU)
9/29/72	0730	0.92	7.08	1.6	17	28	0.1	7	5.9	11.5	364/164	
10/6	0750	0.86	7.30	2.3	22	24	0.2	8	6.4	10.6	384/200	
10/13	0715	0.96	7.4	2.8	18	10	0.05	9	7.0	14.8	384/168	
11/17	0745	0.83	7.4	3.3	14	12	0.1	8	3.3	11.5	366/196	
11/8	0800	0.87	7.58	3.4	7	14	0.2	8	5.2	9.8	378/166	
11/29	0800	0.87	7.4	3.6	32	18	0.2	6	5.0	14.6	378/200	
11/24	0710	0.52	7.29	3.2	31	16	0.2	6	4.0	14.3	386/178	
1/5/73	0800	0.52	7.10	3.5	11	12	0.05	10	5.9	11.3	394/184	
3/7	0740	0.81	7.38	3.4	18	12	0.1	8	4.8	13.0	366/222	
2/22	0720	0.82	7.32	4.0	15	15	0.3	10	4.5	9.0	350/172	14
3/23	0815	0.75	7.45	3.2	15	12	0.3	7	8.4	17.1	372/198	14
4/5	0840	0.65	7.6	4.0	10	18	0.05	18	4.8	14.0	348/158	13
4/27	0800	0.58	7.13	2.9	11	10	0.1	9	4.8	16.5	358/182	18
5/18	0720	0.85	7.10	3.2	22	30	0.1	10	7.1	13.0	362/192	24
5/31	0810	0.75	7.60	2.8	17	18	0.1	10	7.1	16.0	354/166	34

SOURCE: CITY AND COUNTY OF HONOLULU.

NOTE: IN mg/l, UNLESS OTHERWISE NOTED.

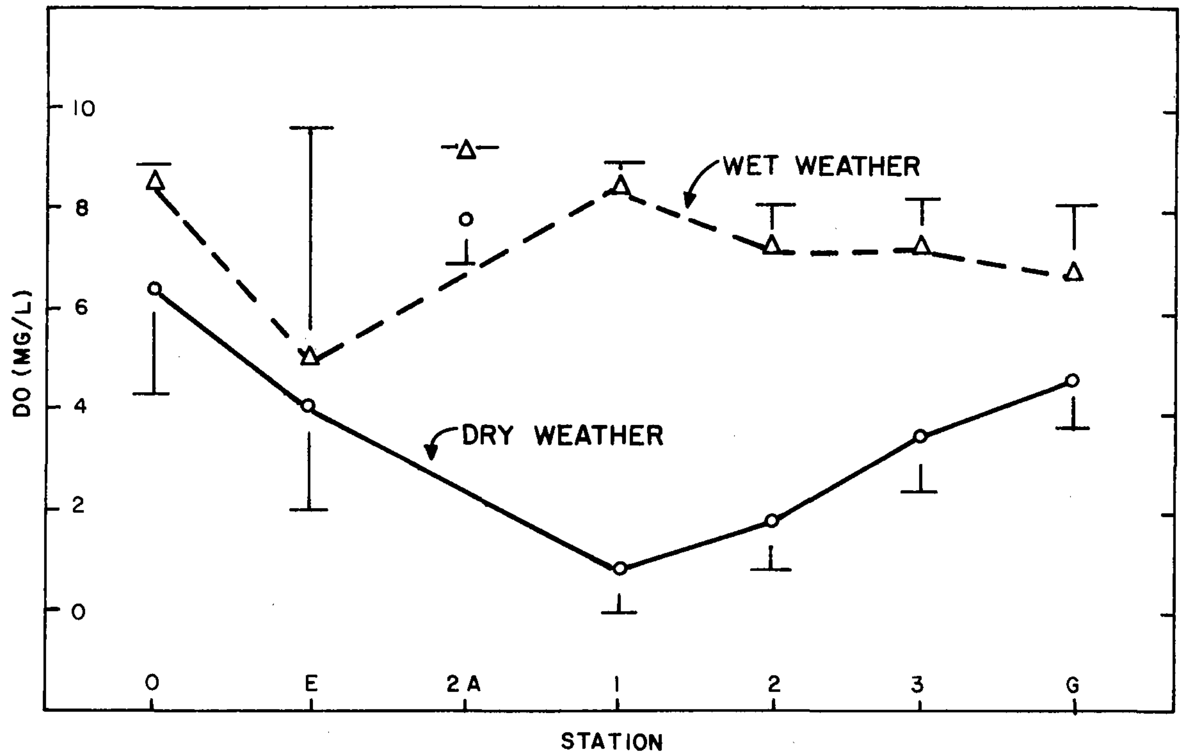

FIGURE 4. DISSOLVED OXYGEN (DO) BY STATIONS.

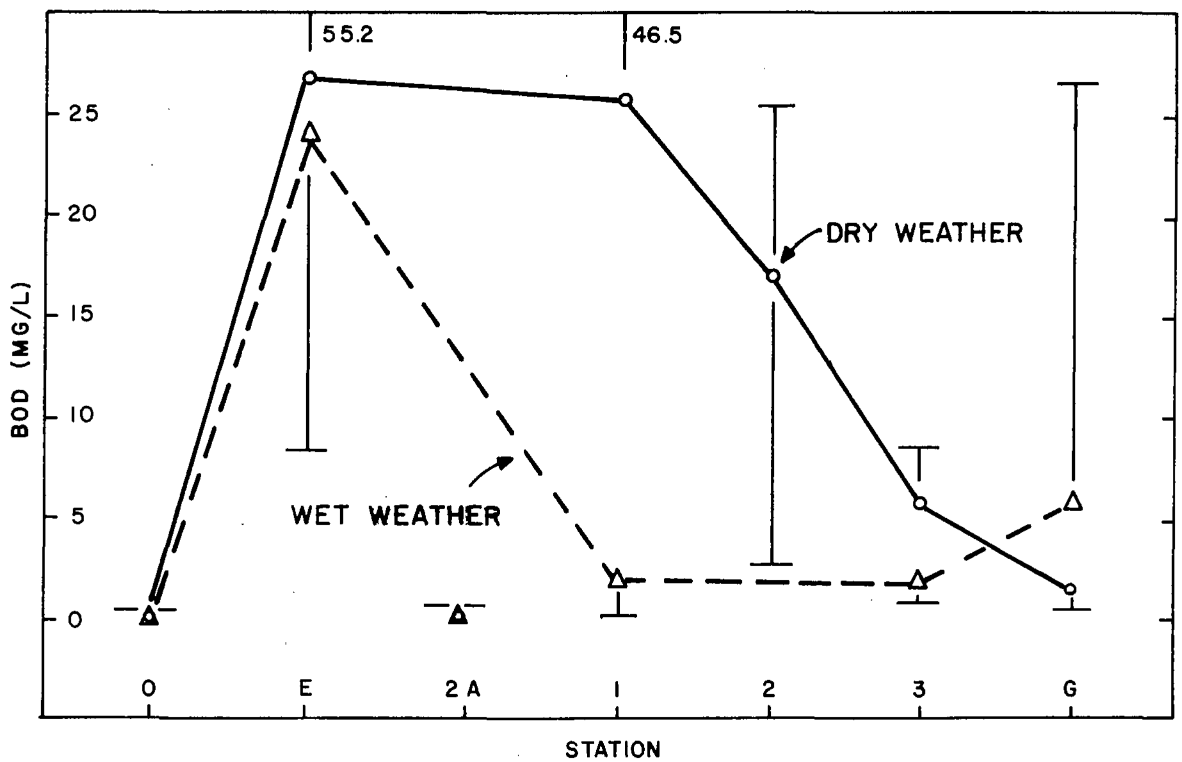

FIGURE 5. BIOCHEMICAL OXYGEN DEMAND (BOD) BY STATIONS.

during dry weather conditions, and a trend correlation with the DO increase downstream. The oxygen demand was being satisfied between the effluent discharge and the gage, and self-purification was occurring.

During wet weather flows, a slight increase in BOD at the gage was noted. This could also be correlated to the wet weather DO, a movement downstream of the oxygen sag curve and could also be due to illegal wastewater discharge, since a few residential dwellings exist in the area above the gage and their means of wastewater disposal is not known since no city sewer extends to that area. The maximum BOD for the gage of 26.7 mg/l occurred during wet weather, but that was due to the increased suspended solids load from the highway construction project of the Waiawa Interchange.

The mean concentrations of suspended solids (Fig. 6) decreased during dry weather in a downstream direction, an indication of gradual sedimentation along various parts of the stream. The volatile solids content (Fig. 7) also decreased downstream during dry weather, indicating either utilization or sedimentation of organic suspended matter. This decrease in volatile matter was consistent with the behavior of the oxygen sag profile and BOD previously discussed.

The maximum concentration of suspended solids occurred during wet weather in the effluent. A concentration of 201 mg/l was determined in the effluent because the chlorine contact chamber was being aerated, and all the settled matter at the bottom of the chamber was suspended. The maximum volatile solids concentration also occurred during the same period. The dry weather suspended solids for the effluent averaged 20.6 mg/l and the wet weather averaged 54.2 mg/l. Without the maximum concentration of 201 mg/l, the wet weather mean concentration of SS was 29.7 mg/l.

The maximum concentration at the gage of 67 mg/l also occurred during wet weather because of heavy sediment load caused by the runoff from the construction of the Waiawa Interchange. As previously stated, the BOD increased at the gage for the same reason.

In general, dry weather concentrations for suspended and volatile suspended matter were higher during dry weather. The percent volatile solids were also higher during dry weather. This was probably due to the fact that samples were collected during the recession of the storm hydrograph, and the "first-flush effect" (Robbins, Howells, and Kriz 1972) had already passed.

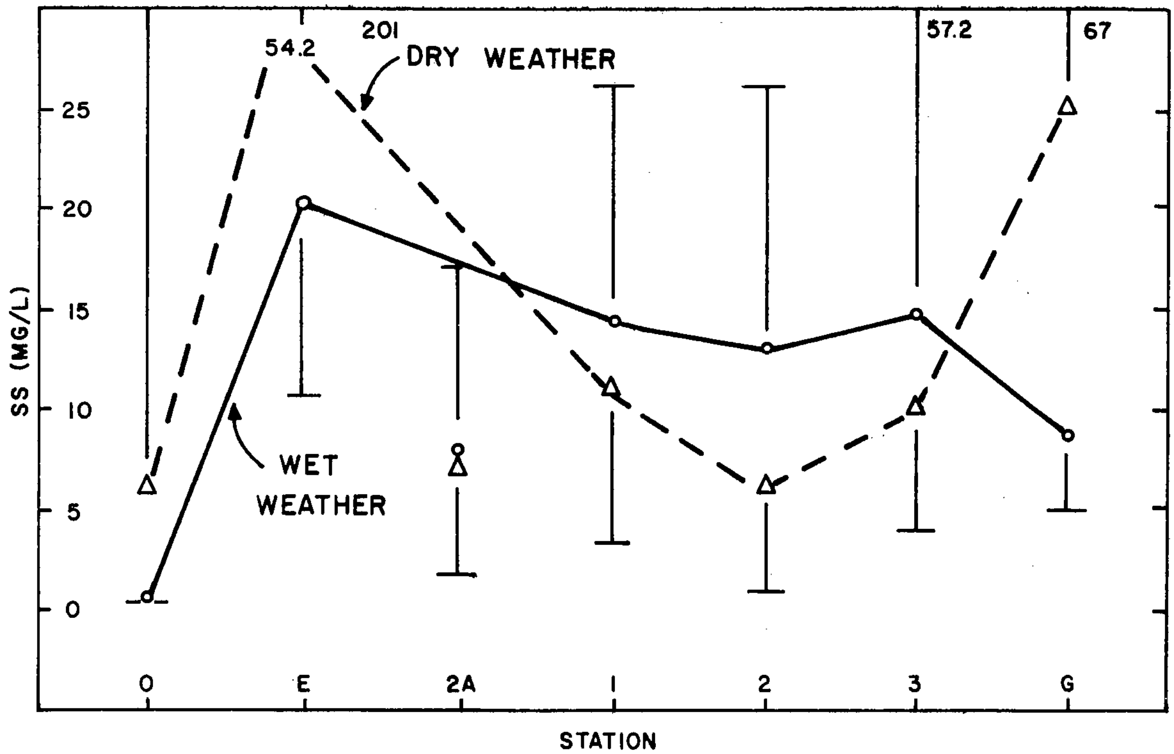

FIGURE 6. SUSPENDED SOLIDS (SS) BY STATIONS.

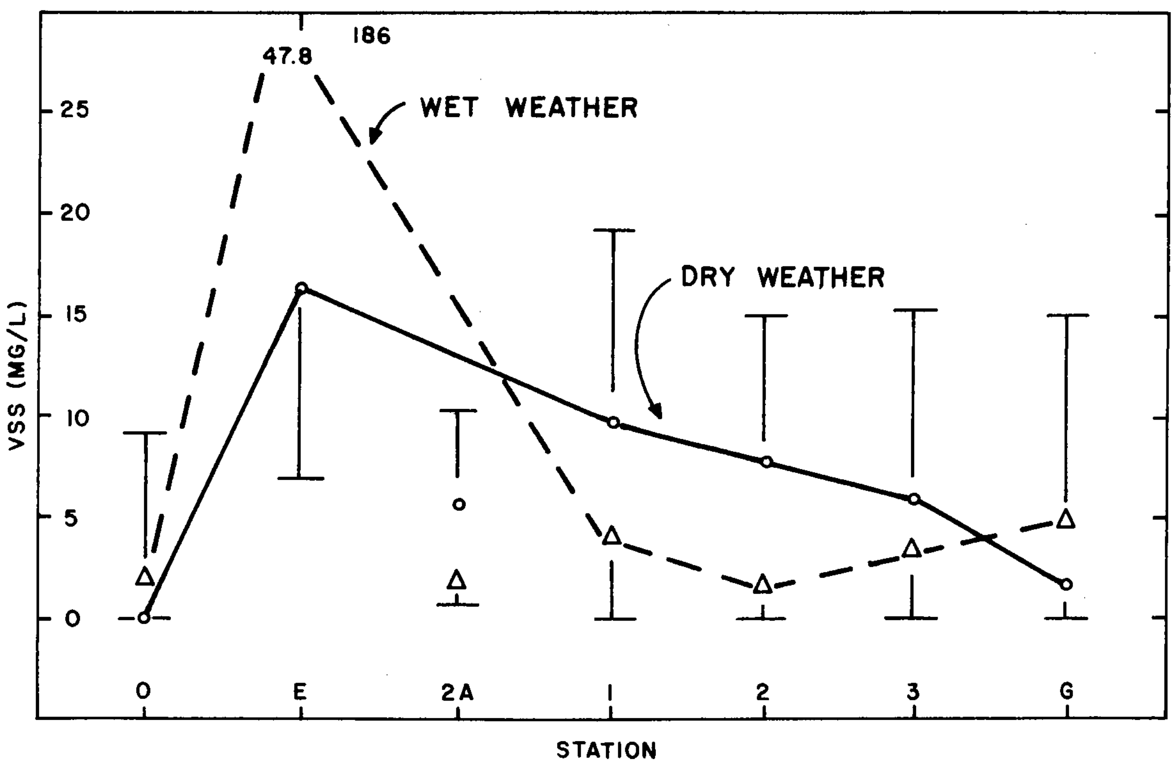

FIGURE 7. VOLATILE SUSPENDED SOLIDS (VSS) BY STATIONS.

