WASTEWATER EFFLUENTS AND SURFACE RUNOFF QUALITY

by

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POLLUTION AND REUSE OF WASTEWATER EFFLUENTS
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ABSTRACT

A three-year study was conducted to determine the quality of domestic wastewater treatment plant effluents and urban surface runoff, including street litter, on Oahu and to examine the reclamation potential of these water resources. The study was conducted in three phases: 1) the examination of effluents of eleven wastewater treatment plants representative of conventional treatment technology, 2) the characterization of street litter and of runoff from a watershed representative of runoff from varied land-use patterns, and 3) the fabrication of a reverse osmosis pilot module and preliminary evaluation of its potential to reclaim secondary sewage effluent.

Domestic sewage flows were found to be characteristically similar to those found elsewhere in the United States. Treatment plant efficiency in reduction of organic matter and suspended solids, for all process trains studied, was comparable to reported literature. Effluent nutrient (N and P) and dissolved oxygen levels do not meet standards of receiving water quality suggesting a need for mixing zone variances, process change or addition or both. Reclamation of the effluents for recharge or direct reuse schemes should be within the capabilities of present technology.

Manoa Stream was selected for the watershed study. Results show generally very low levels of all parameters as compared to wastewater effluents but an extreme range of variability dependent on flow conditions. Constituent levels or "degree of contamination" were found to vary directly with urban population density, urban development and land-use activity. The most significant factor determined was that in both dry and wet weather conditions, the State Water Quality Standards. However, low fecal coliform to fecal streptococcus ratios indicate the probable source of bacterial contamination as non-human, warm-blooded animals and thus the stream waters may still be considered suitable for recreational use.

Street sweepings were obtained from locations of urban activity in downtown Honolulu and Waikiki. Compared to data available from a Chicago study, these street litter had a higher BOD, nitrate, phosphate, and water soluble material content. Results showed a considerable potential for pollution of surface runoff by the street litter but this impact requires further evaluation since the litter was obtained by sweeping of only the gutter areas, not the entire paved street surface, and may not be totally representative of the suspended and dissolved materials load that may be transported with runoff into stormwater collection systems.

In the final phase of study a spiral-wound test module reverse osmosis unit was fabricated for evaluation in reclamation of wastewater effluents. The effluent was selected over runoff or streamflow because of its relative constant flow volume. Initial test results with intermittent operation of over 320 hours yielded a product comparable to a low mineral content water supply from chlorinated activated sludge effluent. Reduction in flux rate occurred, however, necessitating the use of an enzyme detergent flushing to restore the unit's production capacity, but the flux rate could not be restored to its original operating level. Continued testing of the unit is planned with effluents of different degrees of wastewater treatment to better determine its treatment capabilities and economics of operation.

TABLE OF CONTENTS

LIST OF TABLES

Table

LIST OF FIGURES

Figure

INTRODUCTION

"Pollution and Reuse of Wastewater Effluents and Stormwater in Hawaii" was initiated in July 1969 as a three-year project of the Water Resources Research Center. The objectives of this project were to determine physical, chemical, and microbiological characteristics of wastewater effluents and stormwater runoff from representative areas, to compare these constituent levels with the State Water Quality Standards (1968), and to determine the suitability of these waters for reuse in irrigation, artificial recharge, or direct application.

The first year of the study concentrated on producing a catalog of wastewater treatment facilities for the state and the results of this study have been published as a Water Resources Research Center Technical Memorandum Report No. 27 (1970). Work was started on a survey of eleven wastewater treatment facilities at a number of locations to determine the effectiveness of each facility.

In the second year of the study, the treatment facility survey was completed and two additional activities were undertaken: (i) a water quality survey of a stream representative of urban runoff, and (ii) an evaluation of the potential pollution from urban stormwater that would result from highly-developed and paved areas.

The planned work for the third year included a reclamation study of wastewater effluent utilizing an advanced waste treatment process, reverse osmosis, on a pilot scale in the field.

The present report details the principal findings of the entire project including the treatment facilities, surface runoff, potential pollution from urbanized areas, and reclamation study. The first work areas or research phases constitute the principal sources of possible low-quality water that could be readily recovered and reclaimed for drinking or other uses, exclusive of the brackish ground water that may exist in caprock or shoreline areas in Hawaii. The principal objective was to examine the quality characteristics of these waters and to consider the possible application of conventional or advanced treatment processes in the reclamation that may be undertaken. The last phase focused on a particular reclamation process, reverse osmosis, selected because it is representative of the most advanced treatment technology currently applied in reclamation.

It is readily recognized that among the domestic wastewaters and runoff waters studied herein, sewage represents the only source that is reliable and fairly constant. Surface runoff in Hawaiian watersheds is not usually a perennial phenomenon and runoff derived from rainfall in urbanized and paved areas is even more "flashy" than streamflow. However, it was considered necessary that these types of waters be examined concurrently to provide a basis of comparison of their respective qualities, particularly since such information for Hawaii is not readily available in the literature.

The research phases are described separately in the following chapters, each chapter detailing the study area methodology and results. The final section of this report consists of a brief summary of the entire research project.

CHAPTER 1

WASTEWATER TREATMENT PLANTS

DESCRIPTION OF THE STUDY SITE

The treatment plants selected for this study (Fig. 1.1) included those in a variety of locations, using different types of treatment processes, and processing a variety of receiving waters on Oahu. The plants, the degree of treatment provided, the average daily sewage volume treated, and the classification of the receiving waters for the respective plant effluents are listed in Table 1.1. Table 1.2 includes a description of some of the uses and specific standards applicable to the classes of receiving waters relevant to this study (1968).

METHODOLOGY

The following fifteen parameters were selected for evaluation of the raw and treated wastewater at the plants under study: chlorine residual,

TABLE 1.1. DESCRIPTION OF ELEVEN OAHU SEWAGE TREATMENT PLANTS INVESTIGATED.

SEWAGE TREATMENT PLANT LOCATION	TYPE OF TREATMENT	FLOW, MGD	RECEIVING WATER	CLASS
WAIPIO	EXTENDED AERATION	0.15	WAIKELE STREAM	2
MILILANI	RAPID BLOC	0.12	KIPAPA STREAM	2
MAKAKILO	ACTIVATED SLUDGE	0.36	PLANTATION IRRIGATION	-
KANEOHE	TRICKLING FILTER	2.53	KANEOHE BAY	AA
KAILUA	TRICKLING FILTER	3.2	KAILUA BAY	A
PACIFIC PALISADES	TRICKLING FILTER	0.69	WAIMANO STREAM	2
PEARL CITY	PRIMARY	4.39	PEARL HARBOR (WEST LOCH)	AA
POHAKUPU	TRICKLING FILTER	0.27	KAIWAINUI STREAM	2
MAUNAWILI	EXTENDED AERATION	0.10	MAUNAWILI STREAM	2
WAIANAE	PRIMARY	0.36	OCEAN	A
WAHIAWA	ACTIVATED SLUDGE	1.12	WAHIAWA RESERVOIR	2

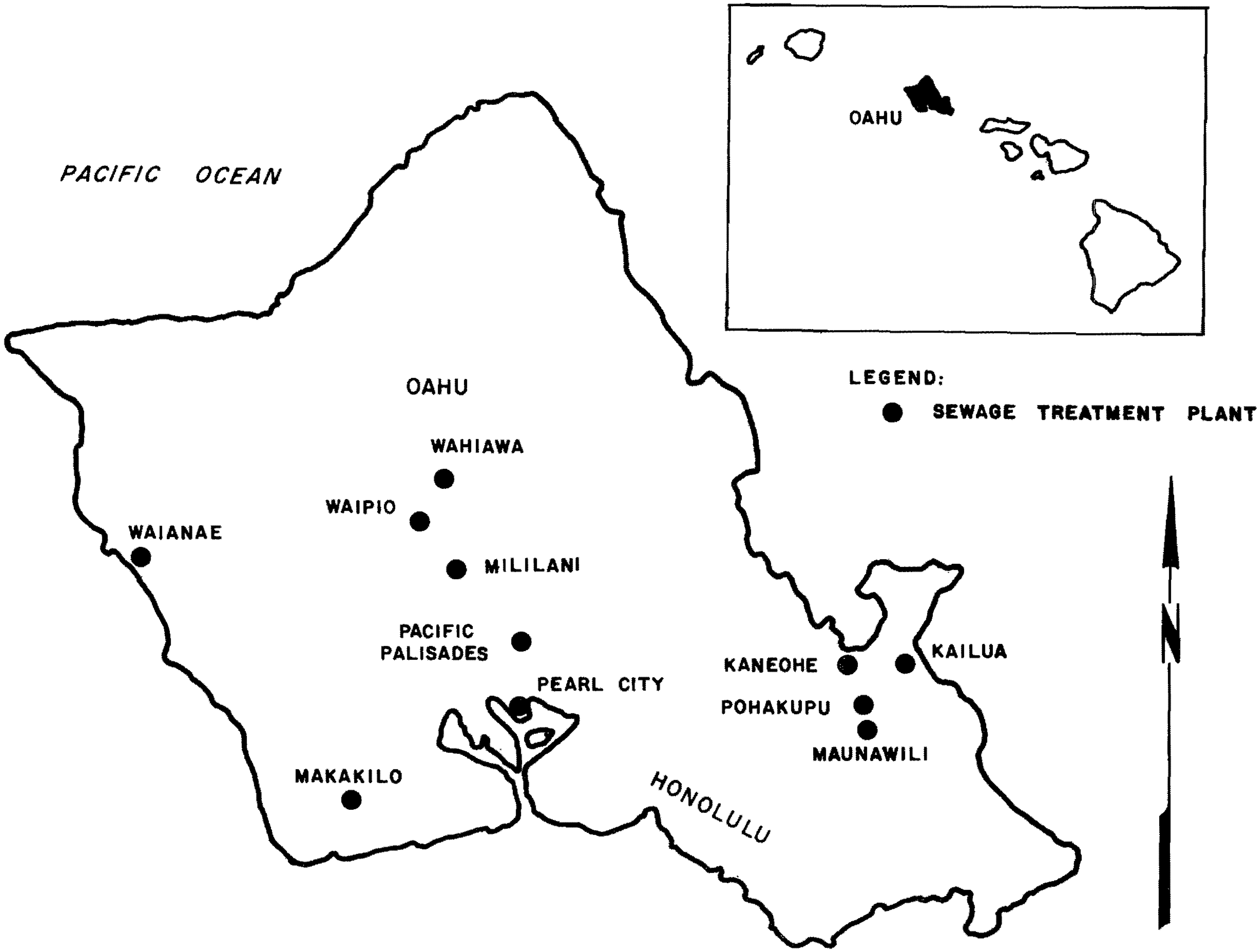

FIGURE 1.1. LOCATION OF ELEVEN OAHU SEWAGE TREATMENT PLANTS INVESTIGATED IN THIS STUDY.

TABLE 1.2. CLASSIFICATION OF HAWAII WATERS BY USE AND SPECIFIC STANDARDS.

CLASS	USE	TOTAL - P (MG/L)	TOTAL - N (MG/L)	D.O. (MG/L)	TEMPERATURE
AA	OCEANOGRAPHIC RESEARCH PROPOGATION OF SHELLFISH AND MARINE LIFE CONSERVATION OF CORAL REEF AND WILDERNESS AREAS & AESTHETIC ENJOYMENT	0.020	0.10	6.0	NOT TO CHANGE MORE THAN 1.5°F FROM NATURAL CONDITIONS
A	RECREATIONAL, INCLUDING SWIMMING, FISHING, BATHING & OTHER WATER CONTACT SPORTS-AESTHETIC ENJOYMENT	0.025	0.15	5.0	SAME
B	SMALL BOAT HARBORS COMMERCIAL SHIPPING & INDUSTRIAL BAIT FISHING AESTHETIC ENJOYMENT	0.030	0.20	4.5	SAME
2	BATHING, SWIMMING, RECREATION GROWTH & PROPAGATION OF FISH & OTHER AQUATIC LIFE AGRICULTURAL & INDUSTRIAL WATER SUPPLY	-	-	5.0	-

CLASS	TURBIDITY	pH	BACTERIA COLIFORM/100 ML	SALINITY
AA	SECCHI DISC OR EQUIVALENT AS "EXTINCTION COEF." SHALL NOT BE ALTERED MORE THAN 5%	8.0-8.5	MEDIAN < 70 ANYTIME < 230	FRESH WATER INFLUX NOT TO CAUSE PERMANENT CHANGES IN ISOHALINE PATTERNS BY MORE THAN 10%
A	SAME BUT 10%	7.0-8.5	MEDIAN < 1000 10% SAMPLES < 2400 FECAL COLIFORM A. < 200 FOR 30 DAY PERIOD B. 10% SAMPLES < 400	NOT APPLICABLE
B	SAME BUT 20%	7.0-8.5	FECAL COLIFORM A. < 200 FOR 30 DAY B. 10% SAMPLES < 1000	NOT APPLICABLE
2		6.5-8.5	SAME AS FOR A	NOT APPLICABLE

dissolved oxygen (DO), temperature, turbidity, settleable solids, suspended solids (SS), grease, orthophosphate, total phosphate, nitrate-nitrogen, total kjeldahl nitrogen, chemical oxygen demand (COD), pH, five-day biochemical oxygen demand (BOD_5), and chlorides.

Although it was not possible to measure all fifteen parameters at all eleven plants (because of the variations in the process), a very comprehensive sampling program was initiated. Two types of sampling surveys were conducted at each plant. The first type consisted of a continuous sampling program for a seven-day period at a fixed pumping rate using a commercial (Brailsford) effluent sampler. The sampler contents were removed at 24-hour intervals for laboratory analysis. The second type of sampling program consisted of a one-day survey with grab samples obtained at hourly or bihourly intervals with these samples being composited into a single representative sample for the day and then analyzed in the lab. All chemical and physical tests were performed in accordance with *Standard Methods* (1970).

RESULTS AND DISCUSSION

The results of this study (Tables 1.3 and 1.4), in general, do not vary appreciably from what may be considered to be normal and it is apparent that there are no real differences between the data from this study and that of previous investigations (Table 1.5).

TABLE 1.3. SUMMARY OF DATA FOR RAW SEWAGE AND EFFLUENT FROM ELEVEN OAHU SEWAGE TREATMENT PLANTS.

