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PROPOSED ZONES OF MIXING IN COASTAL WATERS OF KAUAI

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Memorandum Report No. 26

August 1970

Water Resources Research Center
University of Hawaii
Honolulu, Hawaii

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INTRODUCTION

This memorandum report pertains to proposals to establish a number of zones of mixing in the coastal waters of Kauai in order to accommodate certain discharges of Kekaha Sugar Co., Gay and Robinson, Olokele Sugar Co., Kauai Electric Co., McBryde Sugar Co., Grove Farm Co., Lihue Plantation Co., Kauai County, and Kilauea Sugar Co., described in a notice of public hearings to be held August 24, 25, and 26 in Lihue, Kauai. The proposals have been made and the hearings have been scheduled pursuant to provisions in the State Water Quality Standards (Department of Health, Public Health Regulations, Chapt. 36 A, 1968).

The State Water Quality Standards were developed on the basis of public hearings held during 1966 and 1967, at which were presented such meager data as was available on water quality and waste discharges, and in which members of the staff of the Water Resources Research Center participated.

A special WRRC study of "Estuarine Pollution in the State of Hawaii", Water Resources Research Center Tech. Rept. 31, vol. 1, 1970, made possible by the support of the Federal Water Pollution Control Administration, included a summary of all information on pollution of the estuaries of Kauai, several of which are in or adjacent to proposed zones of mixing. Earlier proposals for zones of mixing in Honolulu Harbor and Kapalama Canal, Oahu, have been reviewed by members of the Center's staff in WRRC Memorandum Report 22 and statements were presented at the public hearings concerning these proposals and a proposal for a zone of mixing in Maui.

Of the authors of this report, Cox, a former resident of Kauai, has been involved in extensive work on the geology and hydrology of Kauai and some work on the oceanography of its coastal waters. Kay, also a former resident of the island, has been involved in extensive work on the coastal ecology of the island. Burbank has been engaged in the determination of waste water strengths and their effects upon discharge in coastal waters of Hawaii. This report has been reviewed by other concerned members of the staff of the Water Resources Research Center. However, any conclusions and recommendations in the report concerning the establishment of the proposed zones of mixing must be regarded as those of its authors alone. Neither the WRRC nor the University as institutions have any direct responsibility for administrative determinations under the Water Quality Standards.

WATER QUALITY CONTROL, PERMITS, AND STANDARDS

The power of the State to control the quality of the waters of the State is delegated to the Director of Health in Chapter 321, Section 16 of Hawaii Revised Statutes, from which the following quotations are pertinent:

"To the extent and insofar as their sanitary or physical condition affects or may affect the public health, safety, or welfare, ... the director of health may ... control all waters of the state .... or the disposal of any ... sewage, garbage, feculent matter, offal, filth, refuse, any animal mineral, or vegetable matter or substance, or any liquid, gaseous, or solid substance into any waters of the State as will or is likely to create a nuisance or render such waters harmful or detrimental or injurious to public health, safety, or welfare ... In connection therewith the director may appoint a master ... to conduct investigations and to hold hearings. In order to effectuate a comprehensive program ... such master ... shall divide such waters into areas and shall recommend standards of water quality for such waters according to their present and future best uses. Upon adoption of the recommendations by the director, it shall be unlawful for any person, including a public body, to use such waters for the disposal of above listed matter or substance without first securing approval in writing from the director."

Implicit in some of the testimony submitted in support of the proposals for the establishment of zones of mixing in the coastal waters of Kauai, as well as those considered earlier for the coastal waters of other islands, is the assumption that zones of mixing are the only means of accommodating the discharge of wastes that result in variances from the usual tolerance limits for pollution parameters set in the Water Quality Standards, Chapter 37-A of the Public Health Regulations. This assumption is not supported by the Regulations. Within Chapter 37-A itself there is no direct provision for enforcement, but rather, in Section 1, reference to the enforcement provisions of Chapter 37 through the following language: "The standards adopted, herein set forth shall be the standards of water quality for the purposes of Chapter 37, Public Health Regulations, Department of Health, State of Hawaii, and shall be enforced and administered as provided therein."