From Figures 8 and 9, it can be noted that the total Kjeldahl nitogen (TKN) at all stations except control stations existed primarily as ammonia-nitrogen (NH_3-N). At the control stations, 0 and 2A, low concentrations of TKN were detected and in contrast to the other stations, most of the nitrogen was organic.

High ammonia during the dry weather indicated active decomposition of organics in the stream. The maximum concentration of ammonia, 36 mg/l N occurred in the effluent, though the concentrations, 32.5 mg/l maximum, at Station 1, were also high. As with BOD and SS, the ammonia concentration decreases downstream during dry weather, consistent with the principles of stream assimilation.

The nitrogen balance of the stream was also consistent during dry weather. As the ammonia decreased in a downstream direction, the nitrite and nitrate concentrations increased (Figs. 10 and 11). Nitrite and nitrate were low at Station 1 and at times down to zero which was expected since the ammonia level there was very high. The nitrite and nitrate content in the effluent was high, averaging, 0.20 mg/l N and 0.62 mg/l N, respectively; however, this was consistent for sewage treatment plant effluents, since the concentration rarely exceeds 1 mg/l nitrite according to Sawyer and McCarty (1967). Nitrite and nitrate were detected in all the effluent samples.

During wet weather, the ammonia was low at all stations except for the effluent, indicating high dilution. Slight increases in ammonia were noted at the stations between Station 1 and gage, but the concentration decreased at the gage as in dry weather. Nitrates increased at the gage as in dry weather, but nitrites decreased at the gage, possibly victims of high flow and dilution.

The nitrogen balance at the effluent and at the gage were not equivalent as in theory. Some ammonia was possibly lost to the atmosphere through turbulence and some denitrification was evident at Station 1 during dry weather and low flow. Dilution was another factor which would reduce the nitrogen concentration at the gage.

The increase in nitrate at Station 3 and the gage may not have been entirely a function of nitrification. As stated previously, there was groundwater leakage into the stream by way of springs, and also irrigation runoff input. Tenorio, Young, and Whitehead (1969) found that waters from

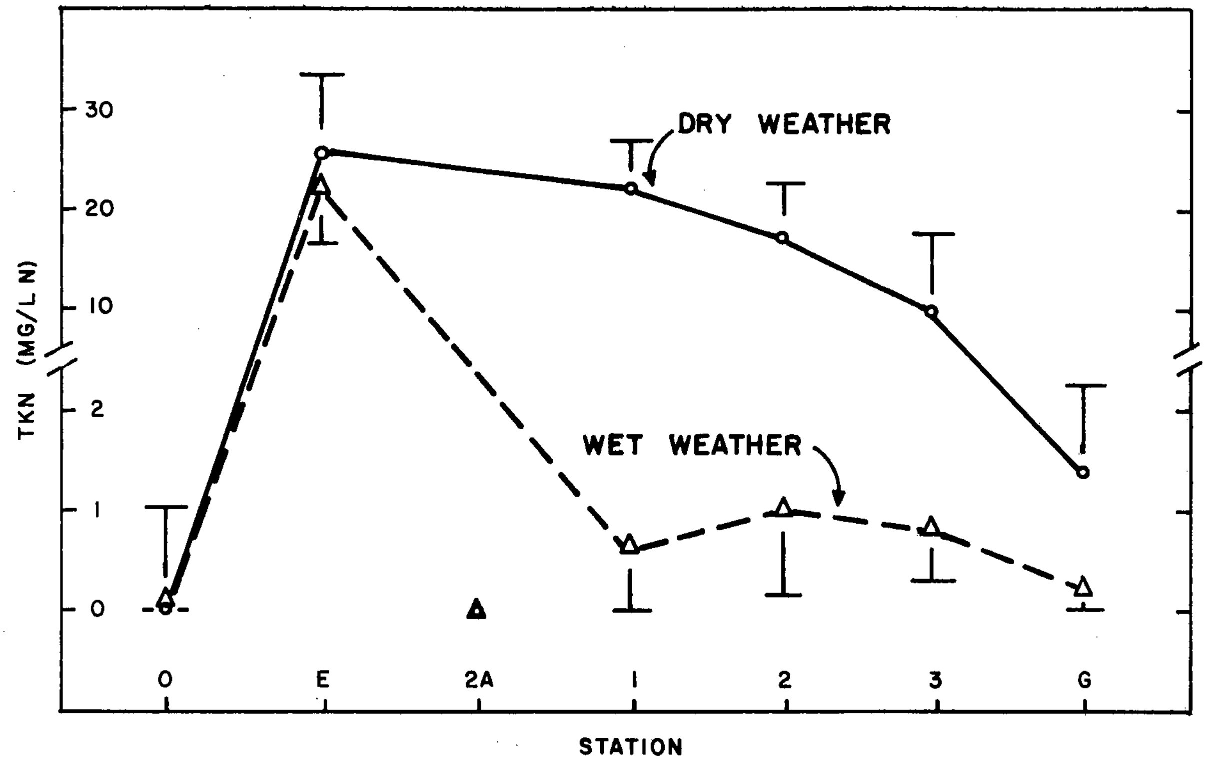

FIGURE 8. TOTAL KJELDAHL NITROGEN (TKN) BY STATIONS.

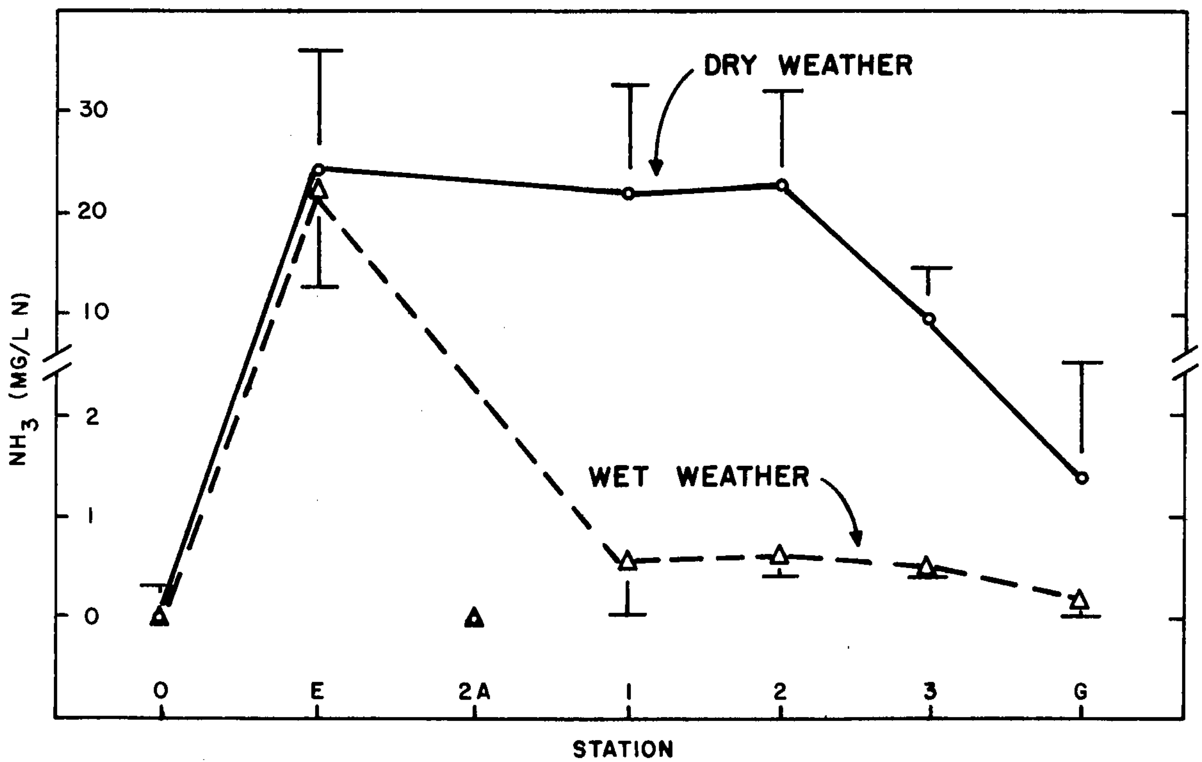

FIGURE 9. AMMONIA-NITROGEN (NH_3-N) BY STATIONS.

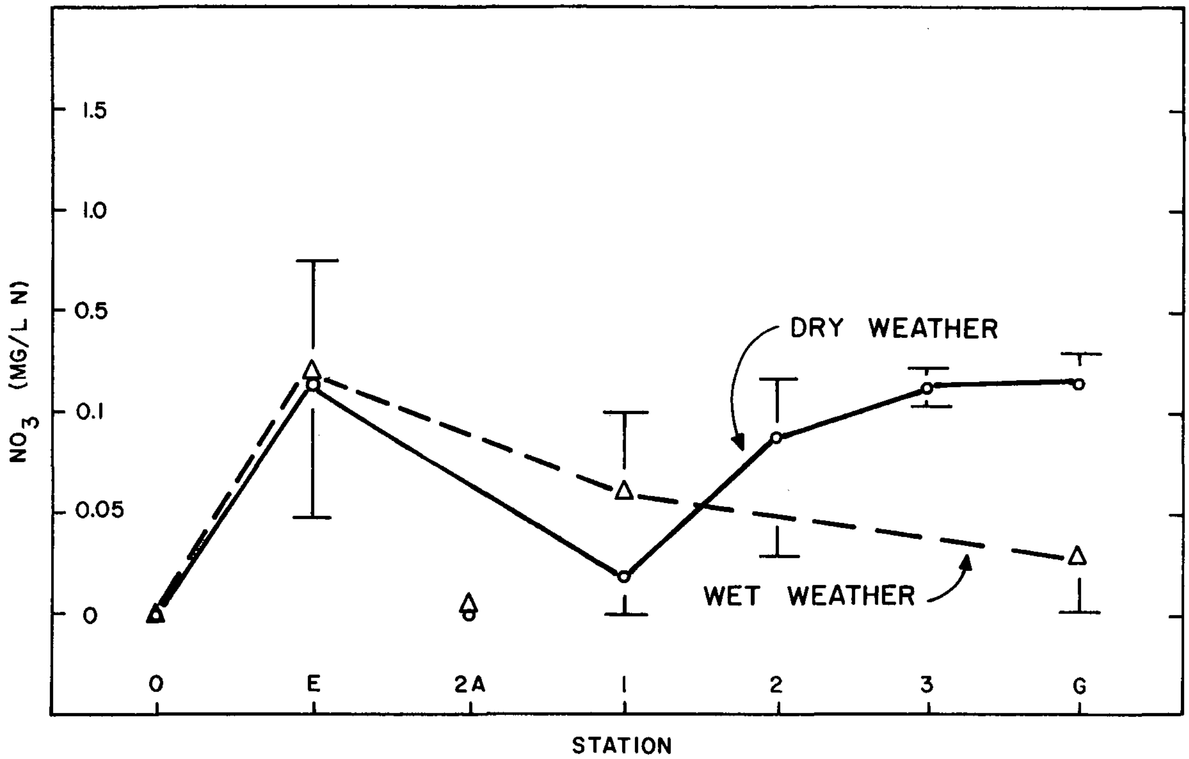

FIGURE 10. NITRITE-NITROGEN (NO_2-N) BY STATIONS.

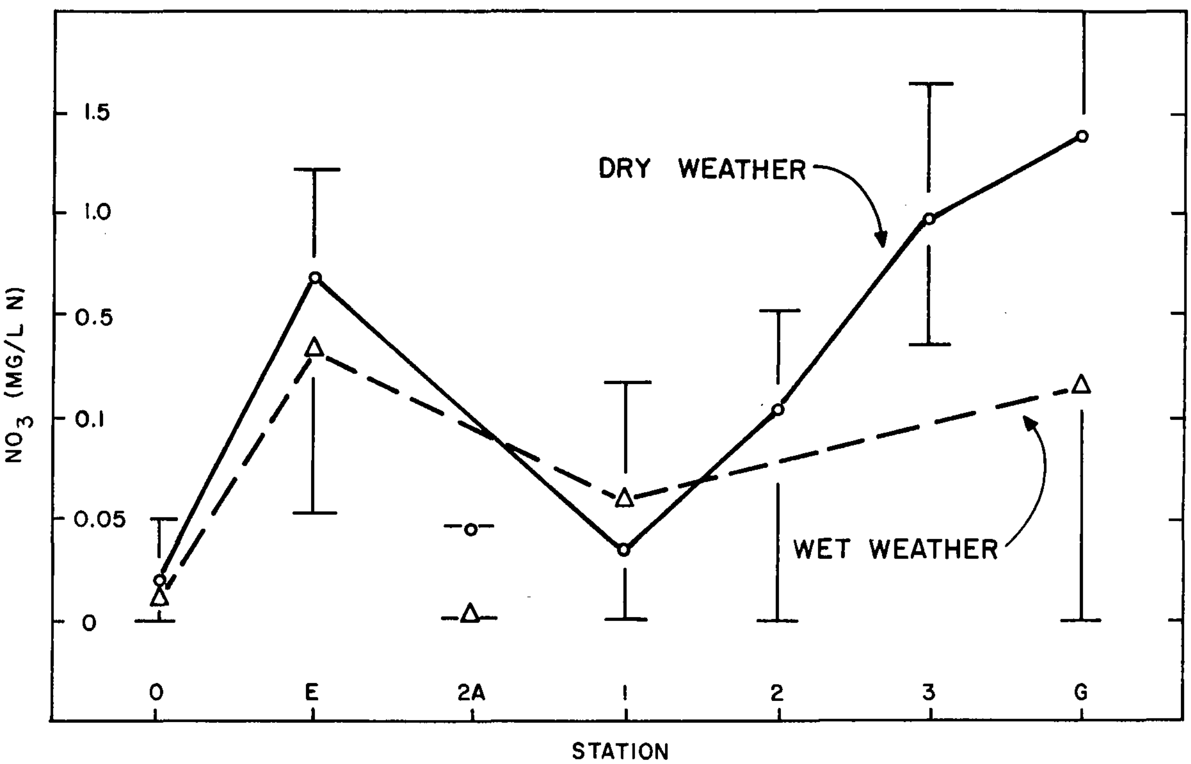

FIGURE 11. NITRATE-NITROGEN (NO_3-N) BY STATIONS.