SEWAGE TREATMENT PLANT	Cl_2 RESIDUAL, MG/L	DISSOLVED O_2, MG/L		TEMPERATURE, °C		TURBIDITY, APPA	SETTLEABLE SOL., MG/L		SUSPENDED SOL., MG/L		GREASE, MG/L		ORTHO - PO_4, MG/L	
	EFF.	INF.	EFF.	INF.	EFF.	EFF.	INF.	EFF.	INF.	EFF.	INF.	EFF.	INF.	EFF.
MAKAKILO	0.3	5.5	6.3	26.6	24.6	25	9.4	0.1	210	89	39	23	10.7	15.7
KANEOHE	1.2	3.4	2.4	29.0	29.3	35	4.7	0	135	16	170	194	17.6	17.8
KAILUA	0.8	2.9	4.1	26.5	26.0	23	5.7	0	107	13	115	110	8.1	8.1
WAIPIO	0.7	4.3	3.2	26.3	25.9	32	7.3	6.9	142	65	30	26		
MILILANI		0.8	2.3	27.0	27.1	30			202	65	58	22	7.2	7.4
PACIFIC PALISADES	0.5	3.7	2.6	29.2	28.8	26	5.8	0.8	285	92	47	29	5.0	5.5
PEARL CITY		2.7	3.2	27.0	27.1	169	8.4	0.3	170	79	70	60	4.6	4.9
POHAKUPU		3.4	5.7	24.7	24.1	32	8.4	0	144	29	36	29	7.6	10.4
MAUNAWILI	0.7	3.8	7.9	28.6	27.9	64	10.6	3.6	242	156	236	166	10.3	10.3
WAHIAWA	0.3	3.8	4.8	25.6	26.4	20	8.9	0			41	12	15.5	11.7
WAIANAE									145	106	27	25		

SEWAGE TREATMENT PLANT	TOTAL PO_4, MG/L		NO_3 - N, MG/L		TOTAL - N,[1] MG/L		COD, MG/L		pH		BOD, MG/L		Cl^-, MG/L	
	INF.	EFF.	INF.	EFF.	INF.	EFF.	INF.	EFF.	INF.	EFF.	INF.	EFF.	INF.	EFF.
MAKAKILO	17.5	15.0	0.29	0.89	30.2	2.1	571	157	7.6	6.8	129	17		
KANEOHE	23.9	15.7	0.06	0.08	33.3	17.4	342	122	7.1	6.9				
KAILUA	10.7	9.2	0.40	5.50	18.2	8.4	535	300	6.9	7.2	105	28	2006	2227
WAIPIO	6.8	7.3	0.07	0.35	32.2	3.0	187	49	7.6	6.1				
MILILANI	9.0	8.0	0.01	0.28	28.7	10.7	277	43	7.0	6.8				
PACIFIC PALISADES	7.0	6.6	0.15	0.21	31.2	21.1	297	103	7.6	7.2				
PEARL CITY	60.0	54.9	0.19	0.24	27.2	19.5	412	244	7.2	7.0				
POHAKUPU	12.9	13.5	0.07	0.40	30.6	12.7	310	89	6.9	6.3				
MAUNAWILI	14.9	12.8	0.23	9.02	21.4	5.6	365	951	7.2	6.9	207	44	44	44
WAHIAWA	17.3	14.2	0.01	0.08	33.8	8.4	475	68	7.4	7.7				
WAIANAE	6.8	7.1	0.12	0.18	17.6	17.1					195	151	1683	1749

[1] TOTAL - N = TOTAL KJELDAHL NITROGEN

TABLE 1.4. SUMMARY OF PLANT PERFORMANCE FOR ELEVEN OAHU SEWAGE TREATMENT PLANTS.

TREATMENT PLANT	TYPE OF TREATMENT	FLOW, MGD	PERCENT OF REMOVAL: SUSPENDED SOLIDS	GREASE	COD	TOTAL - N[1]	TOTAL - P
MAKAKILO	ACTIVATED SLUDGE	0.36	58	41	73	93	14
KANEOHE	TRICKLING FILTER	2.53	88	-	64	48	34
KAILUA	TRICKLING FILTER	3.20	88	4	44	54	14
WAIPIO	EXTENDED AERATION	0.15	54	13	74	91	-
MILILANI	RAPID BLOC	0.12	68	62	84	63	11
PACIFIC PALISADES	TRICKLING FILTER	0.69	68	38	65	32	6
PEARL CITY	PRIMARY	4.39	54	14	41	28	9
POHAKUPU	TRICKLING FILTER	0.27	80	19	71	58	-
MAUNAWILI	EXTENDED AERATION	0.10	36	30	74	74	14
WAHIAWA	ACTIVATED SLUDGE	1.12	-	71	86	75	18
WAIANAE	PRIMARY	0.36	27	7	-	3	-

[1] TOTAL - N = TOTAL KJELDAHL NITROGEN

TABLE 1.5. EFFLUENT DATA FROM SELECTED STUDIES ON OAHU SEWAGE TREATMENT PLANTS.

TREATMENT PLANT	BOD, MG/L				SUSPENDED SOLIDS, MG/L				TOTAL KJELDAHL-N, MG/L				TOTAL-P, MG/L				GREASE, MG/L			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
MAKAKILO	17	11	50		89	27	45		2.1		21		15.0		10		23		21	
KANEOHE	65	21	40	39	16	66	40	97	17.4	17.1	15	21.6	15.7	23.3	6.5	28	10	5	7	42
KAILUA	28	7	56	20	13	37	60	27	8.4		19	2.0	9.2		6.5	44	69		23	19
WAIPIO			40	31	65		45	33	3.0		21	8.1	7.3		10	33	26		20	14.0
MILILANI			10		65		8		10.7		21		8.0		10		22		20	
PACIFIC PALISADES		19	31	32	92	23	36	36	21.1		20	18.5	6.6		18	49	29		7	24
PEARL CITY			71	67	79		90	86	19.5		15	18.3	5.5		8.6	30	59		19	76
POHAKUPU		17	50	8	29	10	45	11	12.7		21	11.7	13.5		10		29		20	4
MAUNAWILI	44	20	40	7	81	29	45	46	5.6		21	3.6	12.8		10	40	166		20	15
WAHIAWA		20	15	15		17	27	28	8.4		26	21.1	14.2		8	23	12		4	7
WAIANAE	151		151		106		110		17.1		16		7.1		7.1		25		25	

1 THIS STUDY.
2 GRAY, M.S. THESIS, UNIVERSITY OF HAWAII, 1969.
3 OAHU WATER QUALITY REPORT, 1971.
4 YOUNG & CHAN, 1970.

In this investigation residual chlorine (Cl_2) ranged from 0.3 to 1.2 mg/l and compared favorably with results obtained by Young and Chan (1970) in similar studies involving several of the facilities included in the current study. Similar values have been described by Babbitt and Baumann (1958) for treatment plant effluent in general.

The Ten-State Standards (1971) suggests a chlorine dosage which would result in a residual of 2 mg/l, a value higher than that observed in this study. Fair and Geyer (1965), on the other hand, suggest a residual ranging between 0.2 and 1.0 mg/l after 15 to 30 minutes contact as being sufficient in establishing a 99.9 percent destruction of *E. coli* and 37° C total bacterial count. This investigation, therefore, shows that the Cl_2 residuals of Oahu sewage treatment plants are satisfactory.

Dissolved oxygen (DO) was present in all influent wastewaters and all plant effluents. Influent DO ranged from 0.8 to 5.5 mg/l and effluent DO ranged from 2.3 to 7.9 mg/l. The depletion of DO in raw sewage is the result of biological decomposition of organic material and is often associated with long sewage flow times in the collection system. These anaerobic septic conditions lead to corrosion problems in sewers and odor and settling problems in sewage treatment plants. When such conditions exist, it may be necessary to provide some preliminary treatment, such as chlorination or aeration, within the collection system itself. The presence of DO in all influent wastewaters studied indicates that the material is in good condition and that nuisance conditions do not exist.

In every case studied, sufficient DO was present in treatment plant effluents to indicate relatively stable conditions. In addition, in all but three of the plants, there was an increase in DO from raw waste to treated effluent.

Liquid temperatures ranged from 24.7 to 29.2° C for influent wastes and from 24.1 to 29.3° C for plant effluents. Although these values were observed during only one week of the year, it can be safely assumed that this temperature range would hold true throughout the year, owing to the small variation in the ambient temperature in Hawaii.

Another indication of the stability of the plant effluents studied is the percent of DO saturation observed. Assuming a chloride concentration of less than 2500 mg/l, the saturation DO is known for a given temperature. Comparison with observed values then enables computation of the percent of

DO saturation (Table 1.6). In five of the plants studied, DO saturation was greater than 50 percent, and the lowest value was 29 percent.

TABLE 1.6. PERCENT OF DISSOLVED OXYGEN SATURATION IN PLANT EFFLUENTS.

TREATMENT PLANT	EFFLUENT TEMPERATURE, °C	SATURATION D.O., MG/L	OBSERVED D.O., MG/L	PERCENT SATURATION
MAKAKILO	24.6	8.2	6.3	77
KANEOHE	29.3	7.6	2.4	32
KAILUA	26.0	8.0	4.1	51
WAIPIO	25.9	8.0	3.2	40
MILILANI	27.1	7.9	2.3	29
PACIFIC PALISADES	28.8	7.6	2.6	34
PEARL CITY	27.1	7.9	3.2	41
POHAKUPU	24.1	8.3	5.7	69
MAUNAWILI	27.9	7.7	7.9	103
WAHIAWA	26.4	8.0	4.8	60

Although turbidity measurements have limited usefulness in wastewater treatment, nevertheless, these measurements can be used effectively as a quality control parameter to reflect suspended solids concentration. The range of turbidity measurements in the present study was from 20 to 169 units, with 80 percent of the effluents having turbidities between 20 and 40 units in comparison with the USPHS (1962) raw drinking water limit of 5 units. Since turbidity in wastewaters is normally caused by suspended and colloidal organic particles, and since relatively high turbidities were observed at ten of the eleven treatment plants, the indication is that a high Cl_2 dosage is required for satisfactory disinfection.

Measurement of settleable solids allows determination of sedimentation efficiency. Except for the Waipio and Maunawili sewage treatment plants which utilize extended aeration biological systems, settleable solids removed was greater than 90 percent. At the Waipio and Maunawili plants, only 5 and 66 percent of the settleable solids were removed, respectively, indicating extremely poor settling efficiency. In these extreme cases, the mixed liquor solids were being washed out of the system, a common occurrence in extended aeration plants without separate sludge wasting. Although solids buildup is slower than in conventional activated sludge plants, there is a definite buildup of solids and when no separate sludge wasting is permitted, these solids periodically are flushed out of the system.

By definition, suspended solids includes both settleable and non-settleable fractions and its measurement offers another method of determining treatment efficiency. In addition, and perhaps more important, it evaluates the strength of influent raw sewage or treated effluent, as these solids are primarily organic. For this reason, suspended solids are considered as important as the biochemical oxygen demand (BOD) of wastewater as an index of treatment efficiency.

Influent suspended solids ranged from 107 to 285 mg/l with influents from six plants containing less than 200 mg/l. Average suspended solid concentration in domestic sewage as reported by Fair and Geyer (1965) is 235 mg/l. For the same plants studied in this project, Young and Chan (1970) reported slightly higher values (Table 1.5). In any case, raw domestic sewage on Oahu can be considered to be typical and not unusual.

With respect to suspended solids removal efficiency, the average for the trickling filter plants (Table 1.4) was 81 percent, well within the range reported by Imhoff and Fair (1956), and essentially the same as that reported by Young and Chan (1970). However, the activated sludge process plants, including the conventional and modified systems, displayed only a 56 percent suspended solids removal (exclusive of the Wahiawa plant, for which complete data are not available). This was probably due to the flushing or carry-over of solids in the extended aeration plants in Waipio and Maunawili. The average removal for the two primary plants was only 41 percent, much lower than the 83 percent value reported by Young and Chan (1970). Under optimum conditions, plain sedimentation could remove approximately 80 percent of the suspended solids within a 3 to 4 hour detention time.

In recent years, determination of the grease content in domestic sewage has become increasingly important because of the increased use of home garbage grinders. Although this hard-to-separate organic material is biodegradable, the decomposition rate is usually very slow and the resulting products often include obnoxious sulfur compounds. In addition, grease is unsightly when allowed to pass into a receiving water. Of the treatment plants investigated, only one had a grease removal greater than 50 percent (Table 1.4).

The major accomplishment of any secondary sewage treatment plant is the removal of organic material from the waste stream and the presence or absence of organic materials determines the efficiency of a treatment plant, operations. More specifically, measurement of organic material by the BOD test allows the determination of true efficiency. In the present study, organic material was measured at four plants: a conventional activated sludge plant, a trickling filter plant, an extended aeration plant, and a primary plant. BOD removals were 87, 73, 79, and 23 percent, respectively. The trickling filter process displayed a slightly lower removal efficiency than is normally expected for that type of process.

The significance of the BOD parameter is comparable to that of suspended solids and effluent quality. The BOD concentration is high for both the extended aeration and primary plants as was predictable because of the process each plant employs. BOD concentrations in raw wastes on Oahu are low and substantiates Young and Chan's findings (1970).

The COD of the influent, measured at ten of the eleven treatment plants, ranged from 187 to 571 mg/l. These values are typical for domestic sewage.

Although the COD test measures non-biodegradable and biodegradable matter, the test is often used as an indication of biological treatment efficiency. The levels of COD removal are normally lower than the BOD data because some of the incoming biodegradable material is transformed to non-biodegradable organic material during treatment with the former being reflected in the COD measurement. For the Makakilo influent and effluent, the BOD:COD ratio decreased from 0.23 to 0.11, respectively, for Kailua influent and effluent from 0.20 to 0.09, respectively, and for the Maunawili influent and effluent from 0.57 to 0.46, respectively. COD removals for the ten plants ranged from 41 to 86 percent and, in every case, the activated sludge plants (conventional and modified) performed more efficiently than the trickling filter plants.

The role of nitrogen and phosphorus as nutrients in aquatic ecosystems is well documented (FWPCA, 1968; FWPCA, 1969; Oglesby, 1969; Sawyer, 1969; Welch, 1952). In the present study, the levels of both elements were found to be similar to those found in domestic sewages throughout the United States. This is predictable on the basis that domestic households are the primary source of these elements in raw sewage.

Removal of nitrogen and phosphorus was generally poor at the eleven plants, ranging from 3 to 93 percent for nitrogen, and from 6 to 34 percent for phosphorus (Table 1.4). A possible explanation for the high removal of nitrogen at Makakilo is the long detention time, which results in the oxidation of ammonia-nitrogen to nitrate-nitrogen. A BOD of 129 mg/l is low for an aeration time of 6 to 8 hours, typical for conventional activated sludge systems. A similar situation probably exists at Waipio, an extended aeration plant, where the influent COD was only 187 mg/l. Long detention of the sludge in the final clarifier promotes anaerobic conditions and nitrate-nitrogen can be reduced to free nitrogen, thus enhancing the overall removal achieved. The results of this study clearly indicate that conventional primary and secondary treatment technology does not provide for efficient and reliable removal of nitrogen and phosphorus.

Effluent values of all the treatment plants for nitrogen and phosphorus exceed, while the dissolved oxygen is lower than the permissible ambient levels given in the State Water Quality Standards (1968) (Table 1.2). Measures for reduction prior to discharge to a zone of mixing in the receiving waters could be required before the discharges are of acceptable quality.

The pH levels were not unusual or atypical. As expected, the pH level of the effluent was slightly lower than that of the influent at all the plants.

Chlorides were measured at only the Kailua and Waianae plants, mainly because of the location of their sewerage systems within the salt or brackish water table. In both cases, evidence of salt water infiltration was present.

This phase of the investigation showed that the domestic sewage flows on Oahu are characteristically much the same as those found elsewhere in the United States. Overall efficiency of treatment with respect to organic matter and suspended solids was fair, and improvement may be possible through operational modifications. Nutrient and dissolved oxygen levels in plant effluents suggest that considerable care be exercised in plant process selection, operation, and effluent disposal so that the effect on the receiving water environment is minimal. The reclamation of these treated wastewaters for recharge or direct reuse schemes whould be within the capabilities of present technology.

CHAPTER 2

STREAM RUNOFF

DESCRIPTION OF THE STUDY SITE

Manoa Stream is located in the Honolulu district and is surrounded by a watershed area known as Manoa Valley (Fig. 2.1). Runoff from the area enters the stream by manmade diversions or by natural means.

Temperatures in the valley are usually lower than the coastal plains of Honolulu. The annual rainfall varies from 25 to 40 inches on the coastal plain in contrast with 140 to 150 inches at the head of the valley (BWS, 1971) which, coupled with the heavy rainfall near the Koolau crest and flows from dike springs at the upper reaches, causes the streamflow in the valley to be perennial. During periods of heavy rainfall, streamflow is increased by stormwater runoff from forest reserve, agricultural land, and urban areas to provide a unique opportunity to investigate the effect of the various types of stormwater on a typical Hawaiian perennial stream.

The waters of Manoa Stream are presently classified as Class 2 waters under the State Water Quality Standards (1968).

Ground-water recharge occurs principally in areas above the 400-foot elevation since the low-lying caprock formations have low permeability and limit the infiltration of rainwater and streamwater.