The pertinent part of Chapter 37 is its Section 3, "Permits Required": "It shall be unlawful for any person to do any one of the following without a permit issued in accordance with the provisions of this Chapter:

"(a) To discharge any wastes into any waters of the State so as to reduce the quality of the water below the standards of water quality adopted for such waters by Chapter 37-A;

"(b) ... "

The requirements for application for and issuance of permits are

then set forth in Section 4 and 5 respectively of Chapter 37. Section 3 clearly exempts from consideration as unlawful behavior any discharges covered by a permit, even if they result in variances from the water quality standards. No zones of mixing need be established to make lawful a discharge covered by a permit.

It is not clear whether or not a permit is necessary for a discharge if a zone of mixing has been established that adequately covers the variances from the standard pollutant tolerances caused by that discharge. The citation in Chapter 37 Section 3 above quoted, "... the standards of water quality adopted for such waters by Chapter 37-A", would seem to refer to the whole of Chapter 37-A, which indeed is titled "Water Quality Standards". Included within this Chapter are the provisions for zones of mixing in Section 4 and 7, the latter specifying that such zones may be established: "Upon the application of any person requesting that a portion of the water areas meeting the basic standards ... be zoned for the assimilation of agricultural, municipal, and industrial discharges ...", and the former specifying that: "It is the objective of [these] limited [zones] to provide for a current realistic means of control over such discharges and at the same time achieve the highest attainable level of water quality." (Without reference to any need for permits). These zones of mixing are thus special zones in which the tolerance limits for pollution parameters that are normal to the class of waters involved are waived, and special tolerance limits are presumably established that will not be exceeded by the discharges to be accommodated.

The language of Chapter 37 Section 3 might conceivably, however, be held to refer solely to Section 6 of Chapter 37-A, which is also titled "Water Quality Standards" and which does not include the provision for zones of mixing. In this case it is not clear why any dischargers would ever take the trouble to apply for a zone of mixing. The most significant difference between the granting of a permit and the establishment of a zone of mixing is that the permit must be limited to a period not to exceed 5 years whereas a zone of mixing is not limited as to duration. This difference is of advantage to the discharger in a zone of mixing only if he does not have to apply for, and risk denial of, a permit. Hence, it seems probable that a zone of mixing alone, without a permit, is sufficient license for a discharge.

There is a further distinction between a permit and a zone of mixing in that the former applies to the discharge itself whereas the latter applies to the receiving waters. Either, however, may be used to accommodate a discharge, and the most important distinction is that pertaining to the time limit and necessity to renew a permit in the case of a continuing discharge. The establishment of a zone of mixing is, thus, a much more important action, and one which should not be undertaken unless it is clear that the long term welfare of the community is served by it.

As previously expressed with regard to zones of mixing proposed in Honolulu Harbor and Kapalama Canal, Oahu (Water Resources Research Center Memo. Rept. 22, 1970), there are five important considerations in establishing a zone of mixing that are implied but not set forth explicitly in the Water Quality regulations:

1) that, with an application for the establishment of a zone of mixing, information must be submitted whereby the pertinent economic, ecological, and esthetic effects may be analyzed.

2) that, to determine the appropriateness of establishing a zone of mixture, there must be such an analysis.

3) that in such an analysis, the overall public interest should be considered, including demonstrably practicable potential uses as well as current uses of the waters.

4) that, in a zone of mixing, special tolerance limits may be set for some pollutants whose mixing is to be accommodated, whereas for other pollutants the normal limits for the water class in question will pertain.

5) that a suitable monitoring program may be required for the continuance of a zone of mixing.

In the case of zones of mixing proposed to accommodate future discharges, it is clear that the responsibility for such studies as are necessary to define the effects of the discharge should rest primarily with the applicant. In the case of zones of mixing intended to accommodate discharges that were begun long before the establishment of the present Water Quality Standards, the responsibility is not so clear. The case may be made that, if the State has drastically changed the conditions under which discharges may be made, the State should reasonably share in and perhaps even provide the major share of such studies as are necessary to determine the effects of those discharges.

Unless and until thorough analysis based on adequate information can be made, a zone of mixing should not be established, but appropriate existing discharges may be accommodated by permit.

APPLICATIONS FOR ZONES OF MIXING AND DISCHARGES TO BE ACCOMMODATED

Applications for the establishment of zones of mixing in the coastal waters of Kauai have been made by one public and nine private agencies. Fifteen separate zones of mixing are involved whose intent it is to accommodate a total of 40 discharges identified in Table 1. Some of these discharges are actually multiple, so that the total in reality probably exceeds 50.