Pumps 6 and 6B of the Oahu Sugar Company, located in the area of Waiawa Stream, had nitrate values of 1.3 mg/l and 1.6 mg/l as N, respectively. This compares with the 1.4 mg/l NO_3-N mean found at the gage for this investigation.

Water quality standards for nitrogen for Class B waters are total nitrogen less than or equal to 0.20 mg/l and for Class A waters, less than or equal to 0.15 mg/l. The two control stations were well under the limit for both classes. All other stations including the gage which was the last downstream station exceeded both limits. The average NO_3-N at the gage was 1.07 mg/l. In a previous study, the Water Quality Program for Oahu (WQPO) for the City and County of Honolulu found 0.56 mg/l NO_3-N at the mouth of Waiawa Stream (Lau 1972).

The major portion of phosphorus detected at all stations was in the soluble form. Very little organically bound phosphorus, as shown in Figures 12 and 13, was detected. The phosphorus in the downstream stations were attributable to the sewage effluent which averaged 8.8 mg/l total phosphorus as P.

The concentration of phosphorus decreases in a downstream direction due to two factors. Very little phosphorus was used by biological forms. Dilution was a factor to be sure and the major factor during wet weather. During dry weather, the phosphorus removal was aided by the adsorption of phosphorus by sediment in the streams. Hawaiian soils have a great affinity for phosphorus and adsorb it readily. Kaya (1971), while investigating Kaneohe Bay sediment, found that at concentrations of about 10 mg/l P, the phosphorus uptake by the sediment was 92.5-93.5 percent of the initial concentration of phosphorus. Also, most of the soluble phosphorus was adsorbed within the first 5 minutes of contact with the sediment.

Water quality criteria for Class A and Class B waters for total phosphorus are set at less than or equal to 0.025 mg/l and 0.050 mg/l, respectively. As with nitrogen, only at the two control stations, 0 and 2A, could this requirement be met, and even then the standards were exceeded occasionally though only slightly. The lowest concentration of total phosphorus recorded at the gage was 0.20 mg/l P during high stream flow, and the mean value overall was 0.9 mg/l P. The WQPO (Lau 1972) reported 0.25 mg/l PO_4-P at the mouth of Waiawa Stream in an earlier study. Thus, more reduction of phosphorus concentration takes place between the gage and

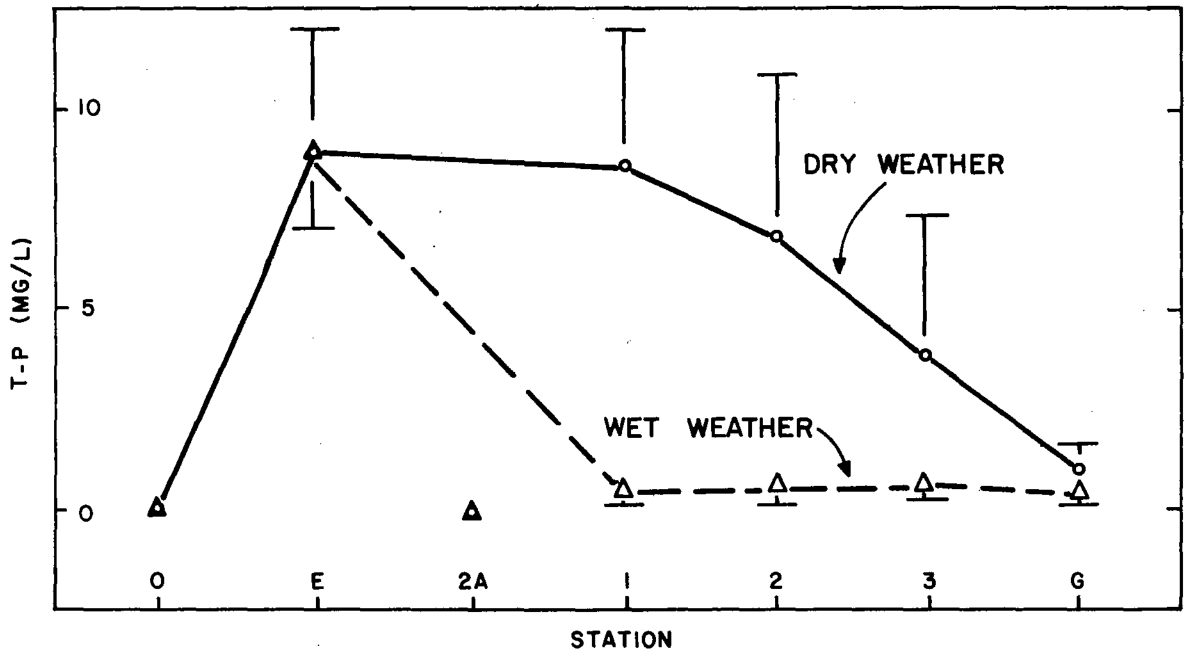

FIGURE 12. TOTAL PHOSPHORUS (T-P) BY STATIONS.

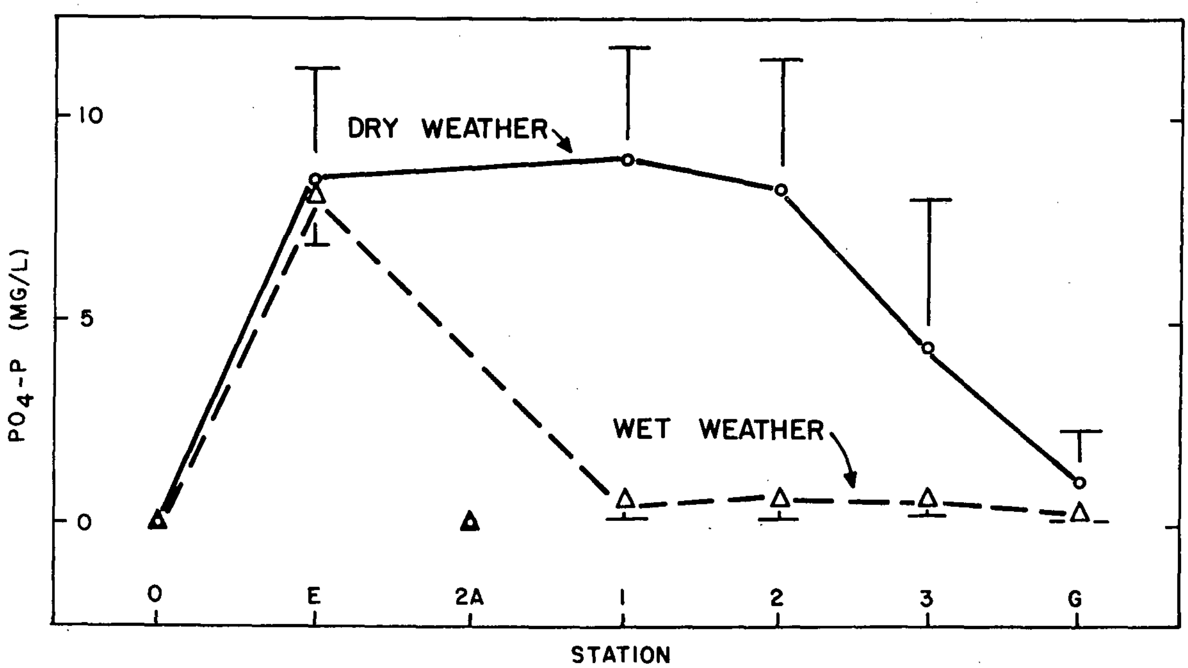

FIGURE 13. ORTHOPHOSPHATE (PO_4-P) BY STATIONS.

the stream mouth, but the water entering Pearl Harbor Middle Loch was still in excess of the standard.

The total solids, T-S, (Fig. 14) and chlorides, Cl^-, (Fig. 15) behaved similarly. Conductivity exhibited almost the same pattern as total solids, so any discussion of T-S would be equally applicable to conductivity.

The total solids and chlorides of the effluent were very consistent at all times, averaging 369 mg/l solids and 55.9 mg/l Cl^-, respectively. The control stations had the lowest values. The total solids at Station 0 and 2A were higher during dry weather as were the chlorides.

The total solids and chlorides were a striking example of the dilution phenomenon. At Station 3, where the highest concentrations were noted, the average dry weather chloride of 609 mg/l was reduced to 83.3 mg/l during wet weather. A similar reduction in total solids existed. This dilution of some 86 percent exhibits the dilution aspect of self-purification. Another example was the approximately 50 percent dilution of the effluent at Station 1 during wet weather, where during dry weather the chlorides at the two stations were almost exactly the same.

The color (Fig. 16) of the stream water was lowest, 5 units during dry weather, at the control Station 0, usually less than the U.S. Public Health Service (USPHS) limit of 15 units (USPHS 1963) for drinking water. Though Waiawa Stream was not used for drinking or domestic use, the USPHS limit was used as a reference figure. The other control, Station 2A, was generally above the USPHS limit, averaging 35 units overall.

The effluent and Station 1 exhibited the highest color averaging 49 and 40 units, respectively. The color of the samples at the two stations was apparent and due to turbidity which could not be removed by high speed centrifuging.

The dry weather color decreased downstream to the gage where the color mean was 12 units, the same as the dry weather mean for Station 0. Dilution from spring leakage was probably the reason. Another possiblity, perhaps farfetched, was the natural color removal by coagulation. The pH at Station 3 decreased to a mean value of 6.6. Burbank et al. (1970) studied removal of color from water on the island of Hawaii, and determined an optimum pH of 6 to 7 for removal by coagulation using a cationic polymer coagulant. While there was no polymer in the Waiawa Stream water, perhaps enough ionic iron existed in the water, (there was a junked automobile

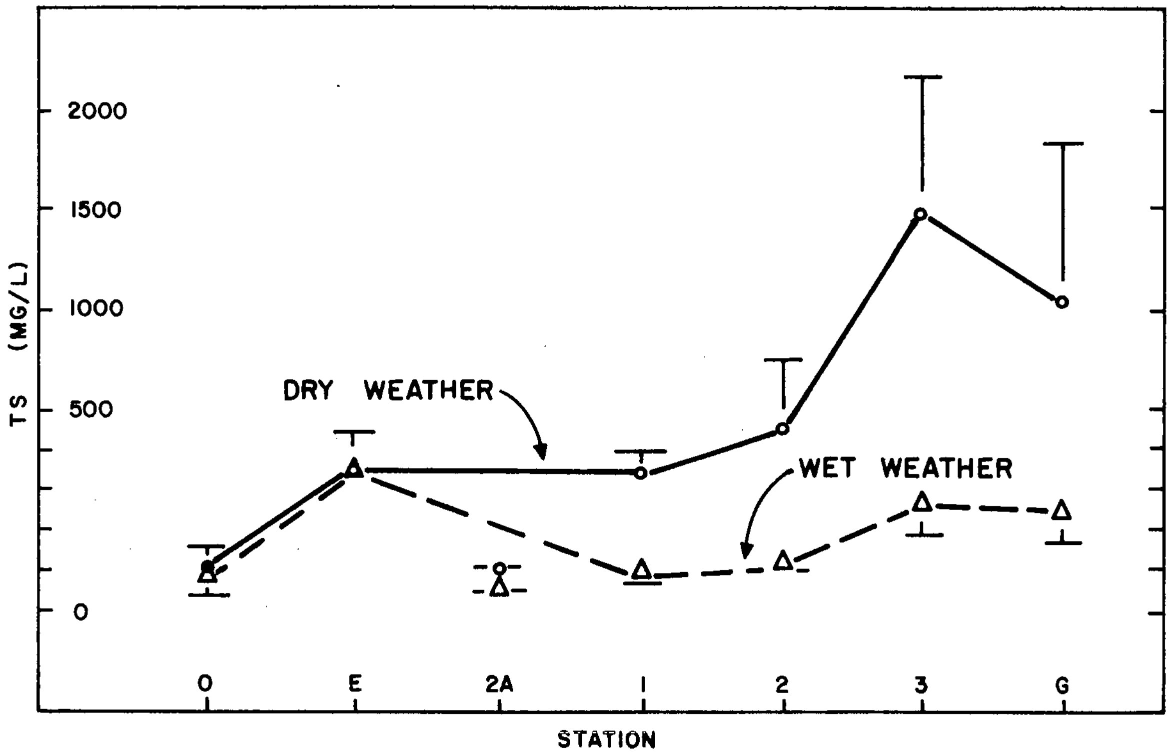

FIGURE 14. TOTAL SOLIDS (TS) BY STATIONS.