Urban development in Manoa Valley has almost reached its maximum capacity. It has increased from approximately 1690 acres in 1960 to 1820 acres in 1971, with a parallel increase in population from 25,000 to 31,000 over the same period and respective population densities of 14.8 and 17.0 persons per acre. A land-use classification for the area is outlined in Table 2.1 (Ching, 1970).

TABLE 2.1. LAND USE IN MANOA VALLEY.

CLASSIFICATION	AREA (ACRES)	TOTAL DRAINAGE AREA (PERCENT)	TOTAL DEVELOPED AREA (PERCENT)
RESIDENTIAL	1319	31.4	72.5
SCHOOL AND PARK	428	10.2	23.5
COMMERCIAL	73	1.8	4.0
UNDEVELOPED	2380	56.6	0.0

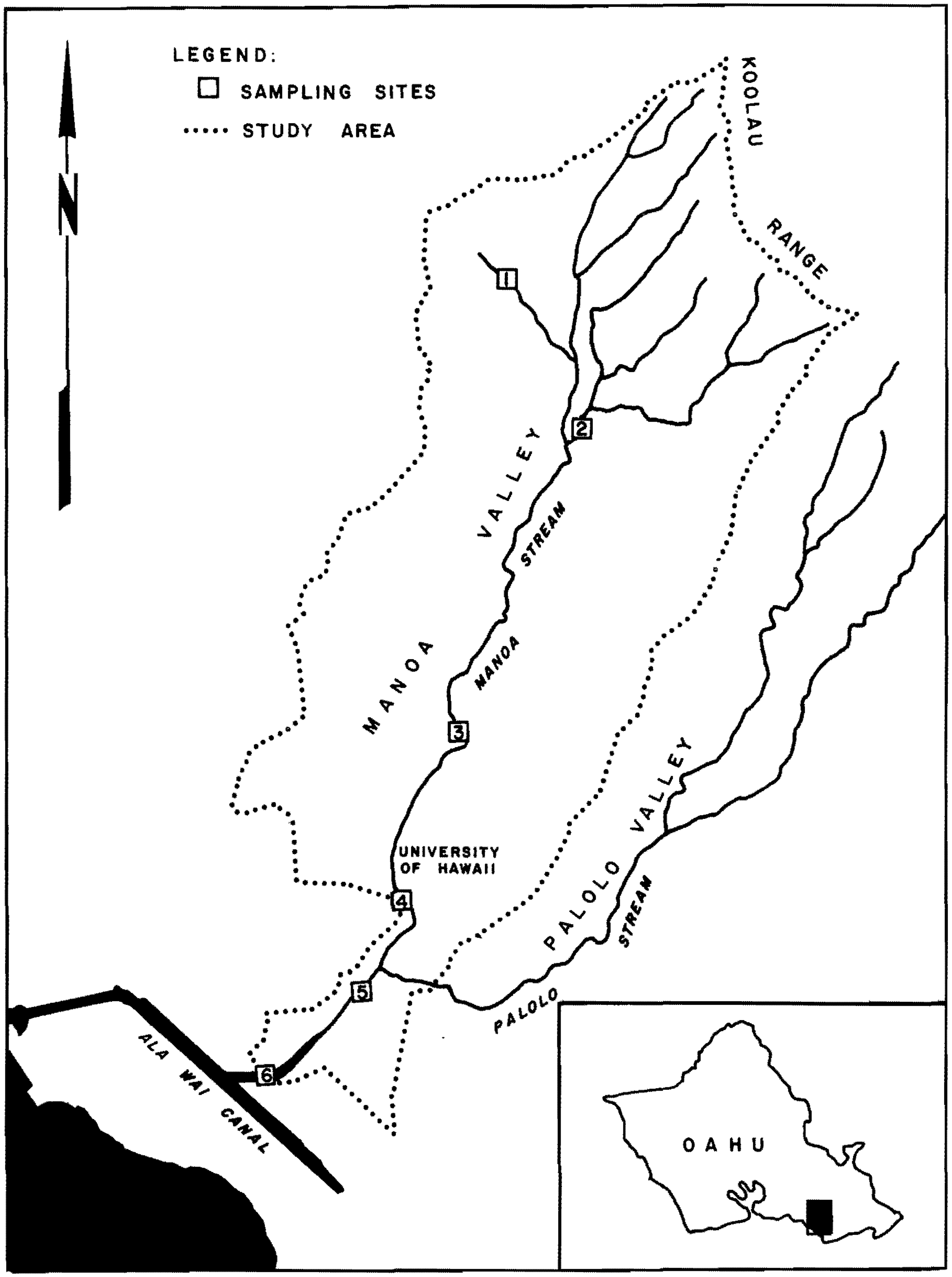

FIGURE 2.1. LOCATION OF STUDY AREA AND SAMPLING SITES, MANOA WATERSHED, OAHU.

METHODOLOGY

Six sampling stations were selected for the Manoa Stream study (Fig. 2.1) on the basis of type of drainage from land-use activity and accessibility. Station 2 was the only site which was monitored by a USGS stream gage so that a flow measurement was available.

Temperature, pH, and dissolved oxygen were evaluated directly in the field. Samples brought to the laboratory were analyzed for color, total nitrogen, total phosphorus, total solids, suspended solids, nitrates, and turbidity. Bacteriological analyses performed in the laboratory determined levels of total coliform, fecal coliform, and fecal streptococcus.

RESULTS AND DISCUSSION

Results of the present research (Tables 2.2 and 2.3) compare favorably with values reported for other water quality studies of Manoa Stream.

TABLE 2.2. SUMMARY OF WATER QUALITY INDICATORS FOR MANOA STREAM.

PARAMETERS	WATER QUALITY UNDER DRY WEATHER CONDITIONS: MEAN OF THE SAMPLING STATIONS	WATER QUALITY UNDER DRY WEATHER CONDITIONS: RANGE OF THE SAMPLING STATIONS MEANS	WATER QUALITY UNDER WET WEATHER CONDITIONS: MEAN OF THE SAMPLING STATIONS	WATER QUALITY UNDER WET WEATHER CONDITIONS: RANGE OF THE SAMPLING STATIONS MEANS
BACTERIAL (NUMBER/100 ML)				
TOTAL BACTERIA (x 10^3)	153	65 -255	121	67 -159
TOTAL COLIFORMS (x 10^3)	18	13 - 22	31	22 - 43
FECAL COLIFORMS (x 10^3)	.89	.14 - 2.0	1.5	.72 - 2.6
FECAL STREPTOCOCCUS (x 10^3)	8.7	2.5 - 14	11.3	6 - 18.5
FC:TC RATIO	0.054 [1]	0.005- 0.093 [1]	0.086	0.033- 0.144
FC:FS RATIO	0.330	0.269- 0.594	0.618	0.170- 1.060
PHYSICAL				
pH	7.30	6.94 - 7.55	7.25	7.01 - 7.50
TEMPERATURE (°F)	22.01	20.50 - 25.0	21.60	20.14 - 23.40
COLOR (COLOR UNITS)	8.66	6.15 - 11.16	26.26	18.42 - 34.85
TURBIDITY (APHA TU)	9.72	2.78 - 31.8	51.6	42.1 - 59.3
DISSOLVED OXYGEN (MG/L)	7.96	6.55 - 8.44	8.01	6.96 - 8.34
CHEMICAL				
CHLORIDES	15.20 [2]	15.3 - 24.6 [2]	13.40 [2]	11.0 - 15.9 [2]
NITRATES (NO_3-N)	1.18	0.745- 1.785	2.64	1.95 - 3.50
SUSPENDED SOLIDS	12.67	6.94 - 30.10	123.6	88.0 -176.7
TOTAL SOLIDS	111.9 [2]	102.9 -183.5 [2]	187.9 [2]	190.5 -260.0 [2]
TOTAL PHOSPHORUS (PO_4)	0.3095	0.232- 0.434	0.603	0.565- 0.658
TOTAL KJELDAHL NITROGEN (TKN)	0.248	0.202- 0.304	0.338	0.231- 0.464

[1] HIGH POLLUTION RATIOS, HUMAN SOURCES OF CONTAMINATION, NOT INCLUDED.
[2] STATION NO. 6 IS NOT INCLUDED BECAUSE OF HIGH CHLORIDE CONCENTRATION AND SEAWATER INTRUSION, NOT RELATIVE TO STREAM QUALITY.

As a general rule, the quality of the streamwater is below the standards set for Class 2 waters, because of failure to meet both total and fecal coliform levels during dry and wet weather conditions (Fig. 2.2 and 2.3). Of great significance is the occurrence of the consistently high bacteriological

TABLE 2.3. TABULATION OF MEAN ANALYTICAL RESULTS AT EACH SAMPLING STATION ON MANOA STREAM.

PARAMETERS	WATER QUALITY UNDER DRY WEATHER CONDITIONS SAMPLING STATIONS						WATER QUALITY UNDER WET WEATHER CONDITIONS SAMPLING STATIONS					
	1	2	3	4	5	6	1	2	3	4	5	6
BACTERIAL (NUMBER/100 ML)												
TOTAL BACTERIA (x 10^3)	168	65	158	179	2:6	93	67	111	145	129	118	159
TOTAL COLIFORMS (x 10^3)	14	22	21	23	21	13	24	23	37	28	44	34
FECAL COLIFORMS (x 10^3)	.150	.560	2.1	.88	1.1	.60	.72	.84	2.50	1.2	2.6	1.2
FECAL STREPTOCOCCUS (x 10^3)	4.3	13.0	6.2	14.0	12.0	2.5	6.1	18	11	18	7.4	7.1
FC:TC RATIO	0.005	0.053	0.093	0.060	0.079	0.037	0.033	0.075	0.12	0.14	0.081	0.062
FC:TS RATIO	0.27	0.29	0.59*	0.33*	0.36	0.14*	0.38	0.17	0.74	1.05	1.06	0.31
PHYSICAL												
pH	6.9	7.1	7.6	7.3	7.5	7.4	7.0	7.0	7.1	7.4	7.5	7.5
TEMPERATURE (°C)	21	21	22	22	22	25	20	21	22	22	23	22
COLOR (COLOR UNITS)	11	6.2	6.7	6.6	11	11	35	23	18	22	26	22
TURBIDITY (APHA TU)	2.8	2.9	3.5	3.1	32	14	59	43	42	53	58	55
DISSOLVED OXYGEN (MG/L)	8.1	8.2	8.4	8.2	8.3	6.6	8.3	8.2	8.3	8.2	8.2	7.0
CHEMICAL (MG/L)												
CHLORIDES	19	15	18	19	25	10,000	11	12	14	14	16	4,000
NITRATES (NO_3-N)	0.74	0.78	0.76	1.3	1.8	1.7	2.3	2.1	2.0	3.1	2.0	3.5
SUSPENDED SOLIDS	7.4	6.9	8.3	10	13	30	108	99	88	139	129	177
TOTAL SOLIDS	103	109	132	144	184	24,000	190	210	208	258	260	9,220
TOTAL PHOSPHORUS (PO_4)	0.27	0.27	0.24	0.23	0.43	0.41	0.66	0.60	0.61	0.62	0.57	0.57
TOTAL KJELDAHL NITROGEN (TKN)	0.20	0.21	0.25	0.30	0.26	0.27	0.27	0.23	0.29	0.46	0.44	0.34

* HIGH POLLUTION RATIOS, HUMAN SOURCES OF CONTAMINATION, NOT INCLUDED IN ARITHMETIC MEAN.

populations which point to a possible need to re-evaluate the uses of the stream since it is clearly unsatisfactory as a general recreational amenity according to the present standards. However, using Geldreich's (1969) fecal coliform to fecal streptococcus ratio (FC:FS) of greater than 4.4 for humans and less than 0.7 for warm-blooded animals, respectively, as a guideline for bacterial populations, Table 2.2 shows that the stream waters contain only contamination from warm-blooded animals under both dry and wet weather conditions. Thus, the waters may be suitable for recreational use even though they do not meet the standards. These results, particularly for the Stations 1 and 2 in the Forest Reserve above areas of human activity, suggest a possible need for re-examination of the types and levels of bacteriological standards in the State Water Quality Standards.

If water quality during dry weather flow is taken as the natural condition of Manoa Stream, the wide range in values presented in Figures 2.2 through 2.9 illustrate the difficulty in establishing standards for the measured parameters. Baselines determined from mean values obtained during dry weather flow would be exceeded much of the time.

It was assumed that when changes in water quality which occurred during wet weather conditions were significantly different from those found in dry weather, the changes could be directly attributed to the effects of surface runoff. As shown in Figures 2.2 through 2.9, there was an increase in the

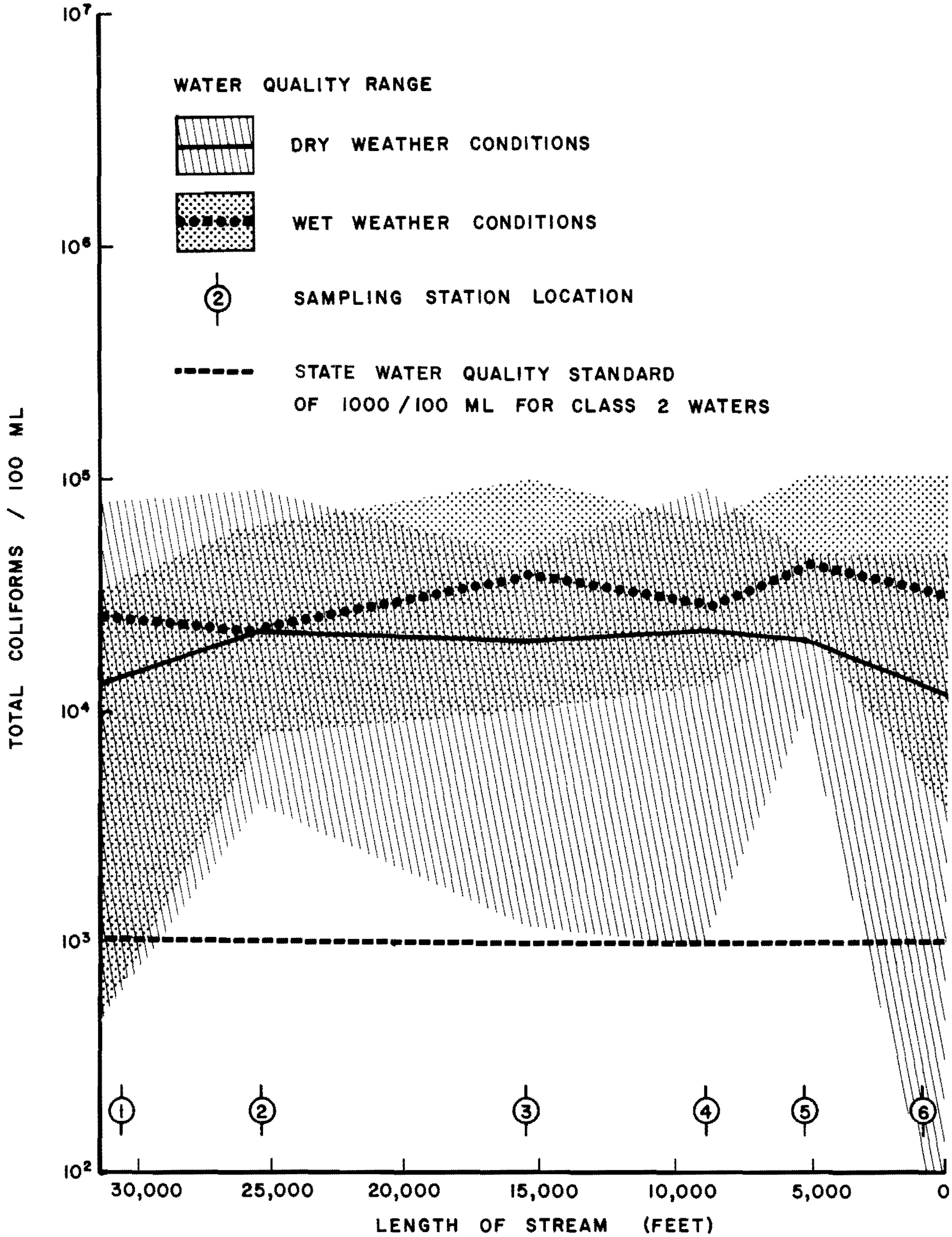

FIGURE 2.2. RANGE IN TOTAL COLIFORM COUNT OBSERVED IN MANOA STREAM, 1970-71.