Chapter 37-A Section 7 of the Public Health Regulations require that an application for a zone of mixing "shall be made on forms furnished by the Director and shall contain the information required therein". It is of interest that the applications to be considered follow two different formats: Those of Kauai Electric Co. and Kauai County are titled "Application for permit for waste discharge outlet and/or for zone of mixing", as are applications by McBryde Sugar Co. for mill-waste discharge and for a tail-water discharge at Kukuiula. Those of Kekaha Sugar Co., Gay and Robinson, Grove Farm Co., Kilauea Sugar Co. are titled "Application for zone of mixing" as is McBryde Sugar Co. for a general zone of mixing for tail water inclusive of that at Kukuiula.

The two formats differ in the information required as shown by Table 2, and an apparent editorial flaw in the form for application for permit and/or zone of mixing results in a failure to solicit discharging flow and quality information in the case of the untreated wastes for which such information is most vital. Several applicants have tried to escape the limitations of the forms and provided additional useful information beyond what is strictly required.

This report is based not only on information in the applications but on such additional information as is readily at hand, including some of the testimony to be presented at the hearings, but has not involved an exhaustive information search or field research developing new information.

Table 1. Applications for Zones of Mixing in Kauai Coastal Waters

Applicant	*	Location	Coastal Water Class	Type of Discharge	Rate of Discharge mean(mgd)	Zone of Mixing Length (ft)	Zone of Mixing Width (ft)	Date of Application	Figure
Kekaha Sugar Co	(1)	Nohili	A	Drainage water	14	30,000	6,000	7 Aug 1969	2
" " "	(2)	Waieli	A	" "	55				3
Gay & Robinson	(1)	Makaweli	A	Tail water	0.027				1
" " "	(2)	"	A	" "	0.027				
" " "	(3)	"	A	" "	0.027				
" " "	(4)	"	A	" "	0.5	11,000	5,300	19 Aug 1969	4
" " "	(5)	"	A	Tail water in stream	0.05				
" " "	(6)	Mahinauli	A	Tail water	0.005				
" " "	(7)	"	A	" "	0.027				
Olokele Sugar Co	(1)	Kaumakani	A	Tail water	0.4				
" " "	(2)	"	A	" "	0.4				
" " "	(3)	"	A	Mill water	1				
" " "	(4)	"	A	Tail water	0.4	13,600	5,300	19 Aug 1969	5
" " "	(5)	"	A	" "	0.4				
" " "	(6)	"	A	" "	0.4				
" " "	(7)	"	A	Mill water	1.8				
" " "	(8)	"	A	Tail water	0.4				
Kauai Electric Co		Port Allen	A	Cooling water	10	?	?	22 Aug 1969	6
McBryde Sugar Co	(1)	Port Allen	A	Tail water	?				
" " "	(2)	Wahiawa	A	" "	?			? ? 1970?	
" " "	(3)	"	A	" " (3)	?				
" " "	(4)	"	A	" "	?				6
				Mill water	?			19 Aug 1970	
" " "	(5)	"	A	Tail water (3)	?				
" " "	(6)	"	A	" " (3)	?				
" " "	(7)	Kalaheo	A	" " (3)	?				7
" " "	(8)	"	A	" "	?	35,000	3,000		
" " "	(9)	"	A	" "	?			? ? 1970?	
" " "	(10)	"	A	" "	?				
" " "	(11)	Lawai	A	" "	?				
" " "	(12)	"	A	" "	?			19 Aug 1969, ? ? 1970?	

* Numbers correspond to those in accompanying figures but not those in original applications.