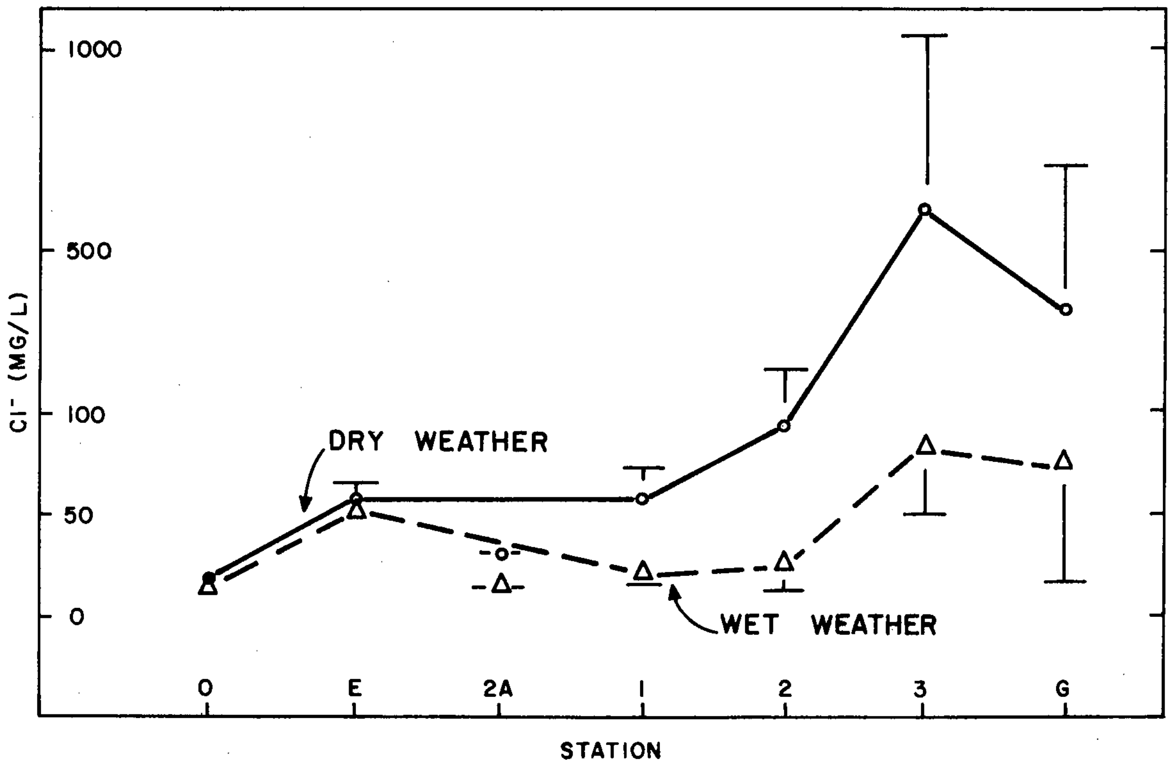

FIGURE 15. CHLORIDE (Cl^-) BY STATIONS.

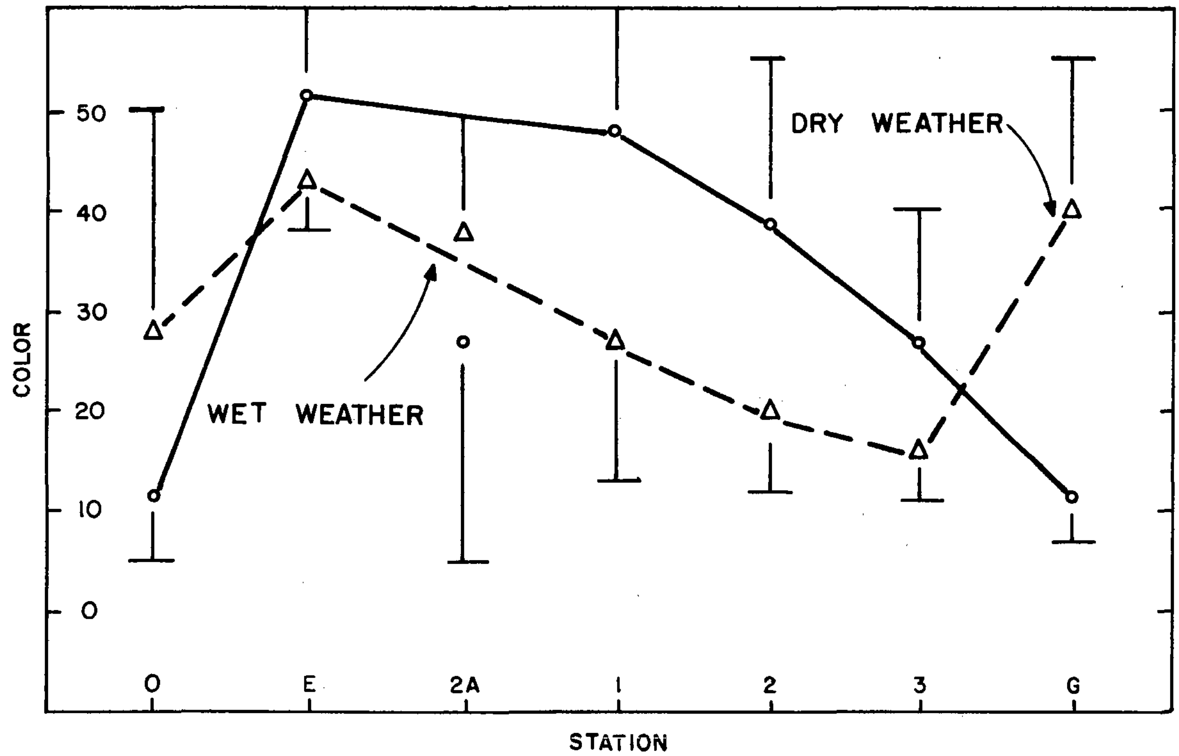

FIGURE 16. COLOR BY STATIONS.

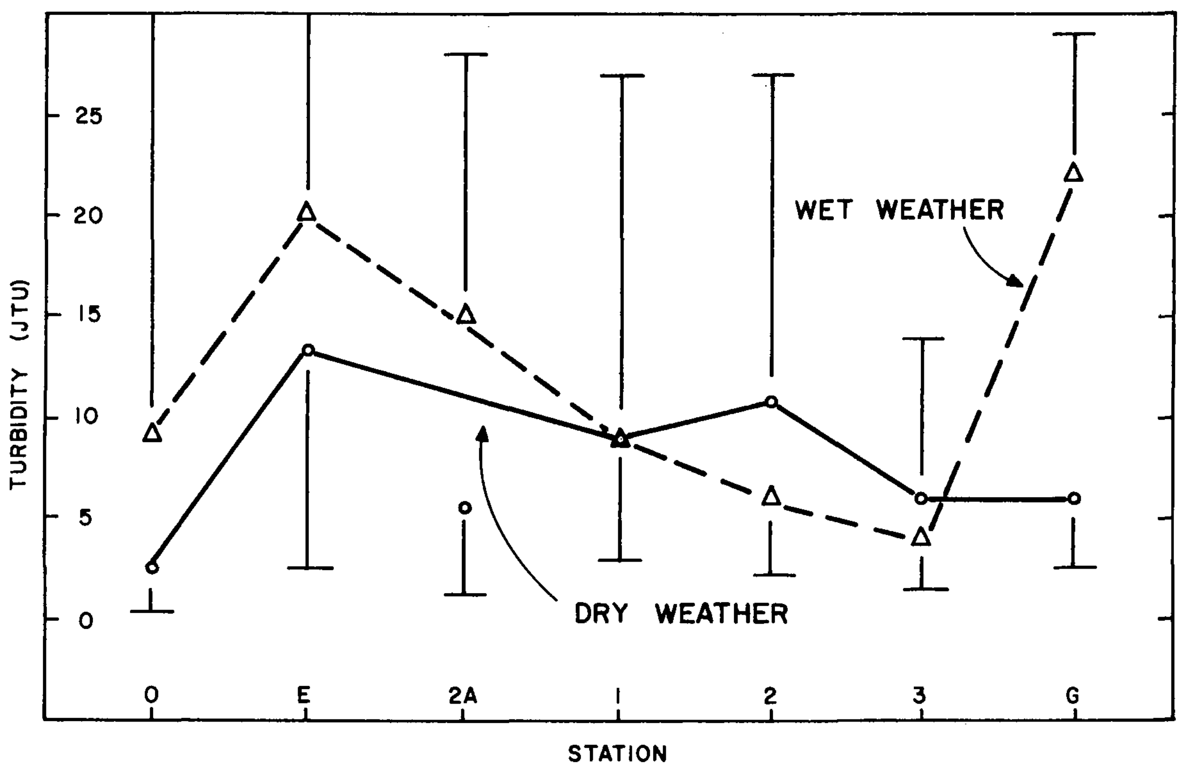

FIGURE 17. TURBIDITY BY STATIONS.

submerged just below Station 2), to act as a coagulant.

During wet weather, the color at the control stations was greater than during dry weather, but the color in dry weather was higher at the intermediate stations. The wet weather color at the gage was much greater than during dry weather, due to higher runoff. Wet weather color averaged 40 units at the gage. True color in water is caused by dissolution of lignins and humic substances from decaying vegetation (Sawyer and McCarty 1967). The higher streamflow during wet weather could have contributed more color because flow rise up the banks may have leached the decaying vegetation.

Turbidity (Fig. 17) varied as color did, low at the control, high for the effluent, decreasing at the gage though not quite as low as at the control stations. The wet weather mean values at Stations 0, E, and 2A were higher than for dry weather. The wet weather turbidity at Stations 2 and 3 was lower due to the limited samples available for averaging; there were more samples of dry weather flow simply because there was more days of dry weather during the investigation period.

The low mean turbidity of 2.6 FTU occurred at Station 0 during dry weather. The high mean turbidity occurred during wet weather at the gage for the same reason the color was high at the gage, increased runoff.

Water quality standards for Class A waters require no more than 10 percent variance from "natural conditions," for turbidity, and for Class B, the allowable variance is 20 percent. Using the dry and wet weather mean turbidities of 2.6 and 9.2 FTU, respectively, at Station 0 as the "natural conditions," the gage values exceeded the natural conditions by about 50 percent. If there was no further reduction below the gage, then one could safely assume that the Waiawa Stream water entering Pearl Harbor could exceed the standards until further dilution occurred.

The highest concentrations of heavy metals were noted for zinc and copper with mean values between 20 to 30 μg/l and 10 to 20 μg/l, respectively (Figs. 18 and 19). Lower values were obtained for nickel, lead, and chromium (Figs. 20, 21, and 22). There was no apparent pattern between wet weather and dry weather conditions for the levels of heavy metals monitored. The mean chromium concentration in dry weather ranged from 1 to 5 μg/l compared to a range of 40 to 100 μg/l obtained by Matsushita (1973) for Kalihi Stream. The data for Waiawa Stream are about the same order of

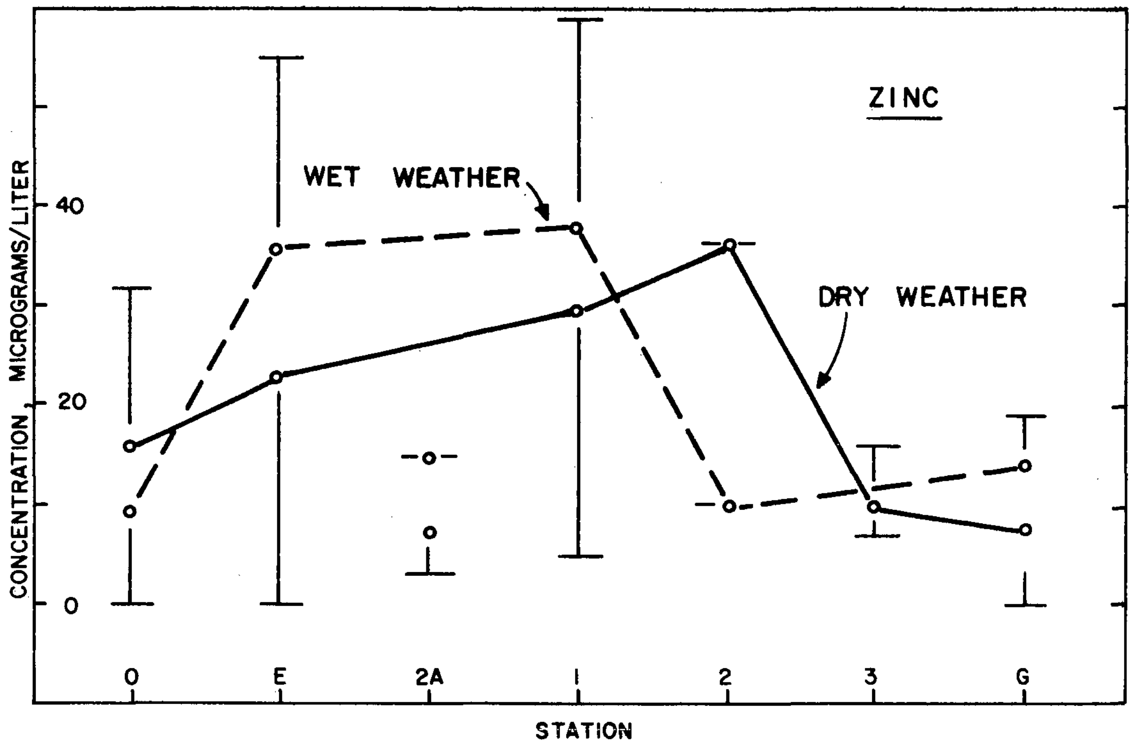

FIGURE 18. ZINC LEVELS BY STATIONS.

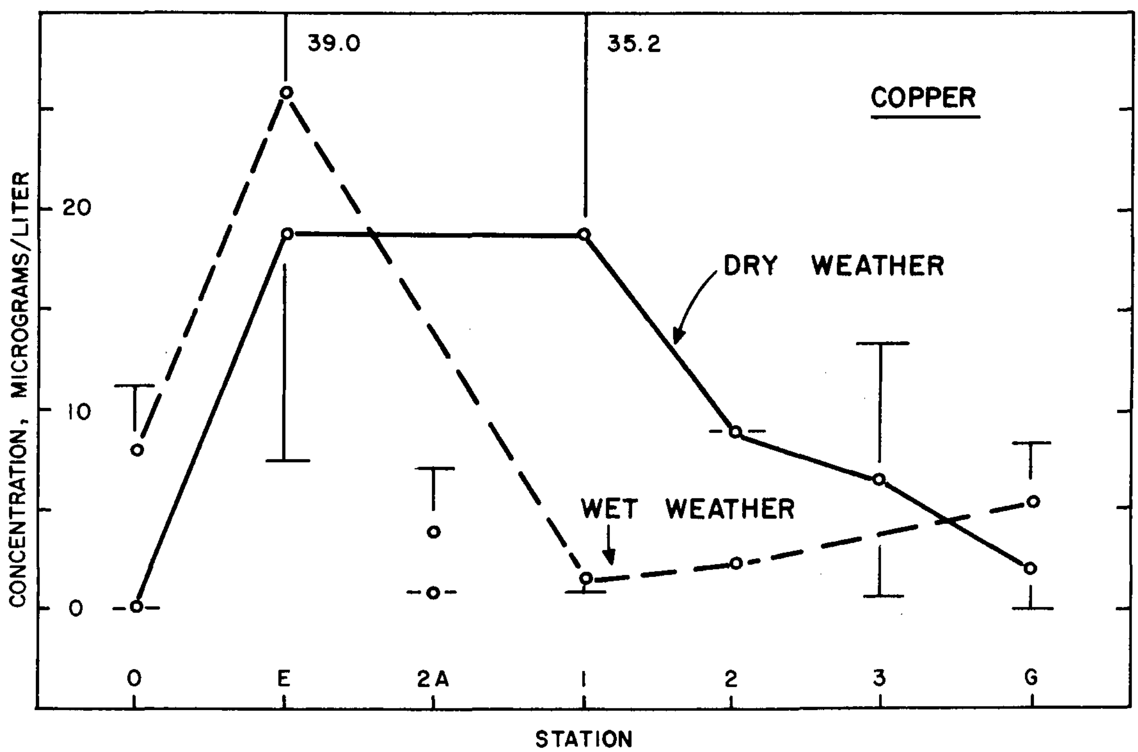

FIGURE 19. COPPER LEVELS BY STATIONS.