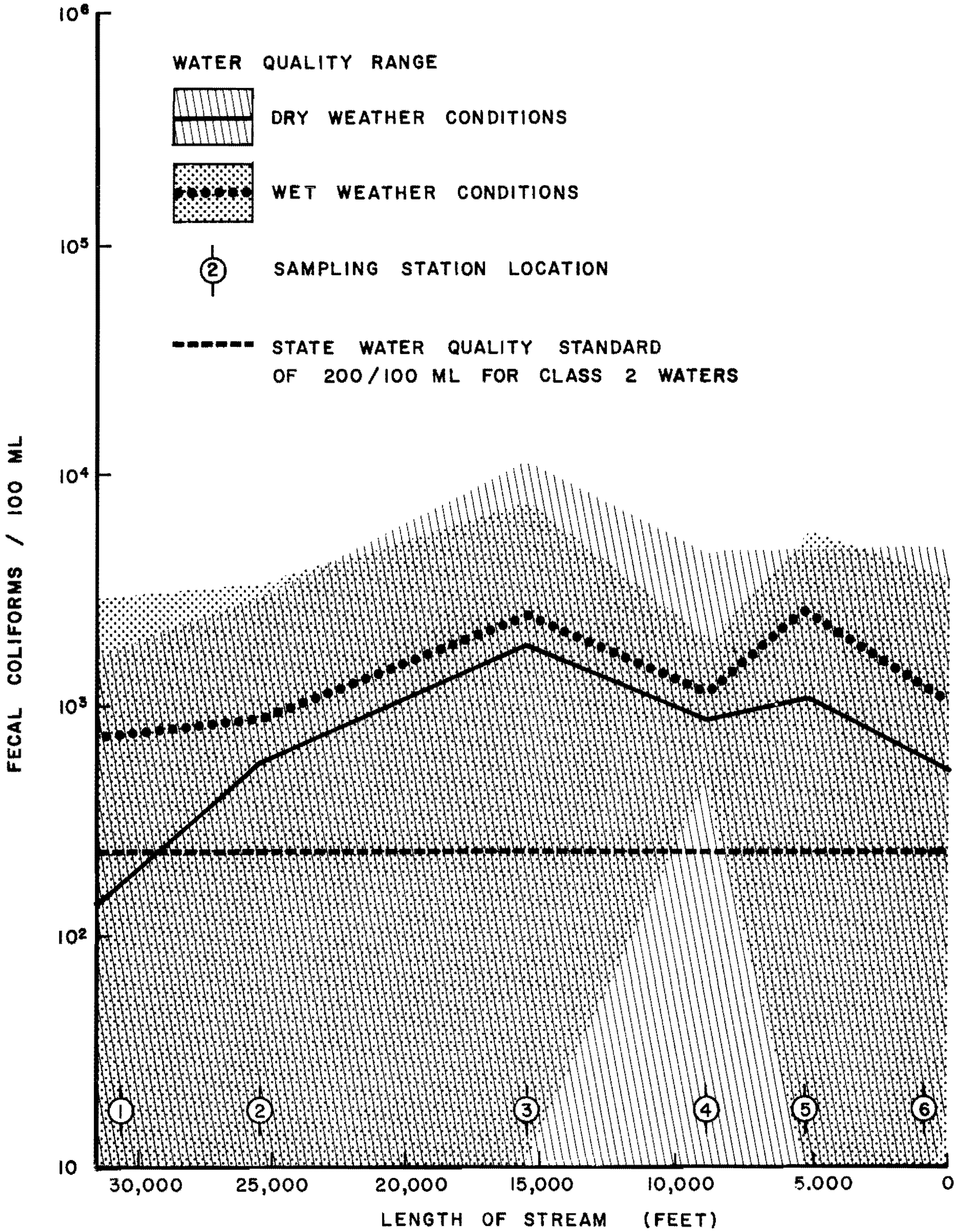

FIGURE 2.3. RANGE IN FECAL COLIFORM COUNT OBSERVED IN MANOA STREAM, 1970-71.

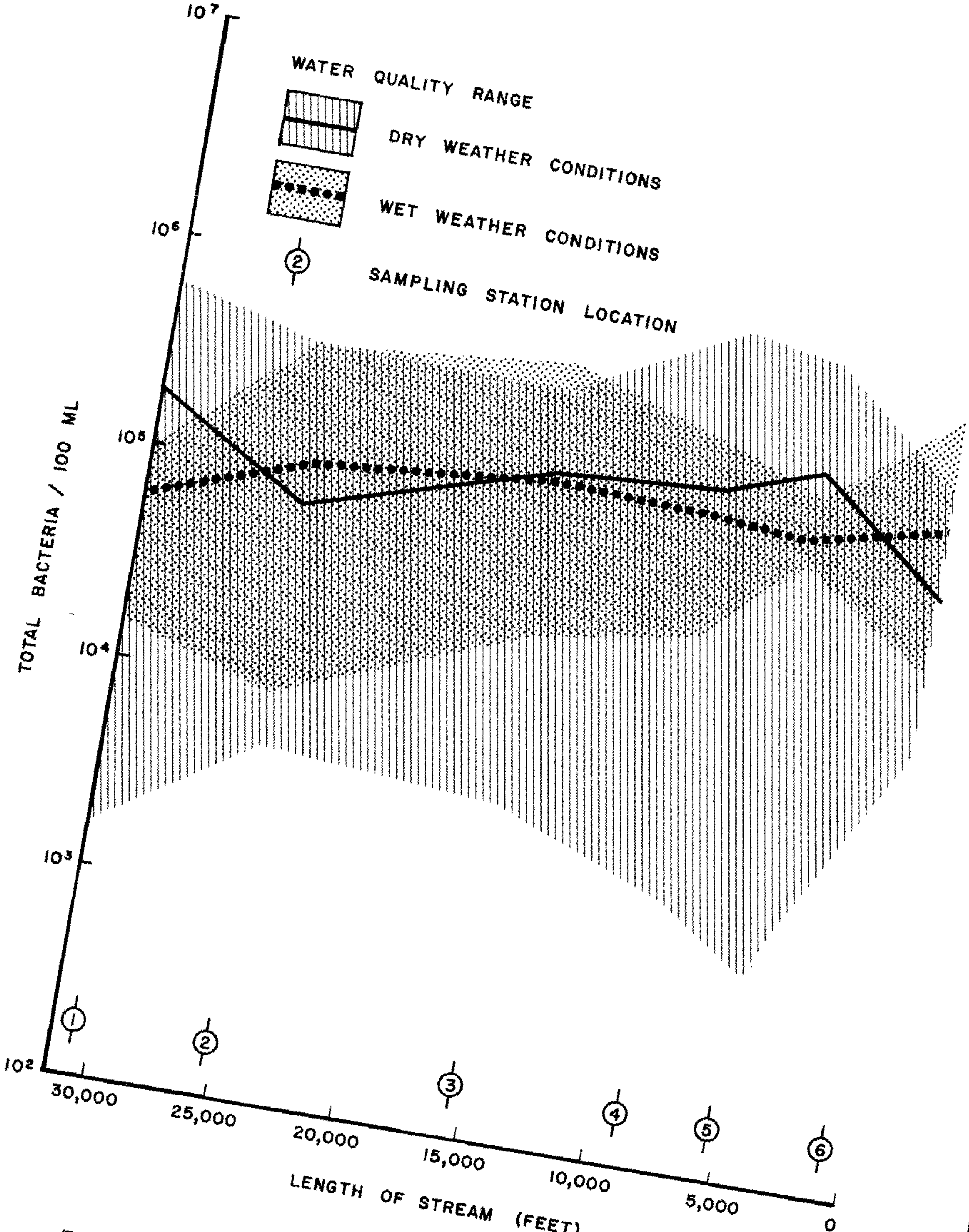

FIGURE 2.4. RANGE IN TOTAL BACTERIA COUNT OBSERVED IN MANOA STREAM, 1970-71.

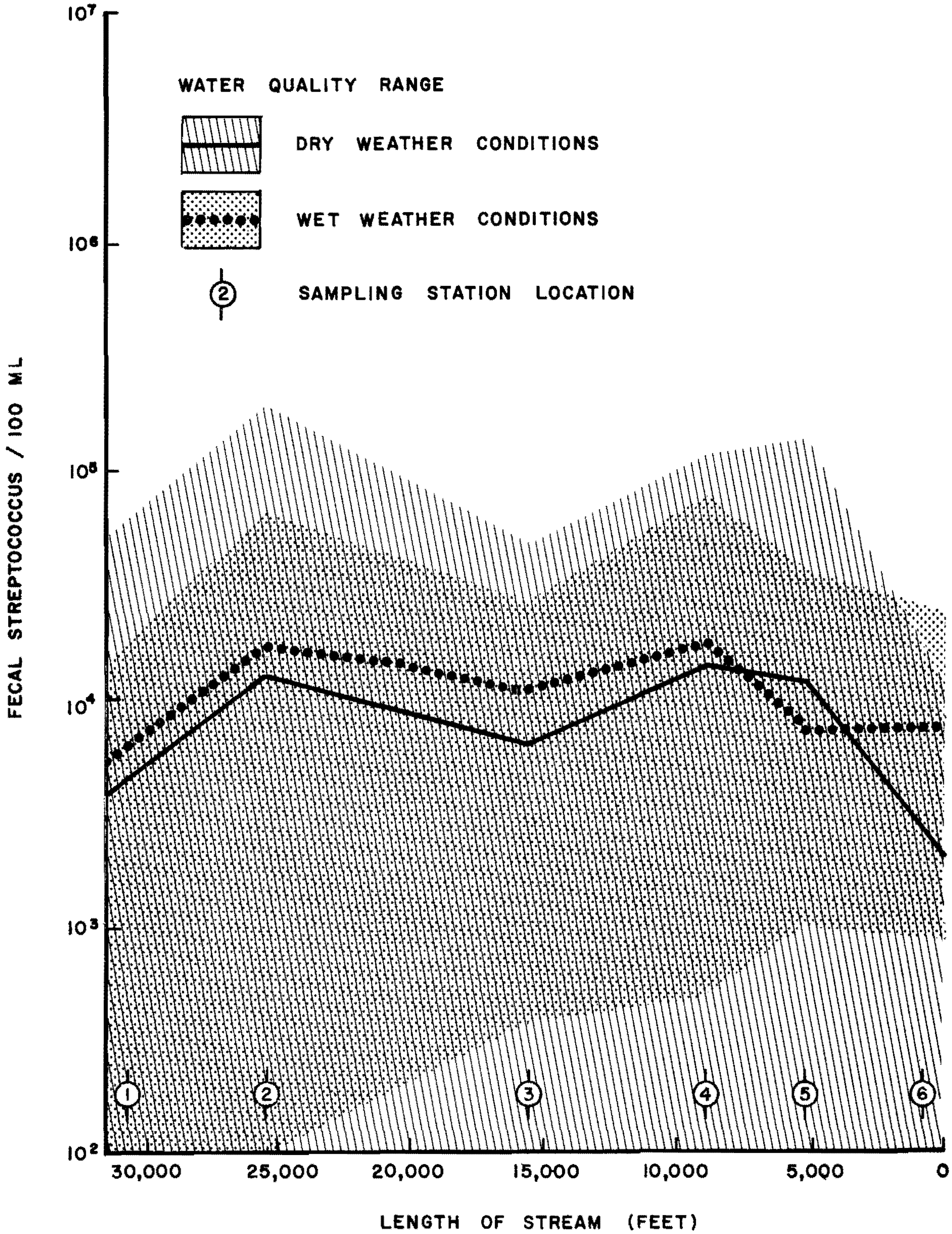

FIGURE 2.5. RANGE IN FECAL STREPTOCOCCUS COUNT OBSERVED IN MANOA STREAM, 1970-71.

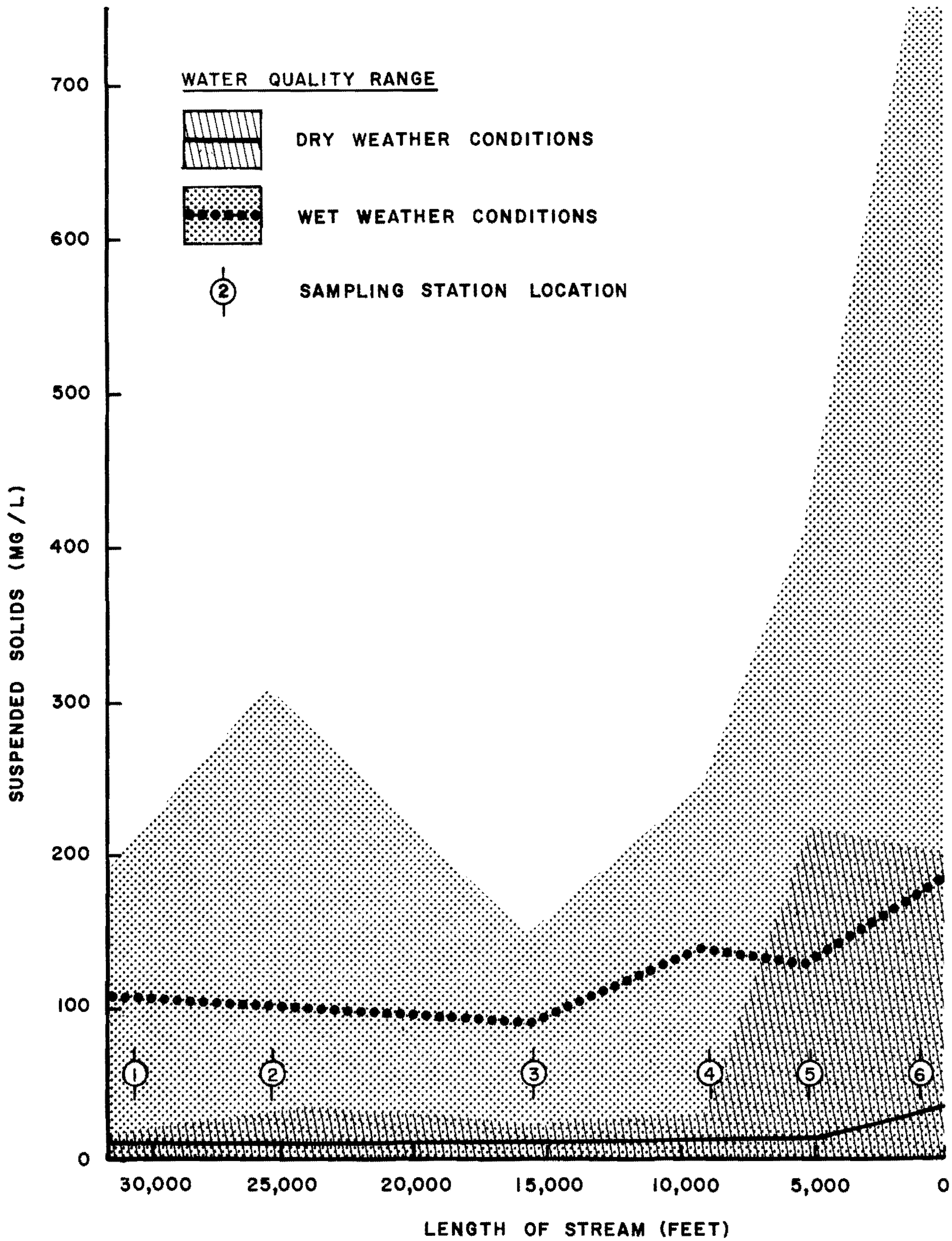

FIGURE 2.6. RANGE IN SUSPENDED SOLIDS CONCENTRATION OBSERVED IN MANOA STREAM, 1970-71.