Table 1. Applications for Zones of Mixing in Kauai Coastal Waters (continued)

Applicant	*	Location	Coastal Water Class	Type of Discharge	Rate of Discharge mean(mgd)	Zone of Mixing Length (ft)	Zone of Mixing Width (ft)	Date of Application	Figure
Grove Farm Co		Kawailoa Bay	A	Tail water	0.5	3,000	1,500	21 Aug 1969	8
Lihue Plantation Co	(1)	Kalapaki-Hanamaulu	A	Tail water (several?) Mill water	7	17,000	2,000	? ? 1969?	9
" " "	(2)	Hanamaulu	A	Tail water	1	500	500	? ? 1969?	10
" " "	(3)	Kawailoa Drain	A	Tail water in drain	1	500	500	? ? 1969?	
Kauai County		Wailua	A	2ndry-treated sewage	0.06	?	?	? ? 1969?	
Lihue Plantation Co	(4)	Waiakea Canal	A	Tail water in canal	5	600	500	? ? 1969?	11
" " "	(5)	Kapaa Stream	A	" " in stream	5	600	500	? ? 1969	
" " "	(6)	Kamalomaloo	A	" " (several?)	5	14,000	500	? ? 1969?	12
" " "	(7)	Papaa	A	Tail water in stream	1	500	500	? ? 1969?	13
Kilauea Sugar Co		Kauapea Beach	A	Mill water	5	27,000	2,600	19 Aug 1969	14

* Numbers correspond to those in accompanying figures but not those in original applications.

Table 2. Key to information on application forms for zones of mixing

Information	Application for permit for waste discharge and/or for zone of mixing	Application for zone of mixing
Inclusion of applicability to zone of mixing	E	
Applicant identification and address	A	1
Applicant's representative		1
Location of zone of mixing		2
Water classification in zone of mixing	C	3
Uses of water in zone of mixing		5
Location of discharge	B	6
Suitability of discharge location	G	
Type of discharge		4
Inclusiveness of discharge	F	
Treatment of discharge	H, I*	11
Schedule for future treatment	N	
Capacity of discharge	K*	
Flow characteristics of discharge	D, L*	7
Quality characteristics of discharge	J*, L*	
Depth at discharge		8
Currents at discharge		9
Winds at discharge		10
Assurance of dispersion of effluent		12
Effects of discharge on receiving waters	M	13
Assurance of no unreasonable interferences in zone of mixing		15
Assurance of no effects outside zone of mixing		16

*An instruction in question H indicates that, if the waste water is discharged without treatment other than screening or comminution, information items I, J, and K are not to be supplied, hence no information will be supplied on the character of the discharge or on its flow rate.

ECOLOGICAL NOTES ON ZONES OF MIXING

The zones of mixing proposed for Kauai coastal waters have an aggregate length of more than 30 miles of the island's 113 mile coastline. The total area involved is over 12,000 acres, nearly 20 square miles. As may be seen in Figure 1, the decisions whether or not to establish these proposed zones are actions that affect a very large part of the coastal waters of Kauai.

The productivity of Kauai's shorelines (bait and other inshore fisheries and shellfish) and the diversity of those shorelines which is one of its principal visitor attractions are in large part due to the communities of marine animals and plants which live in the island's offshore waters. In great measure these biotic associations are coral communities of one type or another such as fringing or subtidal reef. Twelve of the points of discharge enumerated are directly located in areas designated on the topographical map of Kauai as fringing reef. There is no inventory of Kauai's subtidal reefs but the occurrence of extensive deposits of calcareous sand along its shorelines suggests that offshore coral communities are in all probability considerable, and it must be anticipated that many of the discharge points will also be into or near these communities.

As is discussed in detail later in this report, the discharges involve a variety of water types and substances: water both low in salinity and higher in temperature than ambient sea temperatures, sediments, colloids, nutrients and pesticides. Many of these are well-documented as inimical to coral growth. A major cause of coral destruction historically seems to be exposure to brackish, silt-laden water. In studies of Hawaiian corals, eight out of 15 species survived less than a week in seawater diluted by one-quarter with freshwater; exposure to freshwater for 30 minutes killed most species; and coral planulae apparently do not settle or grow at reduced salinities (Edmondson, C. H. 1928, Bishop Mus. Bull. 45; 1929, Bishop Mus. Bull. 58). In Kaneohe Bay, Oahu, fine, clay-sized terrigenous sediments have apparently killed many of the corals in the south end of the bay (Bathen, K. H. 1968, HIMB Tech. Rpt. 14), and a very common species of Hawaiian coral, *Porites compressa*, is apparently one of the most sensitive of all corals to sedimentation (Edmondson, C. H. 1928, Bishop Mus. Bull. 45). Changes in temperature, especially increasing temperatures also affect coral communities. Tropical organisms characteristically live at temperatures only a few degrees below their lethal temperatures: 11 out of 13 species of Hawaiian corals survived less than 24 hours at 32°C, a temperature of only $5 - 6^{\circ}$ higher than ambient summer water temperatures (Edmondson, C. H. 1929, Bishop Mus. Bull. 58), and the larvae of the single Hawaiian mollusk studied with respect to temperatures (Taylor, J. B., unpublished). Finally, both changes in nutrient concentration and the addition of pesticides and/or herbicides to seawater affect marine communities, excessive nitrates and phosphates resulting in algal blooms (Johannes, R. E., unpublished) and pesticides and herbicides tending to sterilize the environment, reducing normal species diversity and hence community

stability.