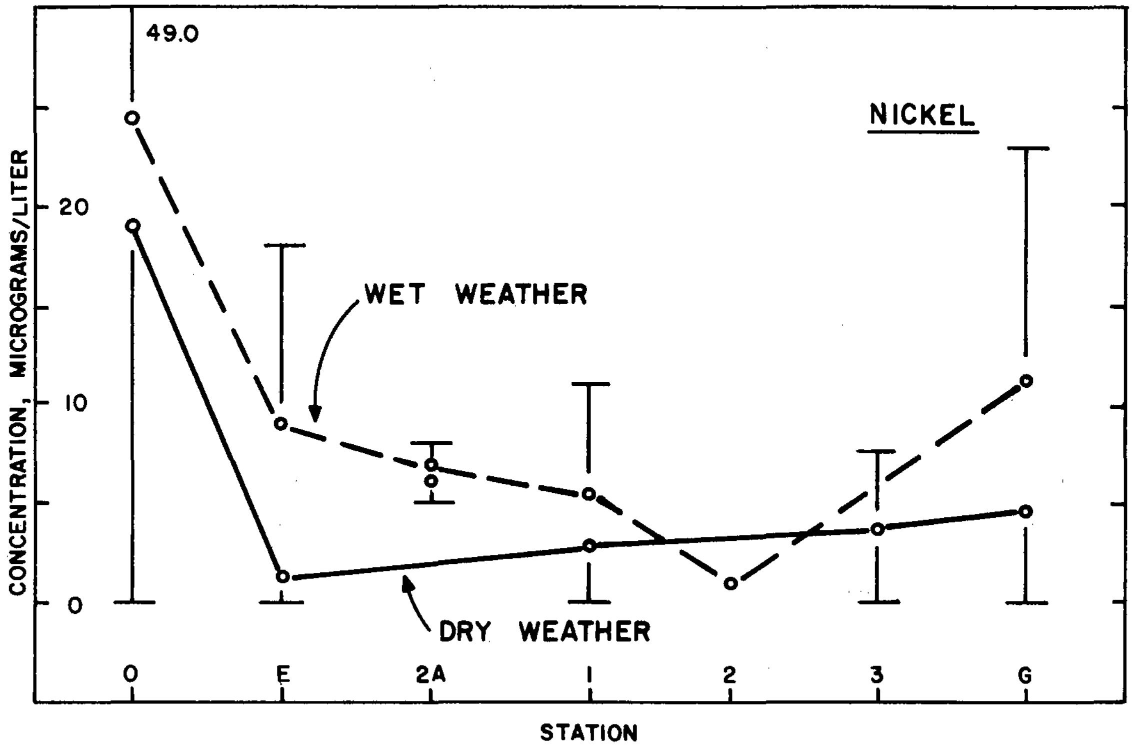

FIGURE 20. NICKEL LEVELS BY STATIONS.

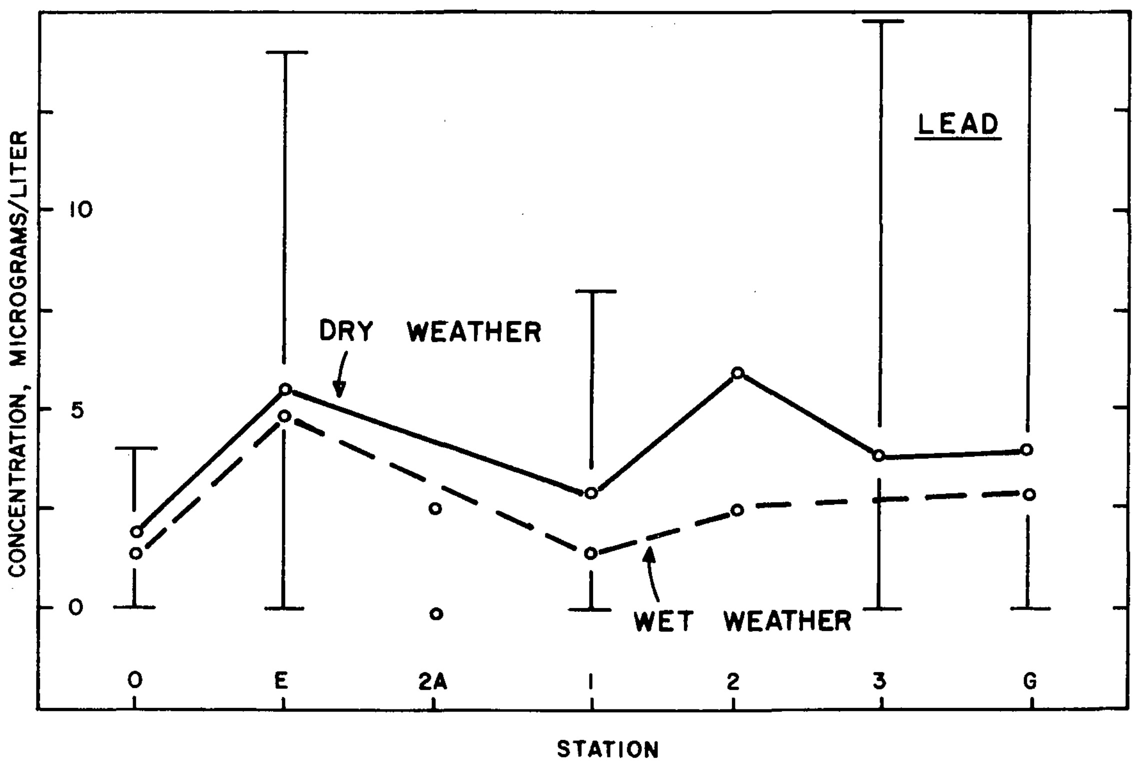

FIGURE 21. LEAD LEVELS BY STATIONS.

magnitude with that noted for surface irrigation at Kilauea, Kauai for lead (7 to 16 μg/l), copper (1 to 2 μg/l), and zinc (5 μg/l) (Lau 1972). These

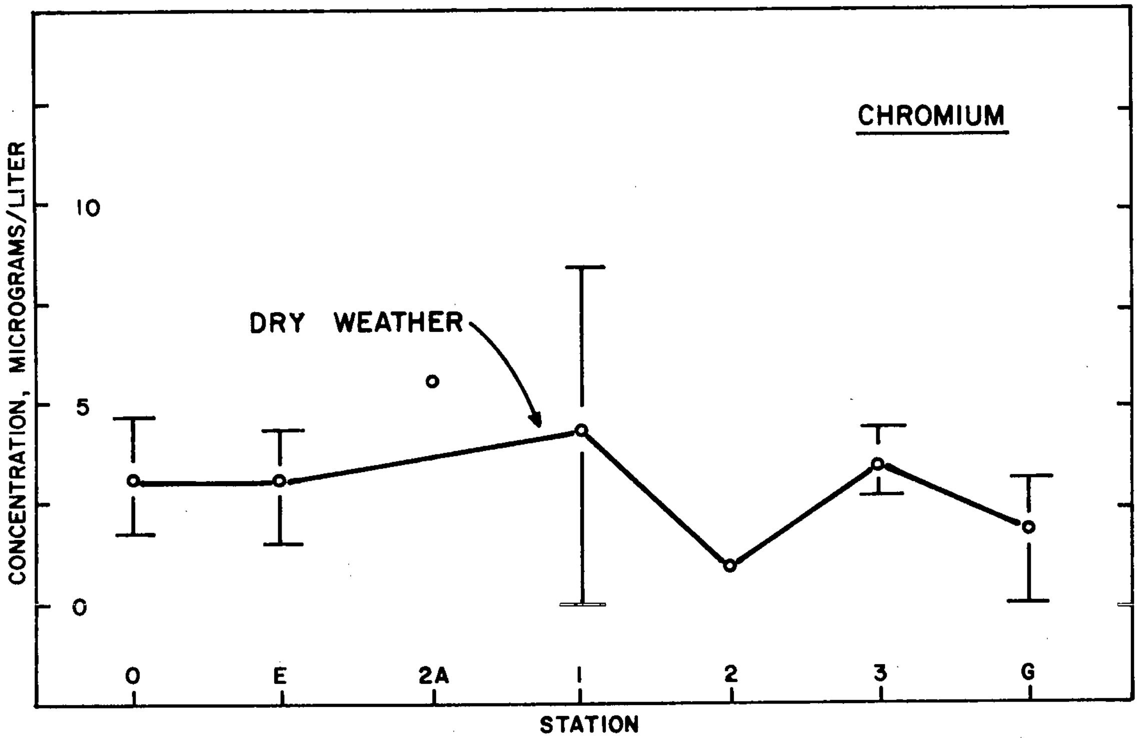

FIGURE 22. CHROMIUM LEVELS BY STATIONS.

low levels of heavy metals in the stream waters may not be of particular detriment to the stream biota, but may add to the load imposed on the waters and sediment of Pearl Harbor.

The temperature varied in a very narrow range for the stream stations. Although the maximum recorded during the investigation was 28.5° C for the effluent with a minimum of 17.5° C for Stations 0 and 2A, the average difference during wet and dry weather between Station 0 and the gage station on any one day was usually less than 2.5° C. Defining the natural conditions would be difficult since the dry weather flow of Waimano Stream often consisted only of the sewage effluent. Despite the temperature changes in excess of the standards, no fish kills or dying plants were observed; in fact, fish seemed to thrive in the stream water, especially at Station 1. Thus, the temperature at each station was assumed to be natural for that individual station.

The pH was usually in the range specified by the standards for Class 2 waters of 6.5 to 8.5 and varied less than one pH unit overall (Fig. 23).

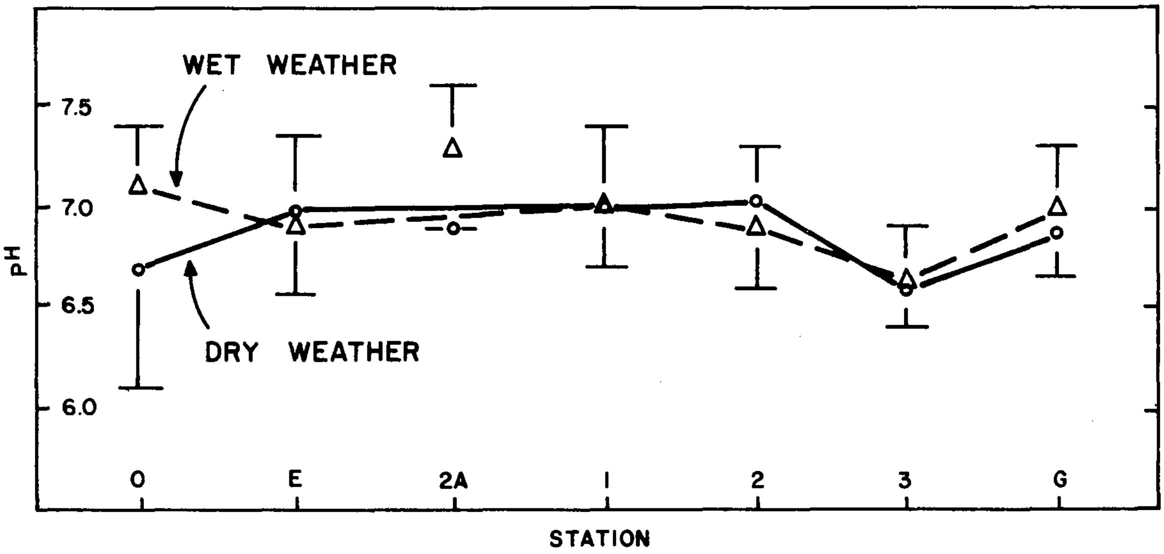

FIGURE 23. pH LEVELS BY STATIONS.

A noticeable change in pH occurred at Station 3, where the pH dropped from an average 7.0 at Station 2 to 6.6 at Station 3. The most probable explanation was groundwater seepage from springs, since chloride values increased also at Station 3 (Fig. 15).

The oxidation-reduction potential (ORP) proved to be relatively satisfactory for indicating the onset of anaerobic conditions. Except for two occasions at Station 1, all samples were well within the positive range. On the two occasions, when negative values of -110 mV and -15 mV were obtained at Station 1, the DO was zero. On other occasions when DO at Station 1 was zero, the ORP was positive, which was possible depending upon the extent to which anaerobic conditions had taken over. The field test for hydrogen sulfide (H_2S) was discontinued at the beginning of the investigation, since only once was H_2S detected. That coincided with the -110 mV ORP recorded at Station 1. The values of ORP for the effluent were affected by the chlorination and were off-scale (> + 400 mV) in the positive direction.

The residual chlorine concentration averaged 1.6 mg/l with a maximum greater than 3.0 mg/l and a minimum of 0.3 mg/l during the period of investigation (Table 4). On four occasions, the residual chlorine was 1.0 mg/l or less, and increases in total and fecal coliform and fecal streptococcus were noted in the effluent. The fecal coliform and fecal strepto-

TABLE 4. EFFLUENT RESIDUAL CHLORINE, GAGE WATER LEVEL, AND EQUIVALENT FLOW DURING DRY AND WET WEATHER.