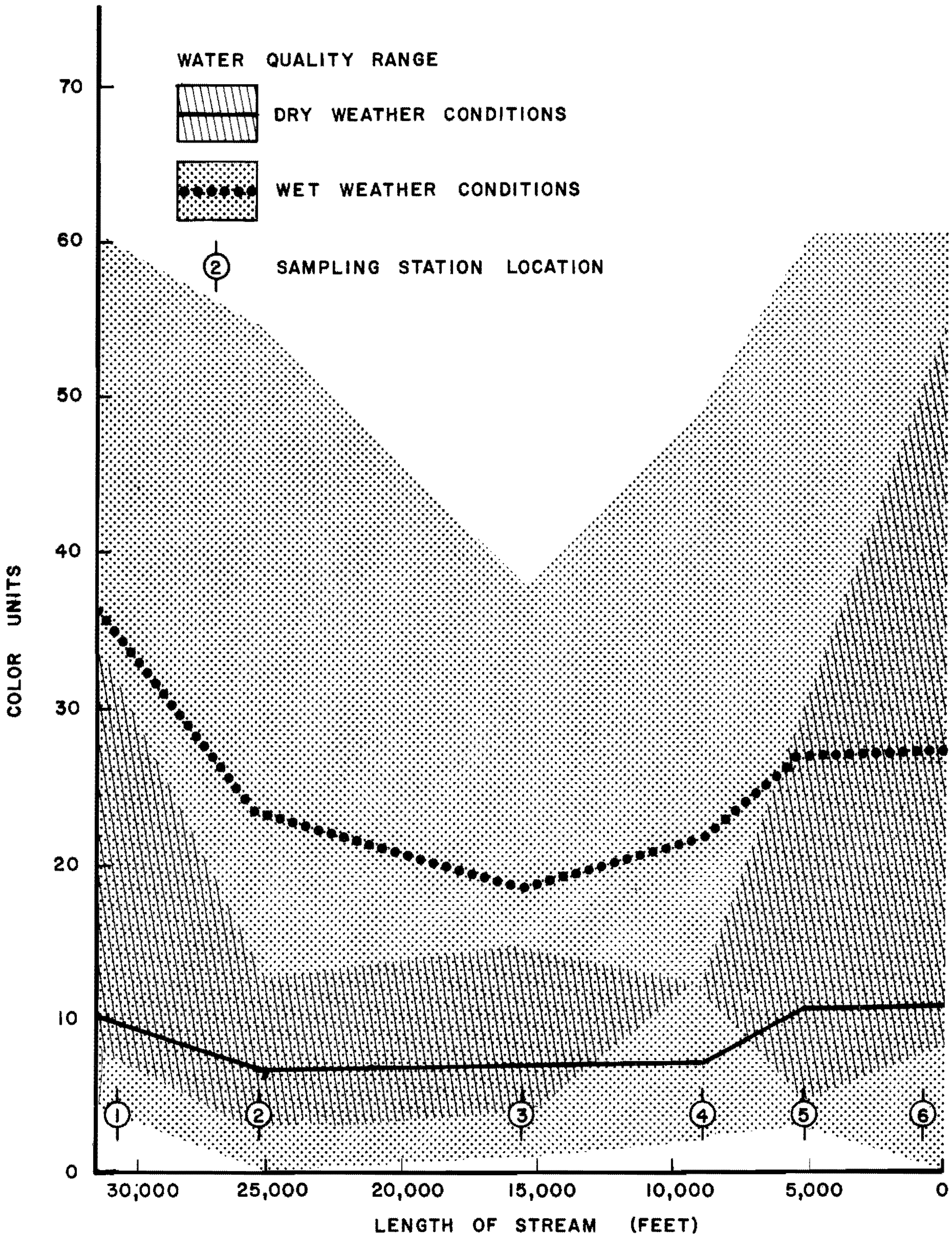

FIGURE 2.7. RANGE IN COLOR UNITS OBSERVED IN MANOA STREAM, 1970-71.

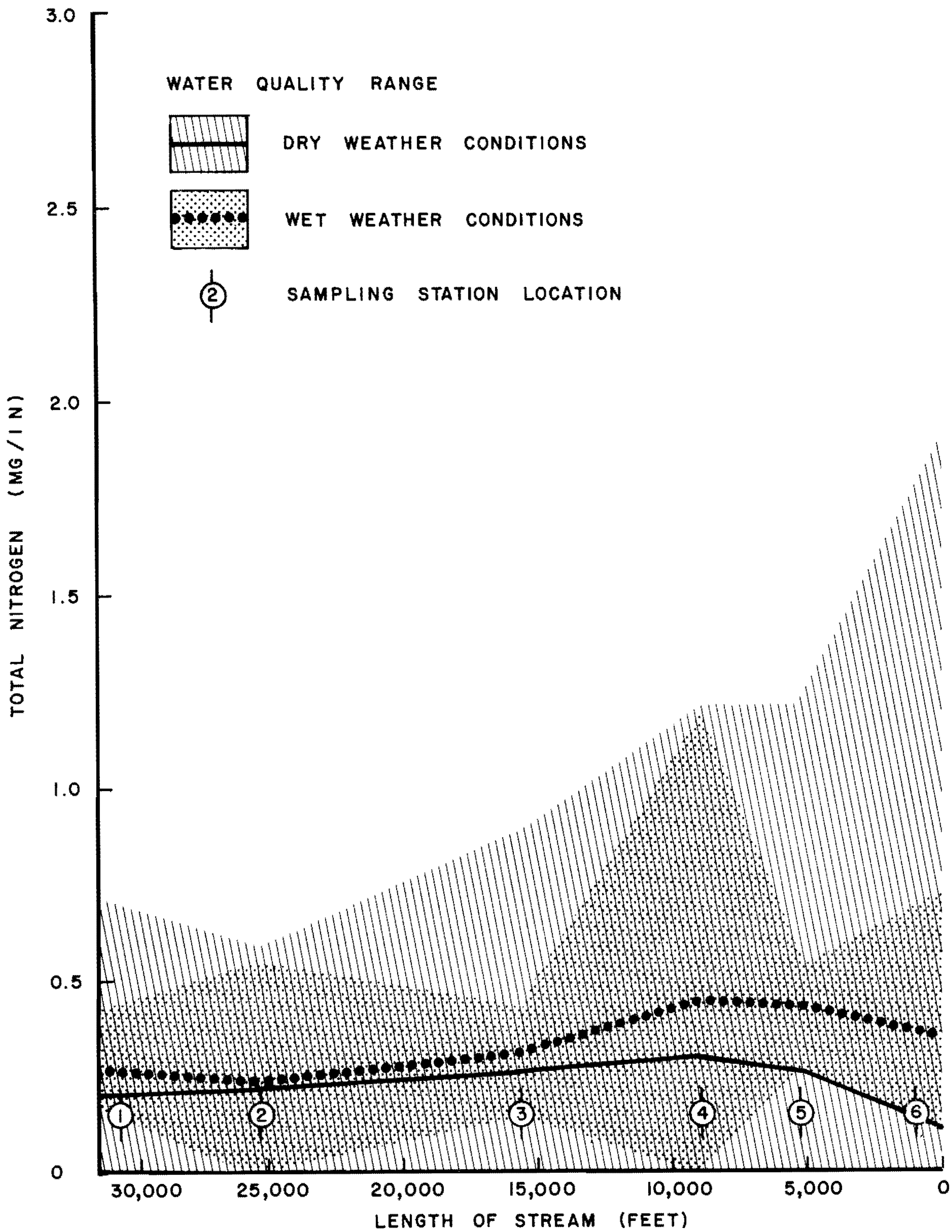

FIGURE 2.8. RANGE IN TOTAL NITROGEN CONCENTRATION OBSERVED IN MANOA STREAM, 1970-71.

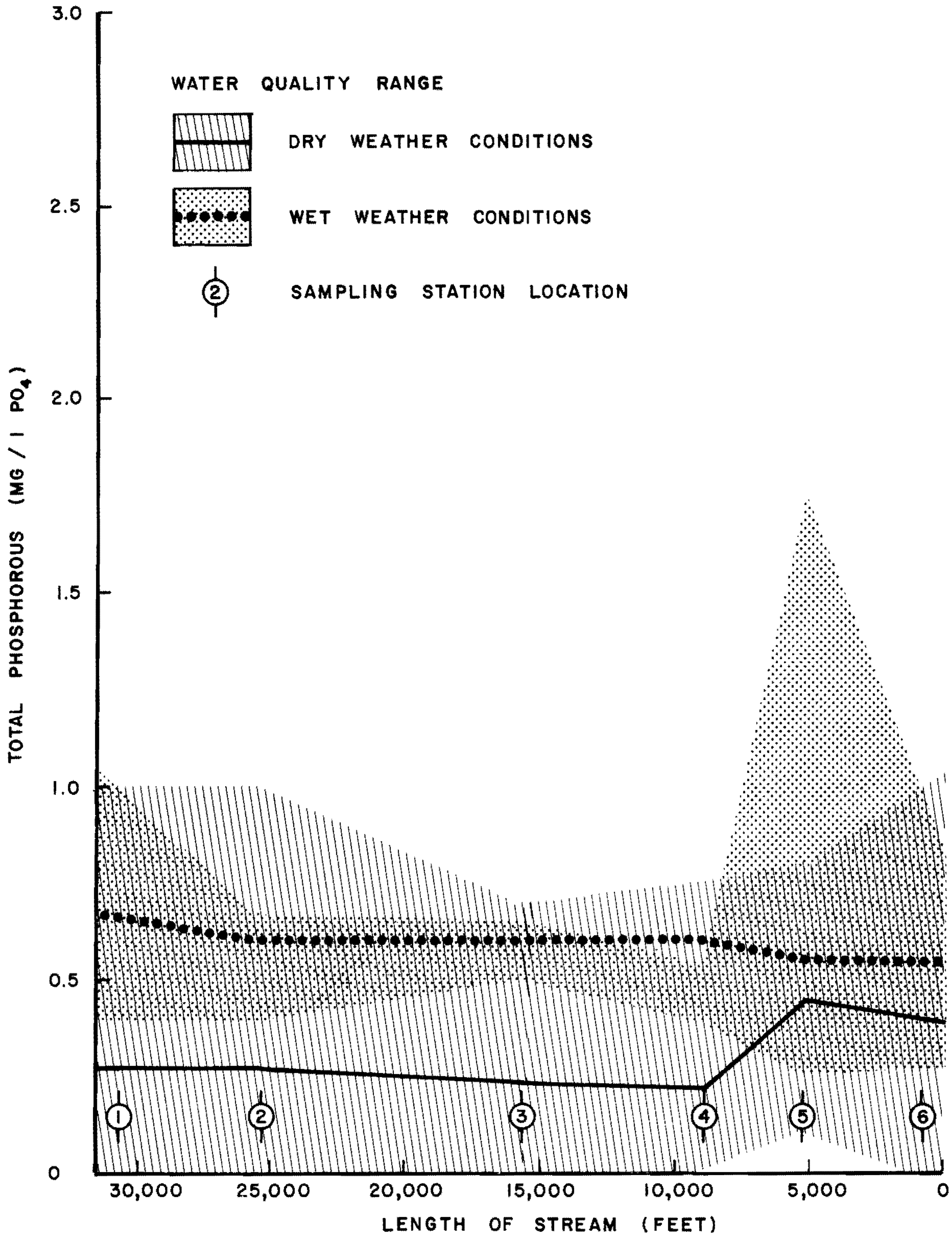

FIGURE 2.9. RANGE IN TOTAL PHOSPHORUS CONCENTRATION OBSERVED IN MANOA STREAM, 1970-71.

mean of each parameter during wet weather flow which was related to the concentration of a given parameter with increased runoff from urban areas. The level of concentration of some parameters increased as much as tenfold.

Initially, a quantitative study of the pollutional character of stream runoff was planned. However, stream discharge at each station could not be accurately determined by application of either the rational formula or any other technique owing to insufficient data on rainfall distribution, intensity, and duration. It would be necessary to establish a stream gauge at each sampling site on the stream if accurate data is to be obtained.

Manoa Stream was investigated under a wide range of climatic conditions. A comparison of its water quality with the water quality requirements for various uses (Table 2.4) shows that the existing stream quality makes the waters suitable, at best, for wildlife propagation, conservation and esthetics, and recreation, if the high coliform populations were reduced.

TABLE 2.4. FRESH WATER QUALITY LIMITS FOR VARIOUS USES.

PARAMETER	MANOA STREAM	USPHS DRINKING WATER STANDARDS[1]	HAWAII FRESH WATER STANDARDS CLASS 1[2]	HAWAII FRESH WATER STANDARDS CLASS 2[2]	DOMESTIC WATER SUPPLY PERMEABLE[3]	WILDLIFE PROPAGATION MAXIMUM[4]	RECREATION & BATHING MAXIMUM[4]	FOOD PROCESS MAXIMUM[4]	INDUSTRIAL COOLING, ETC. MAXIMUM[4]	AGRICULTURAL IRRIGATION MAXIMUM[4]
TOTAL COLIFORM, PER 100 ML	18,000	0	1,000	1,000	10,000	10,000	100	100	1,000	1,000
FECAL COLIFORM, PER 100 ML	890	0	20	200	2,000					
pH	7.3			6.5-8.5	6.0-8.5	6.5-8.5	6.5-8.5	6.0-9.0	4.0-10.0	6.0-9.0
TEMPERATURE, °F	22				85± OR ±5 VAR	65	65			
COLOR, STANDARD UNIT	9	15	OBJECTIONABLE	OBJECTIONABLE	75	10	30	30		
TURBIDITY, JCU	10	5	OBJECTIONABLE	OBJECTIONABLE	NO VARIATION	10	20	20		
DISSOLVED OXYGEN, MG/L	7.9	1		NLT 5.0	NLT 3	NLT 3	NLT 2	NLT 1	NLT 1	
SUSPENDED SOLIDS, MG/L	12					20	100	50	150	
CHLORIDES, MG/L	115	250			250	2,500		1,000		750
NITRATES, MG/L	1.18	45			45					
TOTAL SOLIDS MG/L	112					5,000		1,500	1,500	1,500
TOTAL PHOSPHOROUS, MG/L	0.31				0.1					

[1] U.S. PUBLIC HEALTH SERVICE DRINKING WATER STANDARDS, 1962. EXTRACTED FROM CAMP (1962).
[2] WATER QUALITY STANDARDS, CHAPTER 37-A, PUBLIC HEALTH REGULATIONS, STATE OF HAWAII (1968).
[3] WATER QUALITY CRITERIA, FEDERAL WATER POLLUTION CONTROL ADMINISTRATION (1968).
[4] THE WATER ENCYCLOPEDIA, WATER INFORMATION CENTER (1970).

If treatment were provided to reduce bacteria, color, turbidity, and suspended solids, the stream can be a potential domestic water source (especially as a standby or augmentation source). However, any treatment facility must consider rainfall frequency and low dry weather flow and the fact that during approximately 15 percent of the time there are high pollutant levels in the stream.

CHAPTER 3

STREET SWEEPINGS

DESCRIPTION OF THE STUDY SITE

King and Maunakea Streets in downtown Honolulu and Kuhio Avenue in metropolitan Honolulu were selected as prototypes of typical city streets in Honolulu where a variety of business activities are conducted (Table 3.1). Kuhio Avenue, in the Waikiki area, was thought to yield data that would be different from that of downtown Honolulu where the relatively clean King Street (a major arterial) and Maunakea Street (a service street) were located.

TABLE 3.1. CHARACTERISTICS OF TEST AREAS IN STREET SWEEPINGS INVESTIGATION.