Years of discharge and land run-off necessitated by Kauai's agricultural economy and the dependence of i-s population on technological developments may have already permanently affected some areas of the island's shorelines. Beaches and basalt benches now are or have been in the past strewn with trash (especially Kalihiwai, Anini, Kealia, Hanamaulu, and Kekaha); there are at least two areas of apparent coral-kill (Anini and Nohili); and two bays (Wahiawa and Kukuiula) are sufficiently turbid and discolored as a result of land run-off that they are neither esthetically pleasing nor productive. The extent of the effects of these superficially observable shoreline alterations on offshore communities has not been assessed, but they may be far from minimal. It has been suggested, for example, that while increases in turbidity may not appear to affect shallow water coral communities, they can be expected to reduce coral and plant growth increasingly with depth because of the dependence of both coral and algae on light penetration (Johannes, R. E., unpublished). The Burm and Morris (1970, 5th Internat. Conf. on Water Pollution Research, Honolulu) report of extensive bottom siltation and severe depression of the growth of coral, sponges and benthic algae as well as lesser numbers of fish in mill waste outfall areas for both McBryde Sugar Co. and Olokele Sugar Co. is therefore indicative of far more extensive changes in marine communities offshore than might be anticipated from shoreline observation. Of concern for the future is the realization that it cannot be taken for granted that even with the cessation of industrially-associated discharges will coral communities now destroyed ever replace themselves.

While the effects of specific pollutants on coral communities and marine environments in general are well documented, the effects of topography, current patterns, and wave action which can ameliorate or enhance pollutant action are neither documented nor predictable from available information for any of the points of discharge requested for Kauai coastal waters. It is obviously neither economically feasible nor justifiable to require detailed studies of topography and current patterns for each of the discharge areas at this juncture. Adherence to a number of recommendations which are detailed in later sections of this report, however, should make it possible to minimize many of the adverse ecological effects which might otherwise be expected to result from the requested discharges.

Within the next decade increasing utilization of island shorelines for food production, recreation, housing, harbor development, etc. can be expected to result in even greater alteration of the marine communities in our coastal waters than have been effected by a heretofore predominantly agricultural economy. The development of an inventory of Hawaiian coastal waters, detailing topography, current patterns, wave action, and marine communities, is, therefore strongly recommended, if we are to insure the continued productivity and diversity of our shorelines.

TREATED SEWAGE EFFLUENT

At the present time there are two major sewage treatment plants in operation on Kauai. These are the Lihue community sewage treatment plant and the Wailua community sewage treatment plant. An industrial waste outfall at Kapaa has been constructed but not yet put into use.

The Lihue waste treatment plant was originally built to handle 0.1 MGD flow but has since increased in size by 0.4 MGD to handle 0.5 MGD total flow. The discharge of the waste from this secondary sewage treatment plant flows into the mill ditch of Lihue Plantation Company which ultimately discharges to the sea over the cliff near Kamilo Point between Nawiliwili Harbor and Ahukini Camp. The discharges are very difficult to trace particularly after they discharge into the plantation's ditch. There is no evidence of their effect upon the ocean although in the past the mill water discharge has resulted in a discolored area offshore. In the survey of coastal waters of the island of Kauai in July 1969 there was evidence of such discharge in elevated coliform counts in the Ahukini district.

The Kapaa industrial waste is now discharged into the Moikeha drainage canal and thence to the ocean (Water Resources Research Center Tech. Rept. 31, Vol. 1). This discharge results in elevated coliform counts and higher than normal values of nitrogen and phosphorous, as detected in the July 1969 survey of the coast of Kauai by the Ultramar Chemical Company for the State of Hawaii, Department of Health.