DRY WEATHER	RESIDUAL CHLORINE (mg/l)	GAGE WATER LEVEL (ft)	FLOW (cfs)	MEAN DAILY FLOW (cfs)
09/27/72		1.73	5.99	5.8
10/13	1.25	1.66	4.50	4.7
10/19	1.5	1.61	3.62	3.9
10/27	2.1	1.78	7.17	7.2
11/17	1.5	1.74	6.22	6.1
11/24	0.3	1.70	5.28	6.1
11/29	1.3	1.70	5.28	4.7
12/06	0.7	1.64	4.14	4.2
12/13	0.8	1.64	4.14	3.7
01/3/73	1.4	1.60	3.46	3.4
01/10	1.0	1.66	4.50	5.1
01/17	1.35	1.65	4.32	5.3
01/30	1.3	1.60	3.46	3.7
02/08	1.8	1.68	4.88	3.8
02/15		1.58	3.15	2.8
02/22	2.7	1.62	3.79	4.6
03/02				3.0
03/08	3.0+	1.62	3.79	4.6
05/04	2.1	1.70	5.28	4.6
05/08	2.4	1.60	3.46	3.7
MEAN	1.6		4.50	
WET WEATHER				
10/06/72		1.83	8.53	9.2
11/08	2.1	2.4	35.5	25
12/20/72	1.1	2.0	14.1	14
05/21/73	1.8	3.06	131	85
05/22	1.9	2.74	71.0	62
05/23	1.4	2.30	29.0	30
05/24	2.2	2.16	21.3	32
05/25/73	1.2	2.44	38.6	33
MEAN	1.7		43.6	

coccus counts were very much higher during those periods.

Figures 24 through 29 compare the total coliform, fecal coliform, and fecal streptococcus density against a probability scale, showing the percent of the time that a particular density would be exceeded. The values for Station 0 indicate density before the sewage effluents entered the stream; the gage values express density as the stream approached Pearl Harbor.

The 50 percent exceedence values indicating the median count were shown on each graph. The coliform standard for Class 2 waters, 1000 organisms/100 ml, was indicated on the total coliform graphs (Figs. 24 and 25). The fecal coliform standard for Class 2 waters, 200 organisms/100 ml was also indicated on Figures 26 and 27.

The total coliform counts for the gage were much higher than at Station 0. The same is true of the fecal coliform counts. The graphical probability indicated that the gage would have coliform and fecal coliform densities exceeding the Class 2 standard 86 percent to 97 percent of the time for both wet and dry weather. Station 0 would also have densities above the standard but by a lesser probability, 50 percent to 55 percent.

There is no water quality standard for fecal streptococcus but there is some significance in the FC:FS ratio. There was a general increase in the fecal coliform and fecal streptococcus counts between Station 3 and the gaging station, as shown in Tables 5 and 6; however, the FC:FS (Figs. 30 and 31) ratios for Station 3 and the gage (Table 7) showed no significant change at the gage. The FC:FS ratio at the gage had a 50 percent or greater probability of being ambiguous or indicating sources other than man of contamination (FC:FS < 4).

The increase in the fecal coliform and fecal streptococcus counts between Station 3 and the gage combined with the probable ambiguity of the FC:FS ratio at the gage, could be an indication of contamination between Station 3 and the gage. There are a few residential dwellings just above the gage, whose residents could be illegally discharging their sanitary wastes. Reference to the residential dwellings was also made in the discussion of BOD, since the BOD increased also between Station 3 and the gage. The MPN of 24,000/100 ml near the mouth of Waiawa Stream in 1957 listed by Cox and Gordon (1970) would tend to add further confirmation of possible contamination from this residential area, since the Pacific Palisades

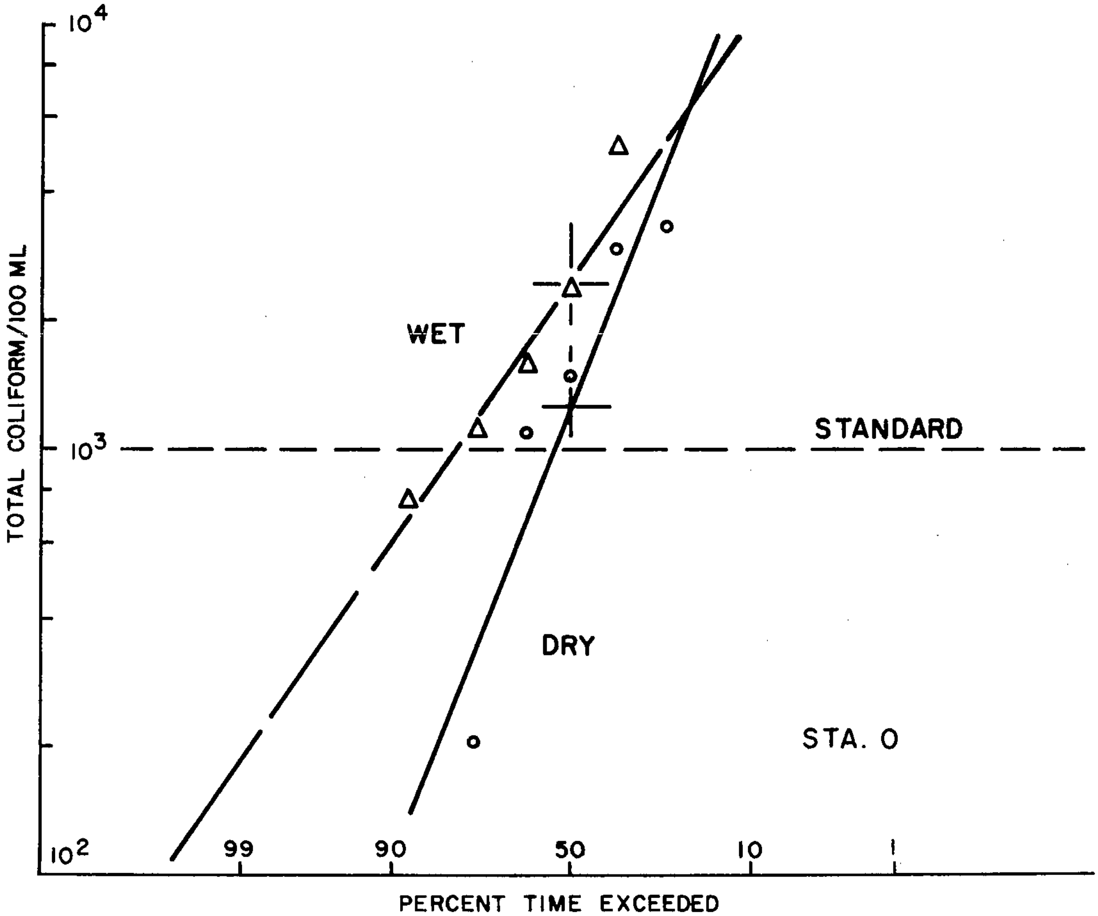

FIGURE 24. LOG-NORMAL PROBABILITY OF TOTAL COLIFORM AT STATION O.

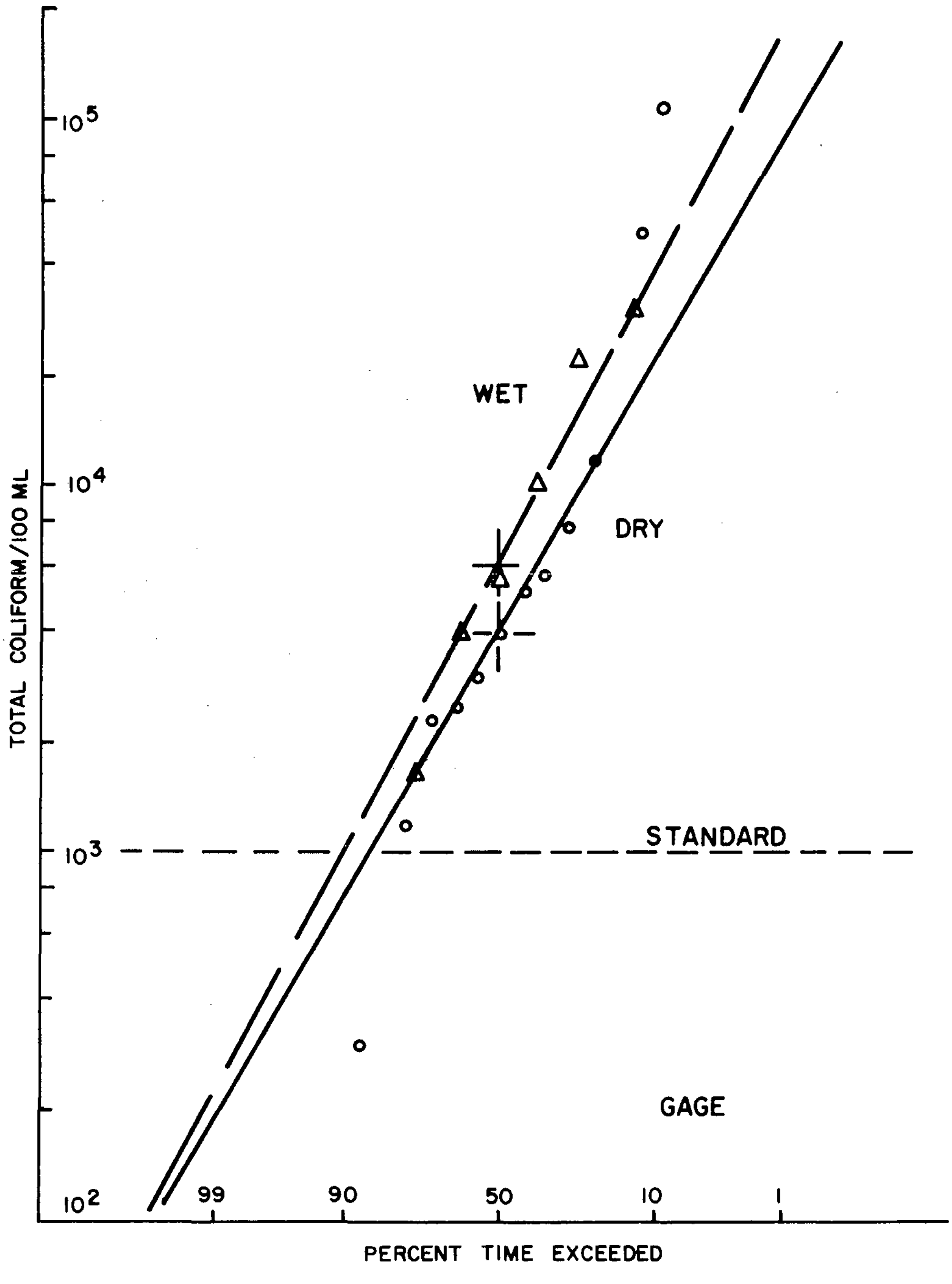

FIGURE 25. LOG-NORMAL PROBABILITY OF TOTAL COLIFORM AT GAGE.

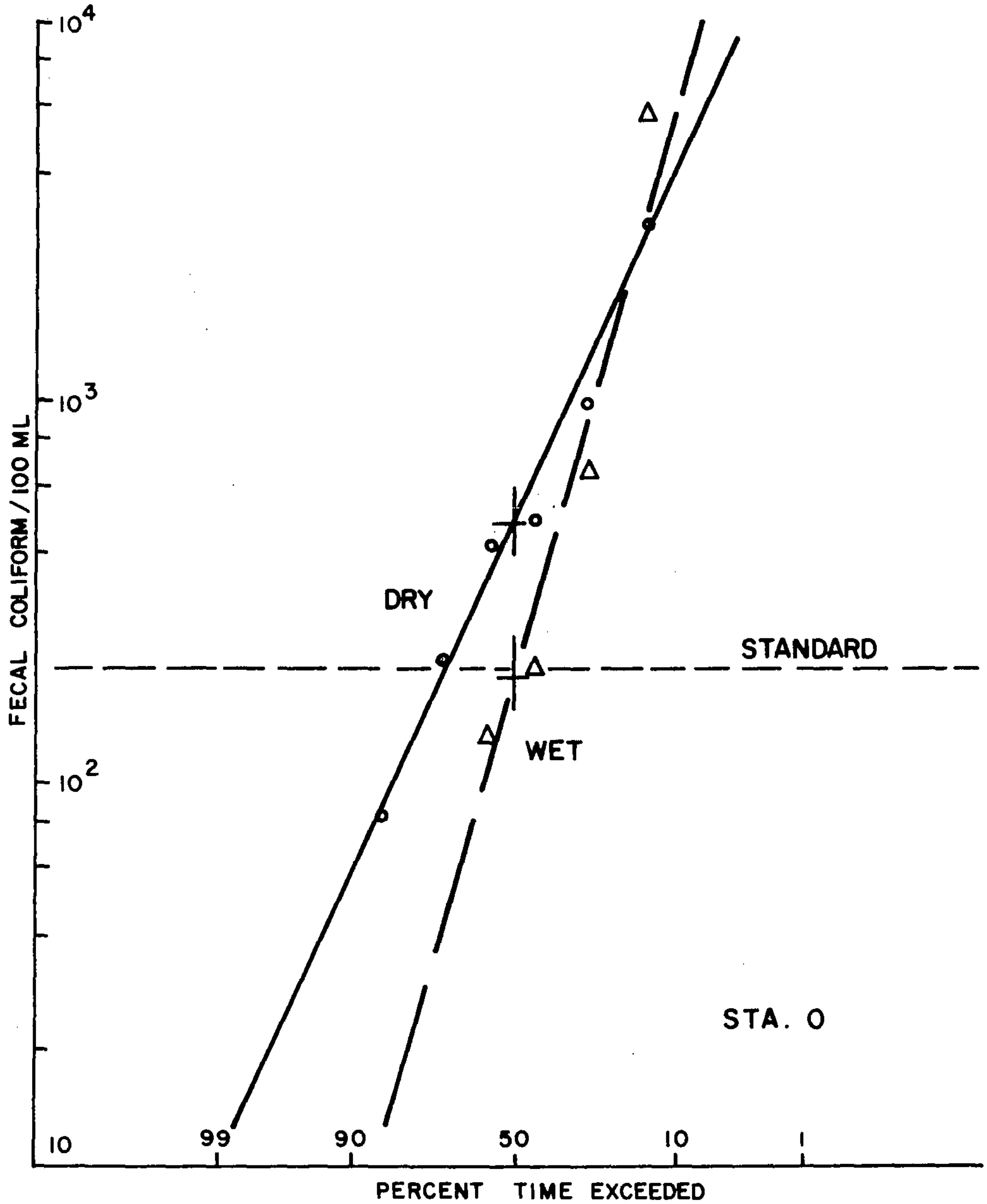

FIGURE 26. LOG-NORMAL PROBABILITY OF FECAL COLIFORM AT STATION O.