STREET & LOCATION	PROPERTY FRONTAGE	COMMENTS
KUHIO AVENUE (2260 - 2270)	RESTAURANT TWO APT. BLDGS. DRIVEWAY	INCLUDES 1 PARKING STALL-50% OCCUPANCY
KING STREET (102 - 118)	OFFICES DRY GOOD SHOP MUSIC SHOP	INCLUDES 2 PARKING STALLS-75% OCCUPANCY
MAUNAKEA STREET	OFFICE TAILOR SHOP CLEANERS-LAUNDRY APTS. 1ST FLOOR	INCLUDES 1 PARKING STALL-90% OCCUPANCY

METHODOLOGY

To assess the pollution potential of urban stormwater, sweepings from selected street sites were characterized using as a guide "Water Pollution Aspects of Urban Runoff", hereafter referred to as the Chicago Study (1969).

An attempt was made to have street sweeping crews of the City and County of Honolulu Refuse Division collect the street refuse for analysis, but this procedure was not adhered to since the workers have large areas to cover each day and consequently pick up only large refuse. Most of the dirt, which in urban runoff studies is usually assumed to contribute toward the pollution load, is left in the street and not removed until the street is washed down either by rain or street cleaning crews. No attempt was made to clean under parked cars and the actual area cleaned each day varied.

Daily samples were collected for a one-week period from three sites on Kuhio Avenue, King Street, and Maunakea Street between midnight and 1:30 a.m., just before the arrival of the City's mechanical sweeping machine. Each sampling area consisted of 100 feet along the length of the curb and 8 feet of the street pavement measured from the curb (the mechanical sweepers are approximately 8 feet wide). The areas selected were fronted by businesses that did not wash the sidewalks. The samples were collected and transported in large plastic bags.

Each sample was air dried for one day if it was slightly damp or at 103° C if wet by rain and screened through a 1/8-inch mesh screen. The materials which remained were segregated and weighed. The material that passed through the screen was the "dust and dirt" fraction which was analyzed for: BOD_5, COD, total bacterial plate count, total coliforms, fecal streptococci, volatile water soluble matter, nitrate-nitrogen, phosphates, and chloride.

The "dust and dirt" fraction was further crushed and screened through a 40-mesh screen prior to laboratory analysis. The procedures for some of the tests differed slightly from those in the Chicago Study. In the BOD and COD tests, weighted quantities of pulverized and screened samples were added directly into the test flasks. This procedure was used because the large, dense particles settled rapidly and made pipetting of a representative sample difficult. For the bacteriological analyses, the dirt and water were not blended but simply shaken together in sterile dilution bottles. The remainder of the analyses were conducted as in the Chicago Study.

RESULTS AND DISCUSSION

As shown in Table 3.2 and Figure 3.1, King Street had the least amount of street refuse, followed by Maunakea Street and Kuhio Avenue. The quantities of refuse were lower than those found for business areas in the Chicago Study, which is summarized in Table 3.3. With the exception of Area 2 in the Chicago Study and King Street in the present study, the amounts of "dust and dirt" agree favorably.

The "dust and dirt" fractions for the three streets in Honolulu contained more water soluble and volatile water soluble material than did similar fractions for the Chicago Study areas (Tables 3.4 through 3.7). The

TABLE 3.2. RESULTS OF STREET LITTER COMPONENT CHARACTERIZATION FOR SAMPLES COLLECTED 4/11/71 - 4/18/71.

COMPONENT	KUHIO PERCENT	KUHIO LBS. PER 100 FEET	KING PERCENT	KING LBS. PER 100 FEET	MAUNAKEA PERCENT	MAUNAKEA LBS. PER 100 FEET
DIRT	72.4	3.58	62.6	0.76	58.6	1.64
ROCK	9.6	0.47	13.2	0.16	11.2	0.33
PAPER	6.6	0.33	4.1	0.05	17.2	0.48
VEGETATION	3.2	0.16	6.6	0.08	0.9	0.02
FOOD	0.7	0.03	2.6	0.03	5.5	0.15
METAL	2.8	0.14	4.3	0.05	4.3	0.12
GLASS	1.3	0.06	1.5	0.02	0.5	0.01
PLASTIC	0.8	0.04	3.4	0.04	1.0	0.03
WOOD	1.2	0.06	1.7	0.02	0.6	0.01
CLOTH	1.4	0.07	0	0	0.2	0.01
TOTAL	100.0	4.94	100.0	1.21	100.0	2.80

phosphate values were higher for Honolulu, but the nitrate values were considerably lower than those for Chicago. The phosphate value could have been influenced somewhat by a laundromat on Maunakea Street from which phosphate-based detergents could have been swept out into the street.

TABLE 3.3. SUMMARY OF STREET LITTER ANALYSES FOR CHICAGO STUDY (1969).

LITTER	BUSINESS AREA 1	BUSINESS AREA 2	BUSINESS AREA 3
TOTAL REFUSE, LBS/DAY/100 FT	4.15	8.05	3.81
DUST AND DIRT, LBS/DAY/100 FT	2.53	6.19	1.35
WATER SOLUBLES, MG/G	9.98	8.47	19.07
VOLATILE WATER SOLUBLES, MG/G	5.25	4.79	10.78
PO_4, MG/G	0.038	0.027	0.142
BOD_5, MG/G	5.05	4.03	14.54
COD, MG/G	26.7	24.8	66.7
TOTAL COLIFORM, MPN/G	3,456,822	576,170	1,022,633

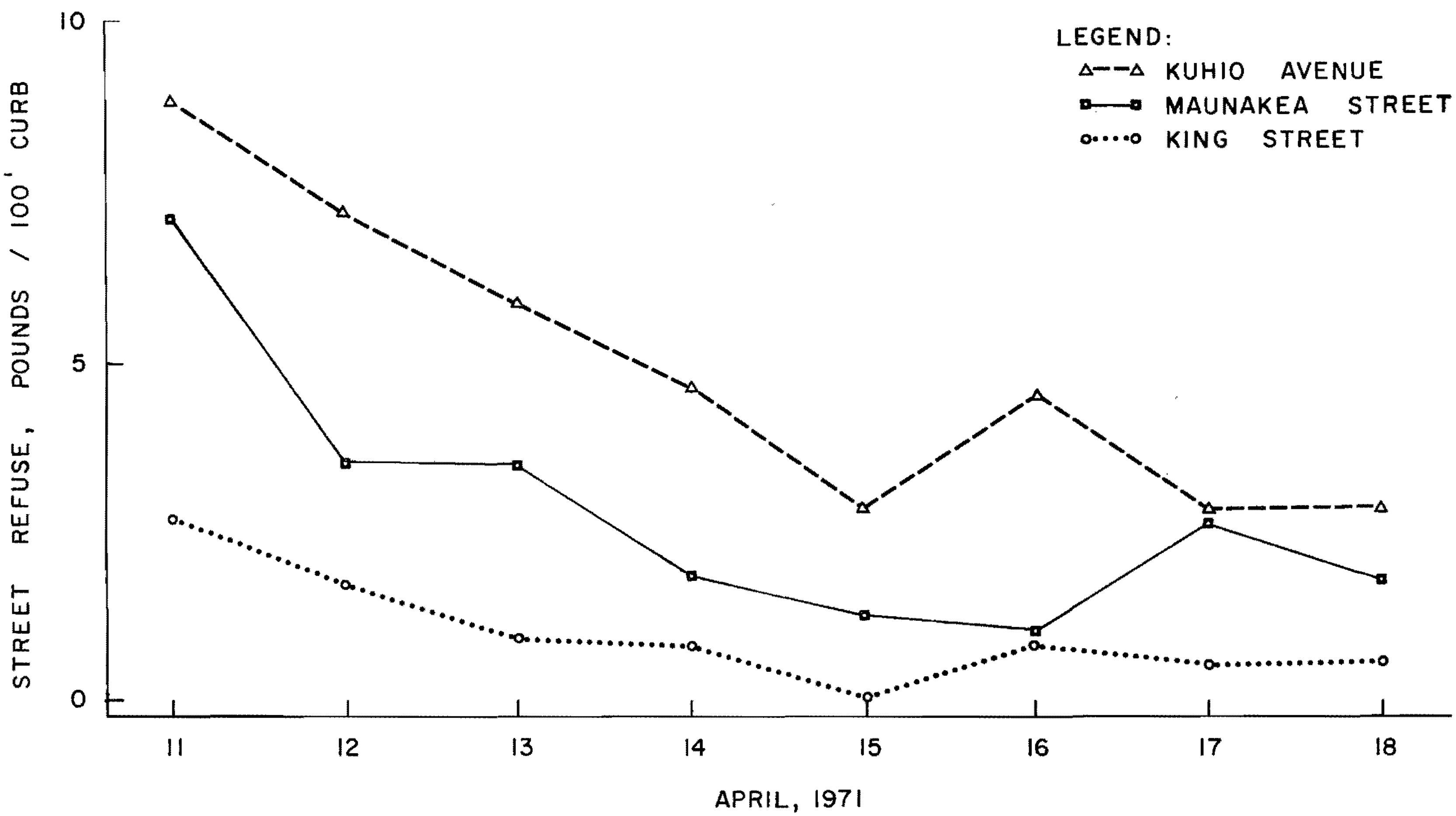

FIGURE 3.1. DAILY AMOUNTS OF STREET REFUSE PER 100 FEET OF CURB.

The BOD_5 values were higher for Honolulu, but the COD values were lower than those reported in the Chicago Study. Maunakea Street had the highest organic content of the three Honolulu study areas, as indicated by the volatile water soluble solids, and the highest BOD_5. In the present study, the BOD:COD ratios were about 0.5 while the Chicago Study reported a ratio of 0.2.

TABLE 3.4. CHEMICAL ANALYSES OF DIRT AND DUST FRACTION OF STREET REFUSE FROM KUHIO AVENUE.

DATE	SOLIDS, H_2O SOLUBLE MG/G	SOLIDS, VOLATILE H_2O SOLUBLE MG/G	PO_4 MG/G	NO_3 MG/G	BOD_5 MG/G	COD MG/G	Cl^- MG/G
4/11/71	24.0	6.0	0.138	0.054	9.9	23.4	1.4
4/12/71	15.4	5.2	0.068	0.035	7.5	21.7	1.6
4/13/71	28.0	11.6	0.121	0.058	12.9	25.2	2.0
4/14/71	23.8	3.0	0.067	0.042	10.2	26.2	1.8
4/15/71	18.8	7.6	0.104	0.054	10.2	24.2	2.6
4/16/71	28.4	10.6	0.081	0.038	9.3	23.6	3.2
4/17/71	35.4	18.6	0.130	0.067	14.1	27.7	2.6
4/18/71	28.0	11.8	0.072	0.019	9.3	28.1	2.2
AVERAGE	25.2	9.3	0.098	0.046	10.4	25.0	2.2

TABLE 3.5. CHEMICAL ANALYSES OF DIRT AND DUST FRACTION OF STREET REFUSE FROM KING STREET.

DATE	SOLIDS, H_2O SOLUBLE MG/G	SOLIDS, VOLATILE H_2O SOLUBLE MG/G	PO_4 MG/G	NO_3 MG/G	BOD_5 MG/G	COD MG/G	Cl^- MG/G
4/11/71	26.6	5.8	0.017	0.032	10.5	25.9	1.8
4/12/71	21.6	9.8	0.033	0.029	13.2	25.9	3.0
4/13/71	21.2	4.0	0.056	0.054	12.9	25.2	1.8
4/14/71	23.4	5.6	0.035	0.045	17.7	34.5	4.0
4/15/71							
4/16/71	19.6	9.2	0.077	0.042	16.2	25.8	2.2
4/17/71	23.4	3.4	0.088	0.074	11.7	29.1	4.0
4/18/71	18.0	7.6	0.039	0.038	6.8	23.7	2.2
AVERAGE	22.0	6.5	0.049	0.045	12.7	27.2	2.7

TABLE 3.6. CHEMICAL ANALYSES OF DIRT AND DUST FRACTION OF STREET REFUSE FROM MAUNAKEA STREET.

DATE	SOLIDS, H_2O SOLUBLE MG/G	SOLIDS, VOLATILE H_2O SOLUBLE MG/G	PO_4 MG/G	NO_3 MG/G	BOD_5 MG/G	COD MG/G	Cl^- MG/G
4/11/71	23.2	8.8	0.200	0.032	17.0	31.9	1.6
4/12/71	17.2	7.0	0.141	0.032	18.5	21.7	1.6
4/13/71	31.4	19.2	0.234	0.074	32.1	31.1	2.0
4/14/71	24.8	9.4	0.200	0.067	16.5	34.5	2.4
4/15/71							
4/16/71	28.6	15.6	0.199	0.042	18.9	32.2	2.4
4/17/71	21.0	11.2	0.177	0.054	19.2	31.8	2.6
4/18/71	22.6	18.6	0.195	0.035	16.8	32.5	2.0
AVERAGE	24.1	12.8	0.192	0.048	19.8	30.8	2.1

TABLE 3.7. PRELIMINARY CHEMICAL ANALYSES OF DIRT AND DUST FRACTION OF STREET REFUSE FROM MAUNAKEA, RIVER, AND OHUA STREETS.

STREET	DATE	SOLIDS, H_2O SOLUBLE MG/G	SOLIDS, VOLATILE H_2O SOLUBLE MG/G	PO_4 MG/G	NO_3 MG/G	BOD_5 MG/G	COD MG/G	Cl^- MG/G
MAUNAKEA	3/10/71	22.0	8.8	0.191	0.029	15.6	35.2	2.0
	3/10/71	17.2	5.4	0.275	0.038	17.7	29.8	1.8
RIVER	3/10/71	16.8	9.2	0.049	0.010	13.8	32.5	1.8
	3/14/71	21.6	7.2	0.122	0.051	7.1	22.5	3.2
OHUA	3/14/71	18.0	5.4	0.037	0.054	3.1	15.9	0.6

Bacterial population is probably determined by the amount of refuse rather than by the type and usage of a street. However, further investigation is required to obtain more information before definitive correlations can be made. There was no definite trend in results (Table 3.8) with time, but the absolute populations remained fairly constant throughout the study period. The greatest fluctuation occurred in the numbers of fecal coliform where most of the values obtained were near or at zero. The origin of these organisms could not be readily determined.

The variation in the quantity of refuse with time, shown in Figure 3.1 indicates that approximately three days were required to reach a "steady state" although it was anticipated that only the first day values would be

TABLE 3.8. BACTERIOLOGICAL ANALYSES OF DIRT AND DUST FRACTION OF STREET REFUSE FOR KING, KUHIO, AND MAUNAKEA STREETS.

STREET	DATE	TOTAL BACTERIA x 10^3/100 MG	TOTAL COLIFORM x 10^3/100 MG	FECAL COLIFORM x 10^3/100 MG
KING	4/10/71	900	38	0
	4/11/71	1,670	10	0
	4/12/71	880	1	0.2
	4/13/71	2,900	20	0
	4/14/71	5,000	340	0
	4/16/71	TNTC	TNTC	0
	4/17/71	15,400	610	0
	4/18/71		0	200
KUHIO	4/11/71	TNTC	200	0
	4/12/71	35,000	10	0
	4/13/71	12,700	100	70
	4/14/71	2,030	220	0
	4/15/71	TNTC	3,600	0
	4/16/71	5,000	0	0
	4/17/71	8,200	30	30
MAUNAKEA	3/10/71	10,000	650	660
	3/10/71	TNTC	TNTC	TNTC
	4/10/71	38	0	0
	4/11/71	25,000	800	60
	4/12/71	6,500	24	0
	4/13/71	910	50	70
	4/14/71	5,100	530	700
	4/16/71		0	0
	4/17/71		100	10
	4/18/71	9,000	1,700	TNTC

high. After the first day, the daily accumulation of street refuse was expected to be constant, and that subsequent sampling would demonstrate this uniformity. However, the data obtained indicated a decrease in daily accumulation over the first four days of sampling. In all probability the daily accumulation was constant, but owing to the cleaning technique, it took several days to remove the "old" material. After four days, during which time an apparent decreasing daily accumulation was reflected, the "old" material was completely removed and in subsequent sweepings only "new" material was collected. The change can be seen in the near constant levels of the daily collection over the last four days of the study.