The effluent from the sewage treatment plant at Wailua is the only sewage, treated or untreated, for whose accommodation a zone of mixing is proposed. This plant provides primary and secondary treatment for sewage from the Wailua hotel complex. It is designed for an ultimate capacity of 750,000 gpd, but its present average load is only 56,000 gpd. The effluent is discharged to the ocean through a 15-inch outfall extending 670 feet to sea, terminating in a diffuser consisting of one 6-inch and six 4-inch ports at a depth of 30 feet. Provision has been made in the design for possible future extension to a total length of 870 feet.

The effluent from the Wailua treatment plant is known to be high in nitrates and phosphates, but analyses of sea water samples taken near the outfall show only slight departures from the norm. No study of ecological effects of the present discharge and no analysis of the probable effects of the full-scale discharge seem to have been made. Until analysis can be made of the environmental effects of the full-scale discharge, it would be better to accommodate the discharge by permit than by establishment of a zone of mixing.

COOLING WATER

The only cooling water discharge for which a zone of mixture is sought is that from the Kauai Electric Co. power plant at Port Allen (Figure 6). This water is salt water drawn from wells. The maximum flow is reported to be 10 mgd. and the temperature is reported to be 93°F, maximum, at one point in the line. The temperature after the water cascades down a cliff and into the ocean is not reported, nor are temperatures in the ocean surrounding.

A small amount of sewage from the power plant is apparently injected into the cooling water discharge (Kauai Electric letter to Health Dept., 29 July 1970), but it is difficult to see how this small amount could account for the analyses reported of total phosphate 0.35 ppm (equivalent to 0.15 mg/1 phosphorus); and nitrate 9.0 ppm (equivalent to 2.0 mg/1 nitrogen). The phosphorus and nitrogen concentrations if correct, are 6 times and 13 times the respective tolerances for Class A water set in the Water Quality standards. The BOD analysis reported is of no consequence, but the oxygen content of salt water drawn from wells is often low, and that of the Port Allen discharge should be checked. For the same reason, the salinity also should be checked.

It is not clear why the sewage from the power plant is discharged with the cooling water instead of into the sanitary sewer system serving the rest of Port Allen. Such rerouting would eliminate any objections to the cooling water discharge based on sanitary considerations, which do not seem to be noted in the application.

It is not unlikely that the effects of the discharge of cooling water would be minimal if the sewage were routed elsewhere, even if the cooling water were deficient in oxygen and salinity as suspected may be the case, but before a zone of mixing is established there should be a much more systematic description of the field of dispersion and the effects of the alterations in water quality than has yet been demonstrated. In the meantime the discharge could readily be accommodated by issuance of a permit.

DRAINAGE WATER

The only drainage water discharges for whose accommodation zones of mixture have specifically been proposed are the two discharges of Kekaha Sugar Co. at Nohili and at Waieli (Figures 2 & 3). The water discharged includes excess irrigation water, waste artesian well water, natural ground-water seepage, and storm runoff. The excess irrigation water, which is derived partly from surface streams and partly from wells on and immediately back of the coastal plain, reaches the drainage canals partly by way of surface overflows but mostly by way of seepage through the coastal plain sediments. According to the application, the average discharges from the Nohili and Waieli drains, 14 mgd, and 55 mgd respectively, must be increased by 20 mgd and 50 mgd respectively, for periods of one to two weeks during and after kona storms to take care of the storm runoff.

In 1910, at the time of the first topographic survey of Kauai, there was a channel from the original coastal-plain swamps through the beach to the ocean at Waieli. This appears, however, to have been a dredged channel, and it is probable that the only original natural discharge from the swamps to the ocean was by ground-water seepage. At any rate, the present discharges represent concentrations of discharge of water a great deal fresher and richer in nutrients and sediments than any that originally reached the ocean in the vicinity, and probably varying in other respects as well.

The pollution control measures in effect, as described in the application for a zone of mixing, consist essentially of settlement, which must remove most of the sediment that would otherwise be discharged, as claimed, and perhaps some of the phosphate, but do not otherwise alter the quality of the water. Considering the flow rates to be accommodated, additional treatment would be expensive far beyond the usual range of treatment of agricultural waste water discharges. It is doubtful, however, that the ecological effects are as negligible as the application suggests, the esthetic effects are certainly obvious at times, and the sanitary effects deserve checking.