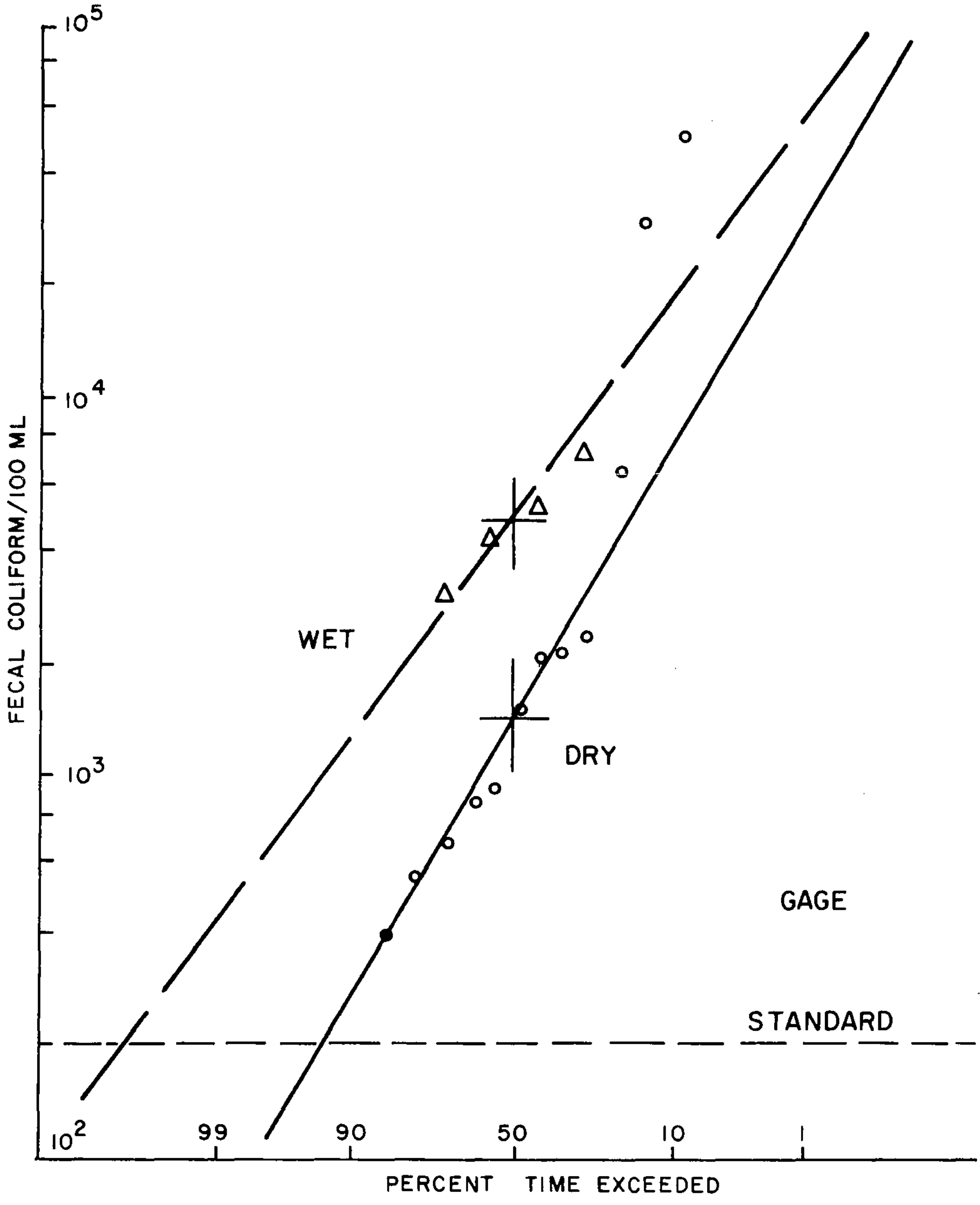

FIGURE 27. LOG-NORMAL PROBABILITY OF FECAL COLIFORM AT GAGE.

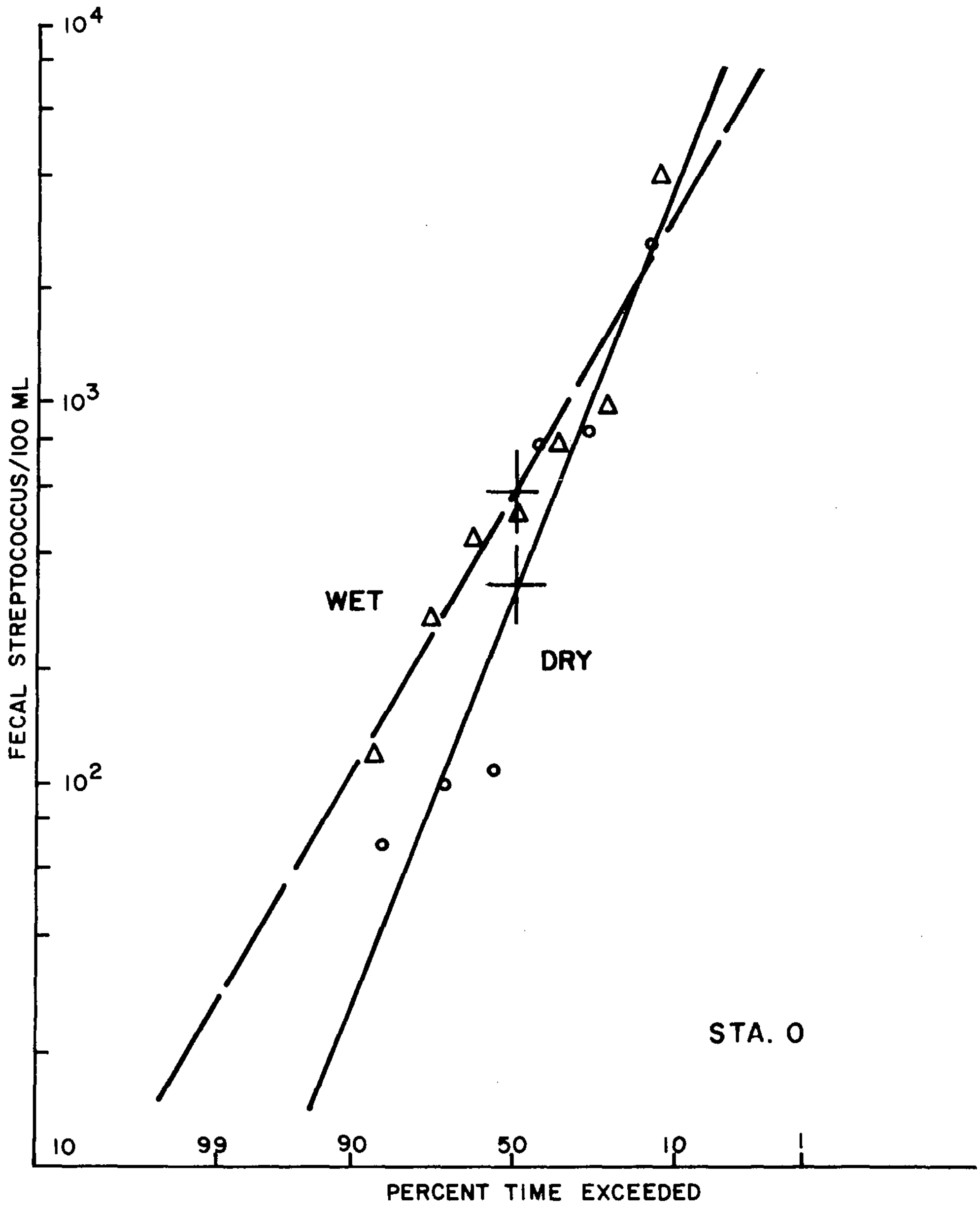

FIGURE 28. LOG-NORMAL PROBABILITY OF FECAL STREPTOCOCCUS AT STATION O.

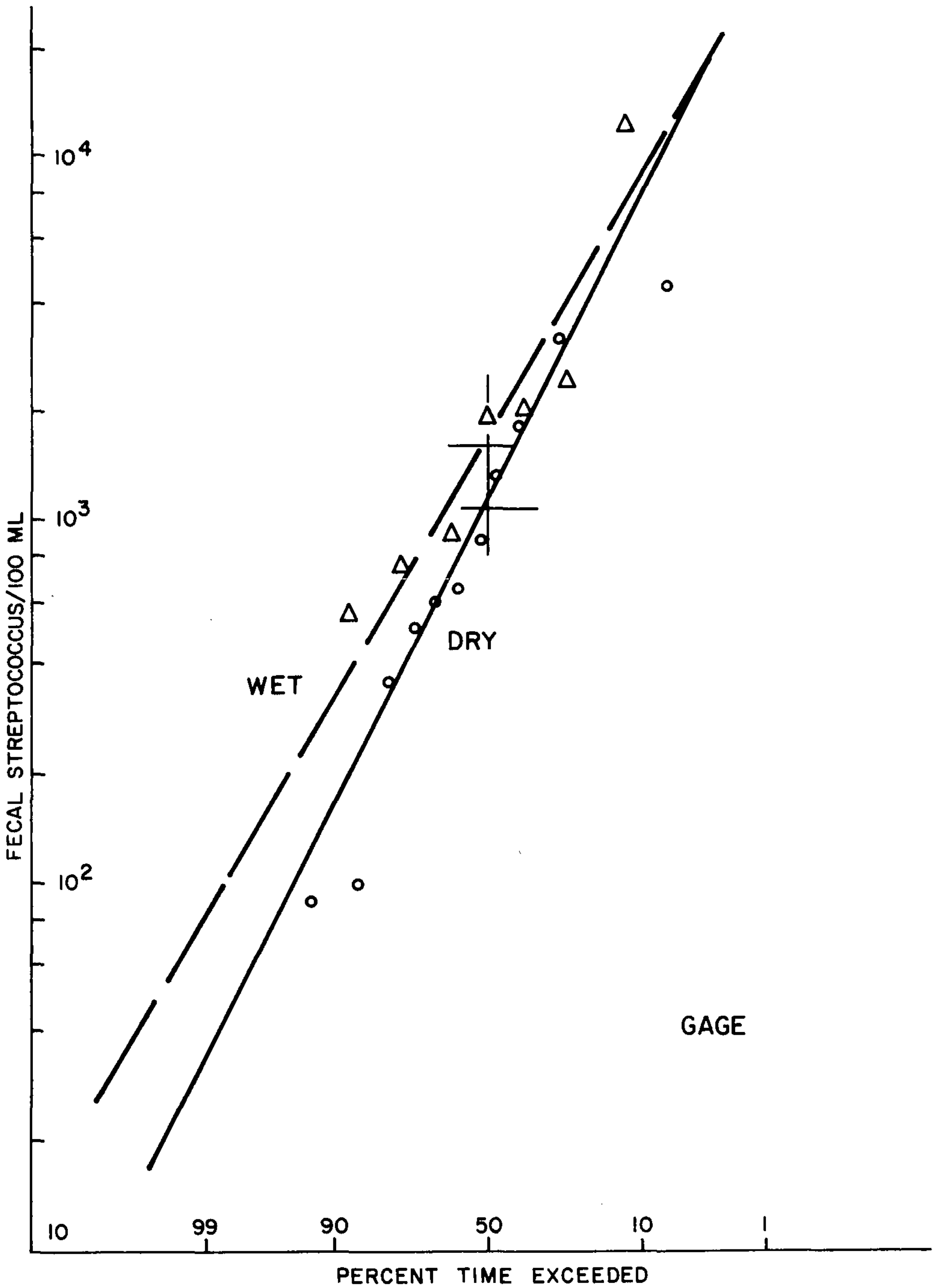

FIGURE 29. LOG-NORMAL PROBABILITY OF FECAL STREPTOCOCCUS AT GAGE.

TABLE 5. FECAL COLIFORM/100 ML BY STATIONS.

	STATION						
	0	E	2A	1	2	3	G
DRY WEATHER							
10/27/72				340,000	14,000	230	30,000
11/17	3000	1		1	1	30	1
11/24	1000			42,000	1		
11/29		1		1700	90	60	550
12/06		1,000,000		20,000	2900	1500	2100
12/13		6300		4200	1000	27,000	6600
01/03/73		180		7300		100	680
01/10		1800		TNTC		400	870
01/17		100		900		300	2400
01/30		1		3200		400	390
02/08		1		2200		80	2200
02/15							
02/22	210	2	1900	400			1500
03/08	81	1		10,000			950
05/04	490	320	790	150,000			
05/08	420	1		12,000			50,000
WET WEATHER							
11/8/72	130	1		1	1	300	1
12/20	200	30		300	400	360	5000
05/21/73	5600	25	1300	2500			7100
05/22	650		990	1100			4300
05/23							
05/24	1	1	1	2400			3000
05/25	1	C	1400	540			800,000

C--CONFLUENT
TNTC--TOO NUMEROUS TO COUNT

TABLE 6. FECAL STREPTOCOCCUS/100 ML BY STATIONS.