Tables 3.9 through 3.12 give the percentages of the components found in the sweepings which are summarized in Table 3.13. The largest single component was dirt. Dirt, rock, paper, and vegetation made up more than 90 percent of the total quantity of material collected. The resulting impact of this after any rainfall would be a high level of suspended solids in the runoff, particularly in the initial period of runoff.

This preliminary study on street refuse indicates the potential of the urban runoff as a contributor to the pollution of receiving waters particularly through contributions of suspended solids and bacterial contamination. However, much more research needs to be conducted, with emphasis on a more complete identification and quantification of pollutants. Some quantification in terms of weight of refuse collected per 100 feet of curb length is provided in Table 3.13 but more data is needed to validate that information and to allow extrapolation for a large area.

TABLE 3.9. PERCENTAGE COMPOSITION OF STREET LITTER, KUHIO AVENUE, 4/11/71 - 4/18/71.

COMPONENT	4/11	4/12	4/13	4/14	4/15	4/16	4/17	4/18	AVER.[1]
DIRT	81.0	77.9	59.3	81.0	75.3	66.0	66.9	71.6	72.4
ROCK	7.2	10.0	5.5	5.8	5.6	17.7	6.4	18.9	9.6
PAPER	4.8	5.0	6.0	6.9	7.7	5.0	13.0	4.4	6.6
VEGETATION	2.7	1.7	3.4	3.7	3.8	2.2	4.2	4.4	3.2
FOOD	1.2	0.7	0.3	0.8	0.4	0.1	2.0	0.1	0.7
METAL	0.5	2.5	5.9	0.7	5.0	1.7	6.4	0	2.8
GLASS	0.2	0.2	8.0	0.2	0.5	0.2	0.2	0.2	1.3
PLASTIC	1.9	1.6	0.8	0.4	0.8	0.3	0.5	0.2	0.8
WOOD	0.4	0.2	1.0	0.5	0.7	6.6	0	0.1	1.2
CLOTH	0.1	0.2	9.8	0	0.2	0.2	0.4	0.1	1.4
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1] AVERAGE EXCLUDES DATA ON 4/15 DUE TO RAIN.

TABLE 3.10. PERCENTAGE COMPOSITION OF STREET LITTER, KING STREET, 4/11/71 TO 4/18/71.

COMPONENT	4/11	4/12	4/13	4/14	4/15	4/16	4/17	4/18	AVER.[1]
DIRT	73.8	52.3	38.8	70.6	22.5	74.8	62.2	66.0	62.6
ROCK	15.0	9.0	9.1	8.1	19.9	12.8	14.8	23.4	13.2
PAPER	2.4	1.7	2.1	4.0	30.8	6.1	5.2	7.0	4.1
VEGETATION	0.8	28.6	13.2	0.5	5.2	1.3	0.5	1.3	6.6
FOOD	1.2	3.4	1.9	4.0	2.3	3.0	4.1	0.8	2.6
METAL	1.2	1.1	26.1	0.7	9.9	0.1	0.5	0	4.3
GLASS	3.8	1.2	1.5	0.3	0	0.6	2.4	0.6	1.5
PLASTIC	1.2	1.5	0.2	11.0	0	0	9.1	0.7	3.4
WOOD	0.6	1.2	7.1	0.8	7.4	1.2	1.2	0.1	1.7
CLOTH	0	0	0	0	2.0	0.1	0	0.1	0
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1] AVERAGE EXCLUDES DATA ON 4/15 DUE TO RAIN.

TABLE 3.11. PERCENTAGE COMPOSITION OF STREET LITTER, MAUNAKEA STREET, 4/11/71 TO 4/18/71.

COMPONENT	4/11	4/12	4/13	4/14	4/15	4/16	4/17	4/18	AVER.[1]
DIRT	62.2	76.3	35.9	66.7	8.6	42.6	65.5	61.0	58.6
ROCK	4.5	9.2	30.5	9.3	33.9	7.5	9.6	7.5	11.2
PAPER	14.8	8.8	11.6	10.8	49.8	40.6	16.4	17.1	17.2
VEGETATION	0.4	0.4	0.5	1.4	0.9	1.8	1.1	0.8	0.9
FOOD	12.6	1.9	9.1	2.2	3.6	4.2	4.5	4.3	5.5
METAL	3.5	1.4	8.0	7.6	0.3	1.0	1.3	7.4	4.3
GLASS	0.5	1.5	0.5	0.3	0.4	0.3	0.6	0.1	0.5
PLASTIC	0.4	0.2	3.5	0.7	1.3	0.8	0.4	0.7	1.0
WOOD	0.4	0.2	0.4	0.9	0.7	1.0	0.5	1.1	0.6
CLOTH	0.7	0.1	0	0.1	0	0.2	0.1	0	0.2
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1] AVERAGE EXCLUDES DATA ON 4/15 DUE TO RAIN.

TABLE 3.12. PERCENTAGE COMPOSITION OF STREET LITTER, PRELIMINARY STUDIES.

COMPOSITION	MAUNAKEA ST.[1] 3/10/71	MAUNAKEA ST.[2] 3/10/71	RIVER ST.[3] 3/10/71	RIVER ST.[4] 3/10/71	OHUA ST. 3/14/71
DIRT	8.0	14.5	20.7	53.4	82.6
ROCK	31.4	23.7	37.7	27.0	15.3
PAPER	32.4	19.1	24.2	5.4	0.4
VEGETATION	1.3	0.6	7.3	10.9	0.6
FOOD	4.9	3.0	1.0	0.2	0
METAL	9.6	7.8	4.7	1.6	0.1
GLASS	10.5	26.3	0.6	0.5	0.8
PLASTICS	1.5	1.9	2.3	0.3	0.2
WOOD	0.3	1.0	1.4	0.6	0
CLOTH	0.1	2.1	0.1	0.1	0
TOTAL	100.0	100.0	100.0	100.0	100.0

[1] EASTERN CURB, BERETANIA TO NIMITZ.

[2] WESTERN CURB, BERETANIA TO NIMITZ.

[3] BOTH SIDES OF STREET, BERETANIA TO NIMITZ.

[4] 210 FEET OF CURB.

TABLE 3.13. WEIGHT OF STREET SWEEPINGS PER 100 FEET CURB.

DATE 1971	KUHIO	KING	MAUNAKEA	RIVER	OHUA
3/10	--	--	0.71	0.43	--
3/14	--	--	--	16	51
4/11	8.79	2.71	5.22	--	--
4/12	7.18	1.73	3.52	--	--
4/13	5.85	0.98	3.52	--	--
4/14	4.62	0.89	1.86	--	--
4/15	2.90	0.06	1.31	--	--
4/16	4.54	0.84	1.03	--	--
4/17	2.82	0.62	2.65	--	--
4/18	2.82	0.69	1.81	--	--

A critical item is the determination of the amount of material that is actually washed off the road surface and into the storm drain. The present study was concerned with the collection and characterization of *all* street refuse. However, under normal conditions, some components of the refuse are removed mechanically and some become attached to the road surface. Varying levels of energy, principally supplied by flowing water, are required to loosen the materials. Surface runoff is largely dependent on precipitation, which varies in intensity and duration, thus not all of the material identified by the present study reaches the storm drains. That portion which does must be more definitively determined and characterized.

During this study, it was found that sorting of the refuse was time consuming and difficult. A standard method of sorting is suggested here based on the experience gained during the present study:

A. Place sweepings on 1/8-inch mesh screen.

B. Sort large, easily segregated material such as paper, cigarette butts, leaves, rocks, bottles, cans, etc.

C. Sift the remaining material to remove the dust and dirt fraction.

D. Weigh the material remaining on the screen.

E. Take a representative sample of this material from the screen and sort into component categories.

F. Calculate the percentages of each component and compute each amount.

G. Add these weights to those obtained in Step B.

The width of the area swept must include the center of the street to obtain a more complete estimate of pollution potential. Arrangements should be made with City or State maintenance personnel so that sampling areas are swept only by the research crew.

CHAPTER 4

WASTEWATER RECLAMATION USING REVERSE OSMOSIS

BACKGROUND

Wastewater renovation can be achieved by supplementing or replacing conventional wastewater treatment techniques with advanced processes that may effect a high degree of removal of undesirable contaminants including nutrients, dissolved mineral salts, oxygen-demanding organics and undesirable bacteria or viruses. These advanced processes are usually accomplished by use of a series of unit processes, each designed to selectively remove a particular fraction of the waste load or a specific contaminant. This process series approach could be enhanced through the development and utilization of a process that could exhibit or produce the same desired result as application of a number of unit processes. The single process that appears to have the potential of effectively reducing both mineral and organic refractory materials and biological organisms is reverse osmosis.

The use of reverse osmosis in demineralizating brackish water has been studied extensively and a considerable amount of operating data exists in the literature. All the results demonstrate that reverse osmosis has the capability of producing a high quality product from brackish water.

The reclamation of wastewater and demineralization of brackish ground water could be feasible applications in Hawaii as a part of the total water resources management goal. It is conceivable that Hawaii can have a system of utilizing natural water combined with recycled wastewater and demineralized brackish water through reverse osmosis process.

PRINCIPLE OF REVERSE OSMOSIS

Osmosis occurs if two solutions of different concentrations, but in the same solvent, are separated from one another by a semi-permeable membrane that allows the passage of the solvent but not the solute. The phenomenon of osmosis is that the solvent flows from the dilute solution to the more concentrated solution until the pressure on the more concentrated side of the membrane rises to a value called osmotic pressure difference between the two solutions. When a pressure greater than the osmotic pressure difference is applied to the more concentrated solution, then the solvent is forced to flow into the dilute solution. This process is reverse osmosis.

Cellulose acetate membranes are now being used in reverse osmosis process. However, due to its finite rejection ability, there is also a flow of solute through the cellulose acetate membrane. The behavior of this membrane can be described by two basic equations. The product water flux through the membrane may be expressed as:

$$F_w = \frac{D_1 C_1 \overline{V}_1}{RT\Delta x} (\Delta P - \Delta\pi) \qquad (1)$$

where

F_w = water flux (g/sq cm-sec),

D_1 = diffusion coefficient for water in the membrane (sq cm/sec),

C_1 = dissolved water concentration in the membrane (g/cc),

$\overline{V}_1$ = partial molar volume of water in the external phase,

R = gas constant,

T = absolute temperature,

Δx = membrane thickness (cm),

ΔP = pressure differential applied across the membrane (atm), and

$\Delta\pi$ = osmotic pressure differential across the membrane (atm).

The solute flux through the membrane may be expressed as:

$$F_s = \frac{D_2 K}{\Delta x} \Delta C \qquad (2)$$

where

F_s = solute flux (g/sq cm-sec)

D_2 = diffusion coefficient for solute in the membrane (sq cm/sec),

K = distribution coefficient ratio of the solute concentration in the membrane (g/cc) to the solute concentration in the solution (g/cc),

Δx = membrane thickness (cm),

ΔC = concentration gradient across the membrane (g/cc).

OBJECTIVE

The objective of this study is to investigate the technical feasibility of utilizing the reverse osmosis process for renovation of wastewater and demineralization of brackish ground water in Hawaii and also to analyze the economical feasibility of it.

LITERATURE SURVEY

Since the pioneering work of Eeid and co-workers in 1953 and the development of high flux, semipermeable cellulose acetate membranes by Leob and Sourirajan (1961) during the 1950's, the reverse osmosis process has been regarded as a method for desalination.

The application of reverse osmosis in treating wastewater was first considered by Aerojet-General Corporation. In late 1962, Aerojet conducted a bench-scale study using the flat-plate test cells to evaluate the potential of reverse osmosis for renovation of filtered secondary effluent. It was found that high quality water could be produced by this process (Final Report No. 2962, 1965).

In early 1965, a series of experiments using a spiral-wound module on diatomaceous earth-filtered secondary effluent were conducted by General Atomic. Results of these tests showed a high organic and inorganic solute rejection (Bray and Merten, 1965).

The first pilot plant investigation of reverse osmosis, conducted at the Pomona Water Renovation Plant in 1966, used a 5,000 GPD spiral-wound module unit on secondary effluent. Improvements in the modules and solution of mechanical problems had been made during the testing period. An air-tap water-flushing procedure was found to be successful in controlling head loss through the system. A continuous wastewater reclamation program at the Pomona Pilot Plant from July 1968 through June 1969 was directed to find the parameters and conditions that would best permit operation of reverse osmosis systems on wastewater receiving secondary treatment. A technique utilizing an enzyme-based detergent as a membrane cleaning agent was also developed (Nusbaum, Sleigh, Jr. and Kremen, 1970).

At the same time, a fifteen-month laboratory program was conducted by Aerojet-General. This study involved over 90 controlled laboratory-scale reverse osmosis tests to determine the effects of wastewater quality and operating conditions on process performance. The results showed that alum-treated secondary sewage, carbon-treated secondary sewage, secondary sewage, alum-treated primary sewage, primary sewage, raw sewage, and digester supernatant could be significantly improved by the reverse osmosis process. High removals of dissolved minerals, organic substances, and suspended matter had all been achieved in the same treatment (Aerojet-General Corporation, 1969).

A program using improved membranes in tertiary treatment by reverse osmosis was performed by Astropower Laboratory in 1970. The test results demonstrated that the removal of wastewater constituents was generally unaffected by the type of feed or time on test and remained essentially constant at 90 to 100 percent during operation on carbon treated secondary, primary, and concentrated primary effluent (Astropower Laboratory, 1970).

The direct water reclamation from raw sewage has been operated in a San Diego, California pilot plant. The San Diego pilot plant did not produce potable water, but the quality was high enough to permit product use for most industrial and agricultural applications (Conn, 1971).

In 1966 Ironside and Sourirajan (1967) conducted a test of pushing two samples of sewage effluent through a laboratory cellulose acetate membrane to determine permeation of coliform organisms. A comparable bacteriological analysis was obtained by Wilford (1967) in 1967 and Hinden, *et. al.*, (1969) in 1969. They reported that a great reduction in the number of organisms was found in treating sewage effluent by the reverse osmosis process.

A number of industrial waste treatment studies using reverse osmosis have been conducted, particularly the production of high quality waters from acid coal mine drainage (Chainbelt, 1970). One of the most successful applications was a 10,000 GPD spiral-wound unit operating in West Virginia.

Possible treatment schemes incorporating reverse osmosis were examined by Smith, *et. al.* (1970). They reported that for reverse osmosis to become competitive with present-day technology for achieving water of potable quality, it should be employed near the primary end of a treatment train. Dryden (1971) indicated that although the reverse osmosis process was in the highest cost estimate of the three processes, namely, reverse osmosis, electrodialysis, and ion exchange, it is the process with the greatest potential for technological development.

A cost optimization technique for a sea-water conversion system employing the reverse osmosis process was first developed by Lonsdale, *et. al.* (1964). This work suggested areas where cost reduction should be sought. A cost calculation of a one MGD reverse osmosis plant for brackish water desalting was completed by Menzel (1967). The capital requirements and cost of producing fresh water from saline water by reverse osmosis was determined by Clark (1969). The important cost variables in this process were identified and the effects of future changes in the key process parameters on the costs of producing fresh water were projected.

METHODOLOGY

The experiments necessary for the present investigation were conducted with a small reverse osmosis test unit. This unit was first tested on brine solutions by varying operating pressure, recovery ratio, and concentration of brine solution. The tests on chlorinated activated sludge effluent from Mililani sewage treatment plant were then conducted at 600 psig operating pressure. These tests continued from April through June, with only intermittent runs and no operation on weekends. The pH value of chlorinated activated sludge effluent was adjusted to 4.5-5.5 to reduce the precipitation of phosphate or carbonate as well as the membrane hydrolysis.