The most obvious effects are the turbidity and color which result from the discharge. These are not only readily visible but the colloids responsible must eventually settle, and their locus of deposition and ecological effects have not been determined. The colloids, by the way, must originate in major part from erosion on lands leased by the plantation, contrary to the impression given in the application, although the rates of erosion in the fields of the plantation may even be less than natural rates.

The nutrient concentration certainly cannot have no ecological effects, as the application claims, some low concentrations of herbicide seem likely to be present but have not been reported, and even the low salinity must be of some ecological consequence. Casual examinations of the coral in the vicinity of the Nohili discharge appears to indicate both growth stimulation and subsequent die-off,

but the relation of the changes to the discharge is unknown.

The current pattern in the vicinity of the discharges as described in the application agrees with that observed by Laevastu and others (Hawaii Inst. of Geophysics HIG-64-1, 1964) although Chamberlain (Hawaii Inst. of Geophysics HIG-65-6, 1965) found only a northward set in the vicinity of Nohili. Aerial observations in the early afternoon of 18 August 1970 indicated a convergence off Nohili marked by floating trash of unknown origin.

No analyses of the field of dispersion of turbidity, nutrients, salinity deficiency, or other pollution indicators have been provided to justify the large area proposed for the zone of mixing. It is quite probable that the dimensions required for the zone required to reduce concentration anomalies to tolerated limits vary considerably from pollutant to pollutant.

Certainly cessation of the discharge of drainage water at Nohili and Waieli would have severe economic effects. During the past few decades there has been considerable reduction in the waste of artesian well water and some further reduction might still be achieved, but the effects on the total discharge of drainage water would probably be slight. It is unlikely that any reasonable treatment would greatly alter the quality of the water discharged.

It seems quite probable that the drainage water discharges cause considerable variance from the water quality standards in the coastal waters. There has as yet, however, been no definition of the variances caused, and no adequate discussion of the ecological effects of the variances and the economic and esthetic consequences. The discharges could be accommodated as by the issuance of permits, for a period great as 5 years during which their consequences could better be defined, and such an accommodation is recommended in place of the more permanent action of establishment of a zone of mixing.

IRRIGATION TAIL WATER

As shown by table 1 and the figures accompanying this report, 11 separate zones of mixing have been proposed wholly or partially to accommodate the discharge of tail water from the irrigation of sugar cane fields. In the applications for these zones of mixing or in accompanying maps 33 tail water discharges have been identified, but some of these discharges probably involve more than one point of discharge, so that in total at least 40 and perhaps more than 50 discharge points must be involved.

The discharges reach the ocean variously by natural perennial streams, natural intermittent streams, artificial drains with perennial discharge, and points of discharge unrelated to any other natural or artificial drainage. In addition to the discharges identified as tail water in Table 1, the major Kekaha drainage water discharges at Nohili and Waieli include some tail water.

The individual tail water discharges are probably all small, and the flow rates appearing in the applications and in Table 1 are probably to some extent misleading. The flows listed for Lihue Plantation Co. discharges 3 (figure 10), 4, and 5 (figure 11), for example, are probably total flows of the drains and streams through which the tail water is discharged rather than the tail water flows themselves. In fact, the applications for zones of mixing for these particular discharges formally refer to Class 2 surface waters rather than Class A coastal waters, although if the portions of the drains and streams into which the discharges are made are tidal, they are properly included in the Class A coastal waters by the Water Quality Standards. The Grove Farm discharge is described at Kawailoa Bay (figure 8), but aerial observation on 18 August 1970 suggests that the discharge is located instead in the next bay to the southeast at the point of outlet of the Kapunakea Spring (at Waiopili Heiau) and hence mixed with the discharge of the spring and storm drainage as well. In the case of other tail water discharges, it is not clear whether the average flow figures shown in the applications are averages only over periods when the discharge is occurring.

The tail waters may introduce into the ocean nitrates, phosphates, soil, herbicides, BOD or oxygen deficiency, and possibly trash, in addition to a deficiency in salinity. The concentrations of the various potential pollutants probably vary greatly from discharge to discharge. There is very little information in the applications on the water quality of the various discharges, but it probably varies considerably, not only from discharge to discharge but in some of the discharges from time to time. Similarly the ecological effects are likely to vary greatly. The water quality in the Waiakea Canal (Lihue Plantation No. 5) (figure 11) fails to meet the standards for Class A waters by reason of bacterial concentration (Water Resources Research Center Tech. Rept. 31, 1970) which has nothing to do with the tail water discharge through the canal, and there may be similar problems with the

water of Kapaa Stream and possibly other perennial streams and drains.