	STATION						
	0	E	2A	1	2	3	G
DRY WEATHER							
10/27/72				9000	4200	800	1300
11/17	70	1		1	1	30	500
11/24	100	1		800	200	730	
11/29		1		1500	10	300	100
12/6		430,000		2700	910	700	880
12/13		170		1000	400	550	600
01/3/73		73		4200		1200	3200
01/10		62,000		4800		1000	4400
01/17		10		450		600	650
01/30		10,000		4700		1100	1800
02/08		2		3600		2100	3200
02/15		3900		2400		2600	90
02/22	2700	1	9700	2800			1800
03/08	780	1		1600			3200
05/04	110	23	430	380			
05/08	850	1		1400			360
WET WEATHER							
11/8/72	270	1		1	100	400	1900
12/20	800	1		1	250	670	2000
05/21/73	4100	1	2800	1200			2400
05/22	520	1180	730	340			910
05/23	120	1	210	1			730
05/24	980	1	660	2000			12,000
05/25	430	1	350	380			54

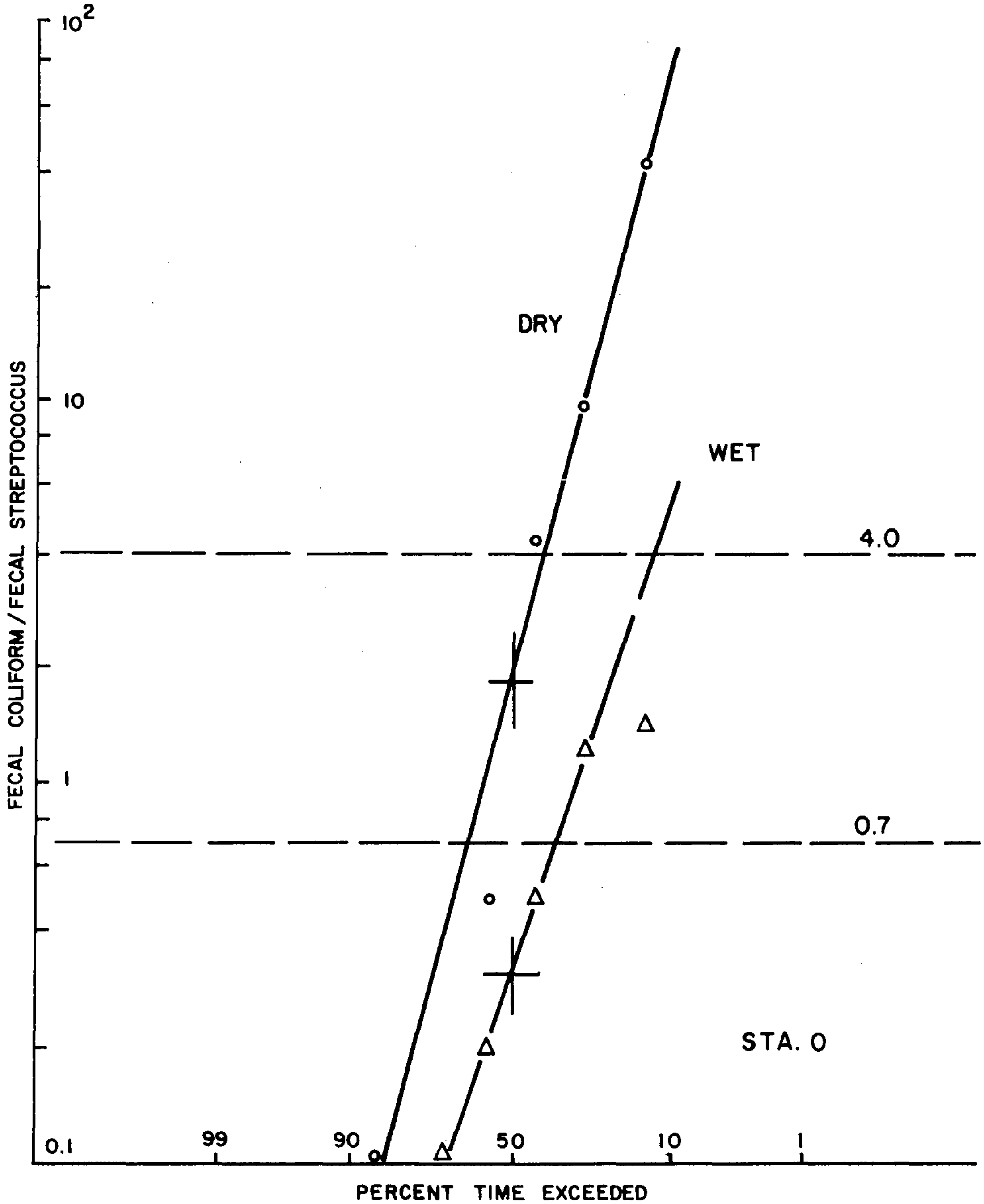

FIGURE 30. LOG-NORMAL PROBABILITY OF FC:FS RATIO AT STATION O.

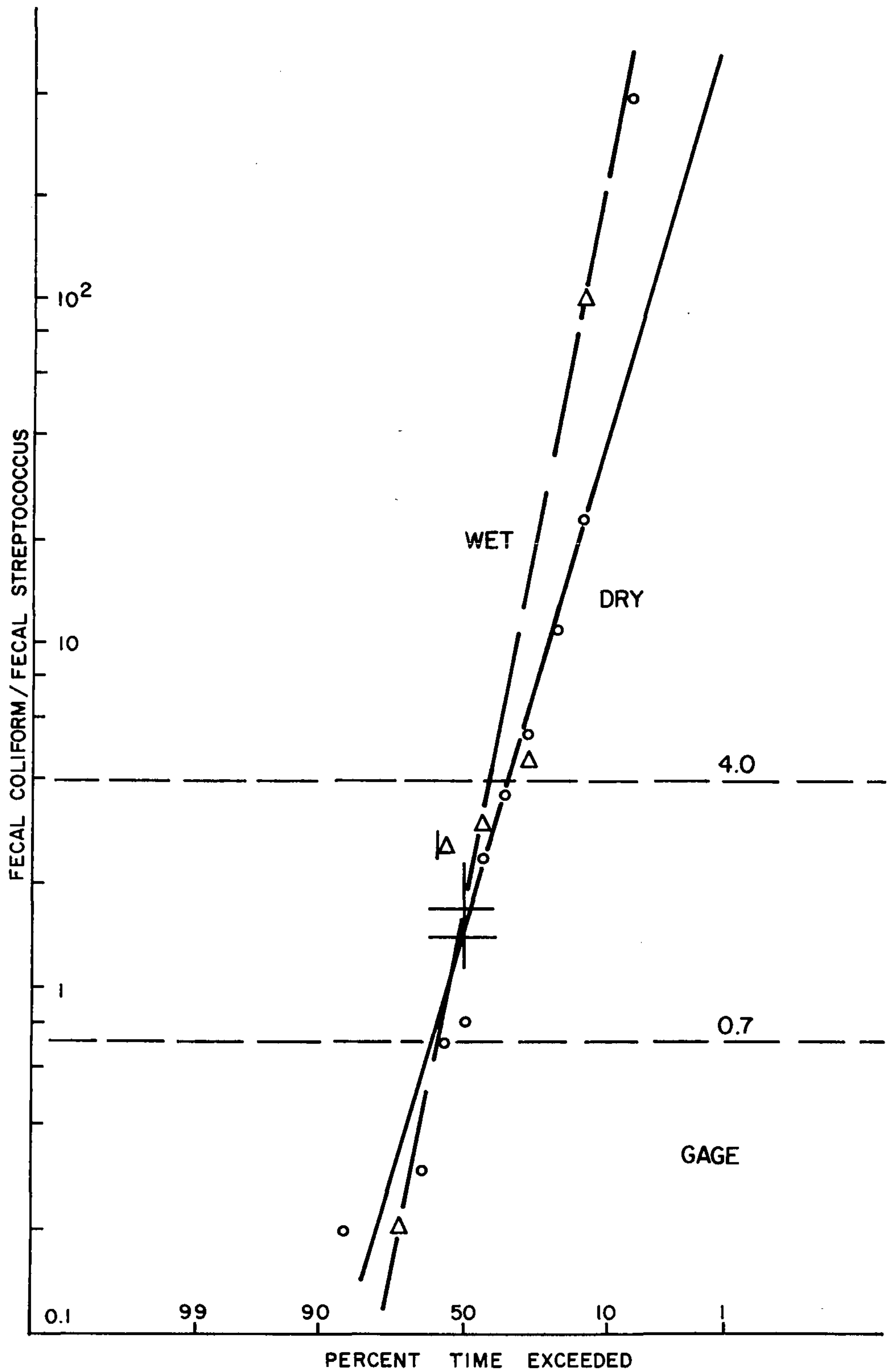

FIGURE 31. LOG-NORMAL PROBABILITY OF FC:FS RATIO AT GAGE.

TABLE 7. FC:FS RATIO BY STATIONS.

	STATION						
	0	E	2A	1	2	3	G
DRY WEATHER							
10/27/72				38	3.3	0.3	23
11/17	43					1	0.002
11/24	10			52	0.005		
11/29				1.1	9	0.2	5.5
12/06		2.3		7.4	3.2	2.1	2.4
12/13		37		4.2	2.5	49	11
01/3/73		2.5		1.7		0.1	0.2
01/10		0.03				0.4	0.2
01/17		10		2		0.5	3.7
01/30		0.01		0.7		0.4	0.2
02/08		0.5		0.6		0.04	0.7
02/15							
02/22	0.1	2	0.2	0.1			0.8
03/08	0.1			6			0.3
05/04	4.4	14	1.8	395			
05/08	0.5			86			139
WET WEATHER							
11/8/72	0.5				0.01	0.8	0.01
12/20	0.2	30		300	1.6	0.5	2.5
05/21/73	1.4	25	0.5	2.1			3
05/22	1.2		1.4	3.2			4.7
05/23							
05/24	0.01		0.002	1.2			0.2
05/25	0.1		4	1.4			100

sewage treatment facility was not in operation in 1957.

SUMMARY

Matsushita (1973) concluded that the stream parameters of his Kalihi Stream investigation compared very closely with those of other investigators in Hawaii. Table 8 compares data of other stream surveys with the data for Waimano and Waiawa Streams.

In general, the results for Waimano and Waiawa Streams were comparable to those of the other investigators on an individual basis; however, Matsushita (1973) and Ching (1972) reported increases in parametric concentrations during wet weather. Contrarily, the concentrations of the parameters for Waiawa Stream and Waimano Stream tended to be higher during dry weather, decreasing during wet weather.

The flows and drainage areas of study for Manoa Stream, Kalihi Stream, and Waimano-Waiawa Streams provided an interesting contrast. The drainage area of Waiawa by itself is 4 to 5 times greater than Manoa or Kalihi, but the wet and dry weather flows for the three drainage areas vary within a narrow range as shown in Table 8.

The increases in the parametric concentration during dry weather together with the small urban developed area within the Waiawa drainage basin points to the developed area as the source of the higher concentrations of stream parameters, specifically the effluent from the Pacific Palisades sewage treatment plant.

Halting the discharge of the sewage effluent into Waimano Stream may not improve the condition of the stream, since some other source may be causing the increase in the parametric concentrations. The Pacific Palisades Sewage Treatment Plant commenced operations January 12, 1962. A comparison of parameters at the gaging station previous to 1962 with the data of this investigation would give an indication whether the streams would return to their unaltered state. Unfortunately, data prior to 1962 was not available from the U.S. Geological Survey (USGS), nor could the USGS suggest any organization which would have the data desired.

Waiawa Stream is an intermittent stream, yet its drainage area is vast. The developed areas within the Waiawa Stream drainage area represent but 20 to 25 percent of the total land area, but the sewage flow from one such developed area, Pacific Palisades, was the source of perennial flow for the

TABLE 8. COMPARISON WITH OTHER INVESTIGATIONS.

	QUAN et al.[a] KANEOHE STREAM KEAAHALA STREAM	YOUNG[b] KAPALAMA STREAM	CHING[c] MANOA STREAM DRY	CHING[c] MANOA STREAM WET	MATSUSHITA[d] KALIHI STREAM DRY	MATSUSHITA[d] KALIHI STREAM WET	WAIMANO STREAM* WAIAWA STREAM DRY	WAIMANO STREAM* WAIAWA STREAM WET
AREA (SQ MI)			6.56		5.24		26.4 (WAIAWA)	
AVG. FLOW (MGD)			3.54	35.4	3.02	30.9	2.9	28.1
DO	---	0-18.7	6.55-8.44	6.96-8.34	5.8-8.0	6.6-7.3	0-8.7	4.1-9.2
BOD	---	0.3-48.0	---	---	0.35-2.25	0.35-2.50	0-46.5	0-26.7
TURB (APHA)	---	---	2.8-32.0	42-59	4.2-11.8	16.3-86	0.4-27(FTU)	1.5-51
COLOR	---	---	6.2-11.0	18.3-35	---	---	5-60	12-55
TS	---	100-470	102-184	190-260	88.4-149	105-246	95-2164	45-423
SS	---	---	6.94-30.1	88-177	6.11-37.2	4.4-46.0	0.4-57.2	1.1-67.0
TP	0.0014-0.007	0.1-2.5	0.08-0.14	0.19-0.22	0.11-0.34	0.03-0.27	0-11.9	0-1.09
TN	---	0-11.8	0.20-0.30	0.23-0.46	0.24-0.43	0.10-0.64	0-26.9(TKN)	0-2.3
NO_3-N	0.05-0.60	---	0.745-1.780	1.95-3.50	---	---	0-2.2	0.001-1.07
CL^-	---	33-121	15.3-24.6	11.0-15.9	21-31	20.5-27.0	17.0-1030	13.3-140
COND	---	---	---	---	100-214	65-119	82-1400	52-410
pH	7.8-8.6	6.6-9.0	6.94-7.55	7.01-7.50	6.7-8.25	6.7-7.6	6.1-7.2	6.55-7.4
TEMP	21.25	---	20.5-25.0	20.1-23.4	19.9-26.2	19.1-21.5	17.5-26.0	17.5-23.0
TC/100 ml	---	800-110,000,000	13,000-22,000	22,000-43,000	3200-23,000	9000-36,000	1-1,800,000	1-69,000
FC/100 ml	---	200-9,600,000	140-2000	720-2600	52 1660	40-12,000	1-340,000	1-800,000
FS/100 ml	0-7000	100-5,400,000	2500-14,000	6000-18,500	150-3700	40-[illegible]0,000	1-9000	1-12,000
FC:FS	---	5.2	0.005-0.093	0.033-0.14	0.18-2.8	0.5-[illegible]36	0.002-395	0.002-300

NOTE: CONCENTRATIONS IN mg/l UNLESS OTHERWISE NOTED.
*EXCLUDING EFFLUENT

[a] QUAN, YOUNG, BURBANK, AND LAU 1970
[b] YOUNG, HAHN, AND JOHNSON 1972
[c] CHING 1972
[d] MATSUSHITA AND YOUNG 1973

lower section of Waiawa Stream. However, even with the large drainage area and intermittent streamflow, self-purification occurred in the short distance from the point of sewage effluent discharge to the Middle Loch of Pearl Harbor.

CONCLUSIONS

1. The water quality of both Waimano Stream and Waiawa Stream were significantly altered from the control conditions at Station 0 and Station 2A by the addition of the effluent from the Pacific Palisades Sewage Treatment Plant.

2. Self-purification was being accomplished in Waimano and Waiawa Streams despite the short distances involved. The changes in DO, BOD, NH_3-N, NO_2-N, NO_3-N follow the typical pattern expected of a free flowing receiving body of water.

3. Wet weather and high flow tended to decrease parametric concentrations indicating the effect of dilution, however, parametric loads increased during wet weather due to the great increase in flow.

4. Nutrient concentrations (nitrogen and phosphorus) exceeded the Water Quality Standards for Class A waters, except at the control stations, during wet and dry weather. The ultimate point of the flow of Waiawa Stream is the Middle Loch of Pearl Harbor which is designated Class A.

5. Bacterial counts (total and fecal coliforms) exceeded the Water Quality Standards for respective Class 2 and Class A waters at all stations and for both wet and dry weather flows.

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