A 30-minute water flush was incorporated occasionally as a cleaning procedure in an effort to minimize membrane fouling problems. A 10,000 mg/l solution of the enzyme detergent, BIZ, was used to restore the product water flux during this testing period. Product water flux, before and 30 minutes after membrane cleaning, was recorded throughout the test.

Samples from feed, product, and concentrate were collected for chemical analysis. Electrical conductivity, total solids, total dissolved solids, total chemical oxygen demand, total organic carbon, phosphorus, total Kjeldahl nitrogen, and nitrate nitrogen were assayed in accordance with procedures described in the thirteenth edition of Standard Methods (1970) for the Examination of Water and Wastewater.

TEST EQUIPMENT

The reverse osmosis test unit used in the study was essentially a pilot module. The unit was fabricated with a 2-inch diameter, schedule 40, pressure vessel, which held a 1-foot long spiral-wound module, containing a nominal membrane area of 4 square feet with a designed rate of 13 GFD flux.

Pressure and flow were produced by a controlled-capacity reciprocating pump which was housed within an aluminum cover. The pump provided a 2.7 GPH feed at a pressure of 600 psig. A pressure regulator was used to maintain the pressure at 600 psig by changing the ratio between product water and concentrate flow rate or volume. A pressure relief valve helped to control the pressure by releasing feed flow to the atmosphere when pressure exceeded 700 psig.

Chlorinated activated sludge effluent from the Mililani sewage treatment plant was delivered into two connected feed tanks, each of which had a 50-gallon capacity. Tank level was regulated by a float valve that was connected to the load circuit. The effluent was pumped through a simple 40-mesh intake screen and a 10-micron cartridge filter which were used to limit particulate matter contained in the feed. A vacuum gage was used to monitor the low feed situation when the screen and filter are clogged. A schematic of this field test unit is shown in Figure 4.1. The major pieces of equipment are described in Table 4.1.

TABLE 4.1. DESCRIPTION OF EQUIPMENT

SPIRAL-WOUND MODULE	ROGA MODEL 4003, 4 FT^2 OF SPECIALLY TREATED CELLULOSE ACETATE MEMBRANE ELEMENT WITH 13 GFD FLUX RATE.
FEED PUMP	AMERICAN METER CONTROL, MODEL 141154-C2 CONTROLLED CAPACITY PUMP.
PRESSURE REGULATOR	EMERSON ELECTRIC CO., BROOKS ELF NEEDLE VALVE MODEL 8503.
INTAKE SCREEN	MUESSCO Y-TYPE STRAINER WITH 40-MESH SCREEN.
INTAKE FILTER	PALL CORPORATION, MODEL MCS1001 EE, 10-MICRON EPOCEL CARTRIDGE.

RESULTS AND DISCUSSION

All tests were conducted with chlorinated effluent. The total operation ran approximately 320 hours, with the longest uninterrupted run of 24 hours. The early tests identified membrane fouling and pump failure as the major operational problems.

The product water flux declined rapidly during the test. After 20 hours of operation the flux had decreased to 83 percent of the initial value and after 5 days it had fallen to 50 percent. Sizable restorations in product water flux were achieved by cleaning the membrane with the enzyme detergent, BIZ. Water flush for 30 minutes also restored product water flux, but to a lesser extent. The variation in product water flux with time is plotted in Figure 4.2.

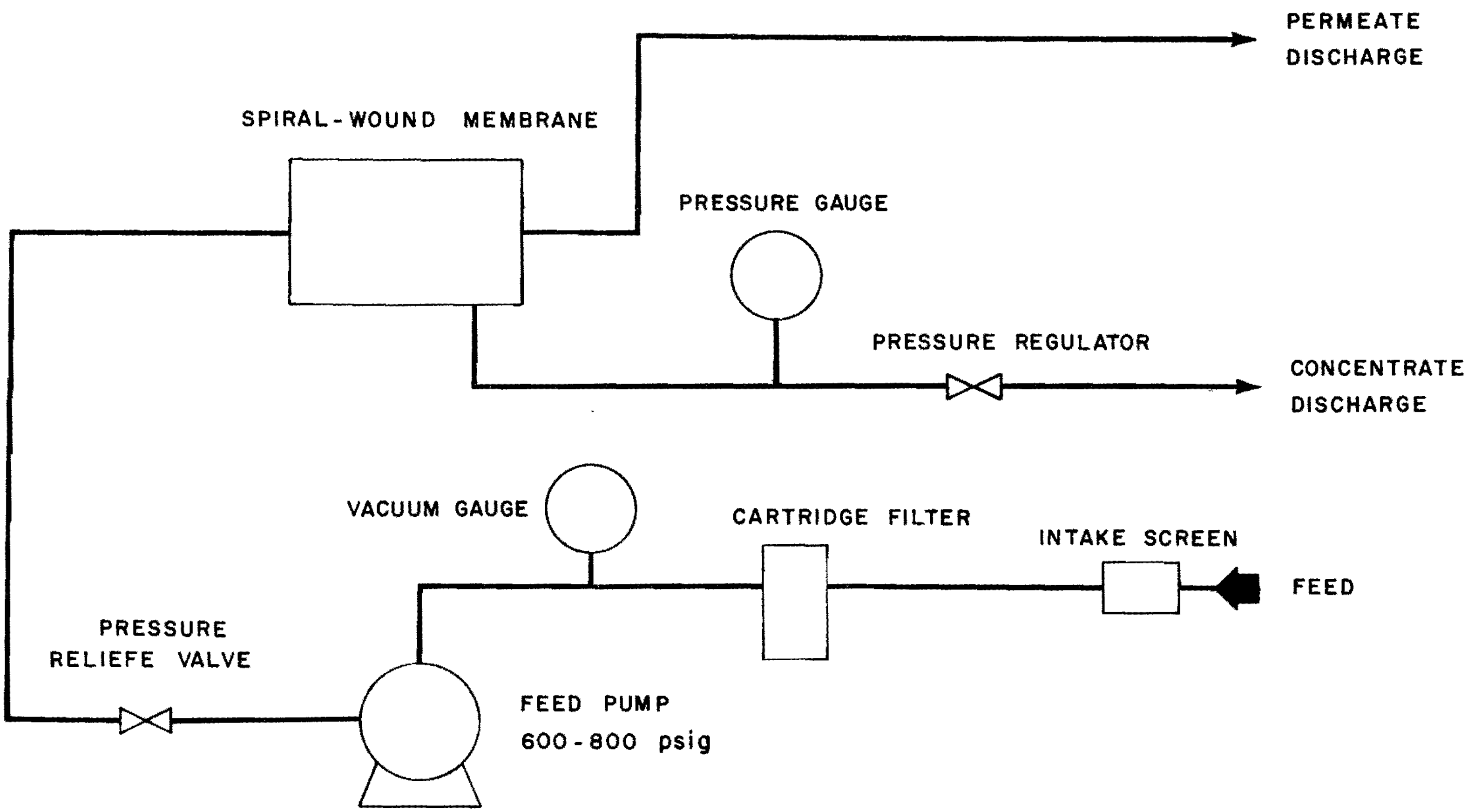

FIGURE 4.1. TEST APPARATUS SCHEMATIC.

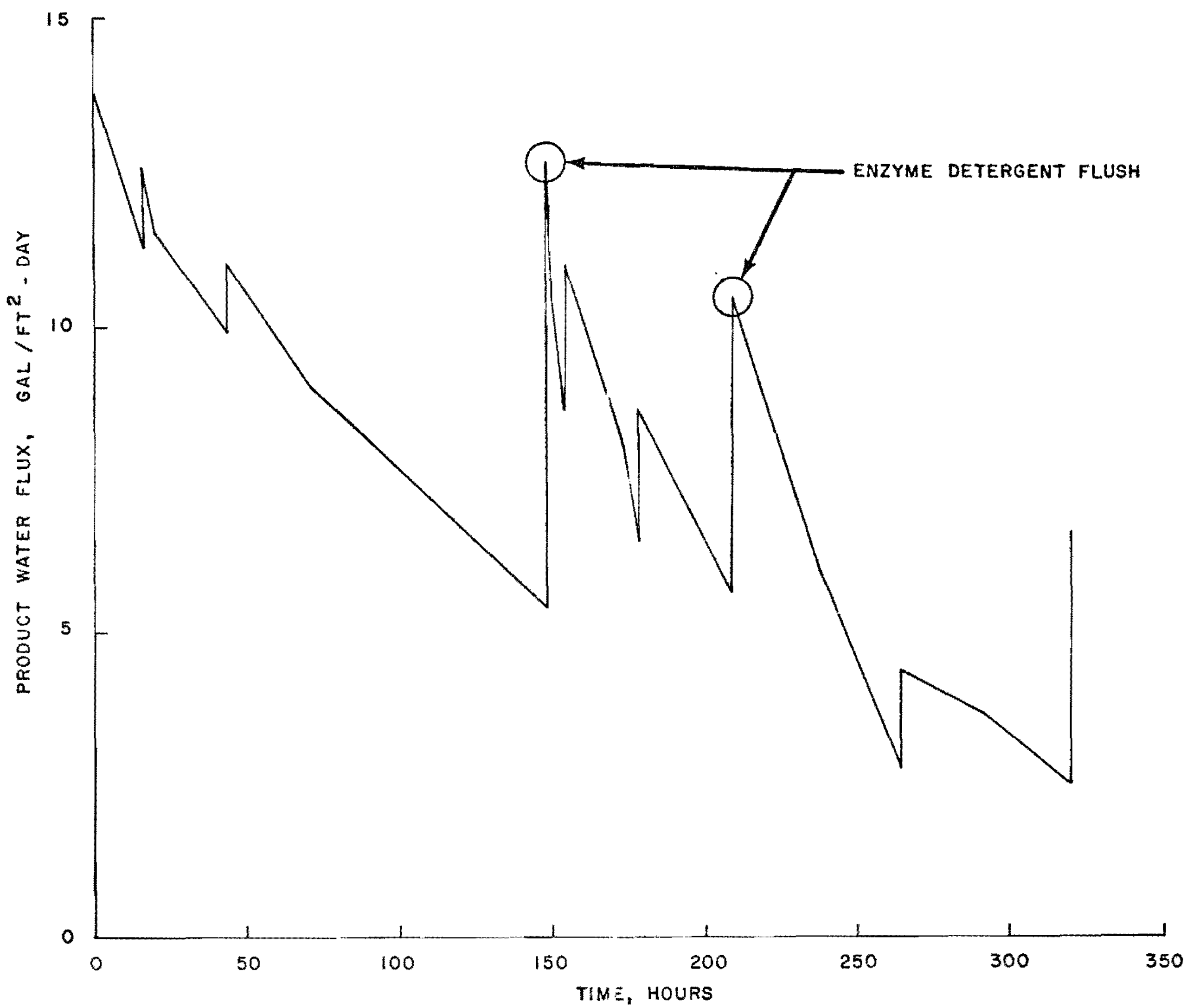

FIGURE 4.2. PRODUCT WATER VERSUS TIME.

The removal of wastewater constituents changed very little during the 320-hour test period. Typical characteristics of the feed, product, and brine are shown in Table 4.2. The data includes chemical analysis and the percent rejection of the various constituents. As noted in Table 4.1., the product concentration is less than 20 percent of the feed concentration in most cases, which means that more than 80 percent demineralization has been accomplished. Of particular interest in organic carbon rejection is that the level of organic carbon (as shown by COD and TOC) is much lower in the product than in the feed. Nitrate rejection is quite variable, ranging between 70 and 50 percent. The reduction in turbidity was found to be so complete as to provide a product water below the sensitivity of the turbidimeter. Bacteriological analysis indicated a presence of coliform organisms in the product water tested. A great reduction in the number of organisms from feed to product was observed but they were not completely removed. The membrane at the end of test was covered with a thick layer of black gelatinous deposit.

TABLE 4.2. SUMMARY OF CHEMICAL ANALYSES.

CONSTITUENTS	CHLORINATED ACTIVATED SLUDGE EFFLUENT				
	CONCENTRATION (mg/l)			% REDUCTION BASED ON	
	FEED	PRODUCT	BRINE	FEED	$\frac{F + BR}{2}$
TOTAL SOLIDS	450	70	1440	85	92
TOTAL DISSOLVED SOLIDS	431	69	1247	82	90
COD	128	20	320	85	91
TOTAL KJELDAHL - N	70	1.6	13	77	84
NO_3 - N	1.0	0.5	2.4	50	85
PO_4 - P	9.2	0.4	29	96	99
TOC	25	7	70	72	85
CHLORIDE	50	9	330	82	95
CALCIUM	14	0.5	55	96	98

CHAPTER 5

SUMMARY AND CONCLUSIONS

The results of the investigation of the eleven sewage treatment facilities provides a general picture of the wastewater disposal practices on Oahu. While it is felt that a satisfactory representation is given of both primary and secondary treatment, it is apparent that this report should only be used to provide baseline information and that further studies need to be conducted, preferably at the same facilities but the scope widened to determine the effects that the effluents may have on receiving waters. The possible reclamation of the effluents for recycling and reuse also can bear careful study, particularly for use by the burgeoning population of Oahu or for use for agricultural or industrial activities. The study of domestic sewage gives no indication that such reclamation is beyond the level of presently available technology.

The Manoa Stream study has provided valuable information on surface water quality. The most important factor determined was that even under dry weather conditions when the stream flow was unaffected by urban runoff, the total and fecal coliform bacterial populations in the water fail to meet the levels set in the State Water Quality Standards. In general the situation is worsened by wet weather conditions, especially in those areas affected by urban storm runoff.

The present study on urban runoff found that such runoff contains constituents that affect water quality and that the degree of "contamination" increases with urban population density, urban development, and land activity. However, for Manoa Stream, the source of coliform organisms are non-human, warm-blooded animals as borne out by the low fecal coliform to fecal streptococcus ratios in all samples. The Manoa Stream study shows a need for a more extensive and in-depth study to establish present water quality levels against which pollution or degradation may be evaluated and a re-examination of the State Water Quality Standards which were established for such waters without prior investigation of the existing conditions.

Surveys of surface water quality should be conducted on a long-term basis, taking into consideration all aspects of environmental degradation including, among other aspects, the effects of landfill operations, pesticide usage, and heavy metal disposal. The scope could be increased to include streams that could be considered as potential water sources, if future demands cannot be met by ground-water supplies. Once the baseline water quality has been established, concern should be focused on the reuse potential and possible treatment methods for stream waters affected by urban runoff.

Since the street sweeping portion of the study was only of a preliminary nature, definitive statements regarding those results cannot be made. The results were, in general, comparable to the values obtained in the Chicago Study, with all parameters, except nitrate-nitrogen varying by no more than a factor or two. The amount of refuse collected in this study, together with BOD and bacteriological content, indicate a considerable pollution potential. The need for further research on this aspect of urban runoff is indicated, particularly to obtain statistically reliable data and to gain a more direct relationship between the amount of street refuse and the area or length of street from which that refuse was obtained.

An attempt was made at wastewater renovation using a single treatment process, reverse osmosis, representative of advanced treatment methods rather than conventional treatment technology. A spiral-wound test module was fabricated, laboratory tested on brine solutions, and then set up at the Mililani sewage treatment plant to process secondary-treated effluent. The unit operated over 320 hours maintaining a product water chemical quality comparable to that of a low mineral content water supply. Reduction in flux rate was experienced, however, necessitating the use of an enzyme detergent flushing to restore the unit production capacity, but the flux rate never was restored to the initial level of operation. The reverse osmosis unit shows some promise as a wastewater renovation method but continued testing is warranted to determine its capabilities in removal of indicator organisms, operating characteristics with varied types of treated wastewater feed supplies, and economics of operation.

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