In the course of the last few of decades there has probably been some general decrease in tail water discharge as a result of attempts to increase irrigation efficiency, and in the applications there is an indication of attempts to reduce objectionable effects, as in the creation of sediment traps at several discharge points and in the rerouting of McBryde discharge no. 12 (figure 7) to avoid Kukuiula Harbor.

The number of discharge sites is so great and the rates of discharge of both water and pollutants so small at any one site, that thorough study of the flow and quality of the discharge, the field of dispersal, and the ecological and esthetic effects at each individual site is probably unwarranted. However, some of the zones of mixing applied for are very extensive. Of the eleven zones of mixing proposed to accommodate tail water discharges, 5 exceed 100 acres in area. Those of these larger zones are proposed to accommodate mill waste water as well as irrigation tail water discharges.

Before any action is taken on the establishment of these zones of mixing, which would be without time limit, it would seem essential that the general character of the discharges in relation to the standards, the general limits of the fields of dispersal, and the general ecological and esthetic effects be determined by a much greater density of sampling and range of analyses than seem to have been utilized to date, and that detailed studies be made in any areas of special ecological sensitivity or esthetic importance. In the meantime the discharges could be permitted by time-limited permits.

MILL WASTE WATER

As indicated by the applications for zones of mixing, waste water from sugar mills is discharged to coastal waters at the following points:

Olokele Sugar Co.	(3) Trash plant water	1 mgd.	Fig. 4
" " "	(5) Mill waste discharge	1.8 mgd.	" "
McBryde Sugar Co.	(4) Intermittent filter cake discharge	?	Fig. 5
Lihue Plantation Co.	(1) Discharge from factory	7 mgd. (incl. some tail water)	Fig. 9
Kilauea Sugar Co.	Mill water discharge	5 mgd.	Fig. 14

Since the advent of mechanical harvesting in the Hawaii sugar plantations, large amounts of cane trash and mud have been transported to the sugar mills with the cane necessitating the operation of cane cleaning plants. The trash and mud in the wash water, together with other wastes including baggasse at some mills, were generally discharged into coastal waters or into gulches tributary to coastal waters. The effects of sugar mill waste water discharges has long been of concern on Kauai as well as elsewhere in Hawaii. As early as 1949, a survey was made of the discharges of Kekaha Sugar Co., Olokele Sugar Co., and McBryde Sugar Co. by the research staff of the Division of Fish and Game, of the Territorial Board of Agriculture and Forestry. To quote from their report (Legislative Holdover Comm. Rept., Exhibit K, 1949):

"The purpose of this survey, which was undertaken at the request of the fishermen on Kauai, was to determine the extent of pollution in these waters and if possible the effect of the pollutants upon the inshore fisheries. Fish such as akule, opelu, kumu, weke, moana, uu, aweoweo, aholehole, manini, etc., which make up the inshore fishery in these waters, are intimately dependent upon the shallow ocean bottom as well as upon the minute suspended planktonic organisms which make up their food. These fish are adapted to life in inshore waters where the conditions of their natural habitat are not subjected to extreme changes in food supply, oxygen tension, salinity and other hydrographic conditions. Any decrease in the abundance of fish in these waters is quickly attributed by fishermen to these changes or to the presence of waste products from shore. Suspicion was directed toward the large volume of mud-saturated water which blanketed a great portion of these coastal waters and also to the great amount of bagasse and cane strippings which floated in these waters."

The report described the turbidity, organic waste pollution and deficient oxygen concentration that resulted in the coastal waters and mud deposits on the bottom, previously at depths between 45 and 70 feet.

Its conclusions were as follows:

"The effect of pollutants in these coastal waters are difficult

to determine quantitatively. The extent of the so-called polluted areas depends upon the physical conditions of the sea and vary from time to time. Most of the fish comprising the present inshore fishery would probably avoid areas of low oxygen concentration as well as those areas containing large quantities of muddy water and cane trash. This would also be probably true for planktonic forms. It is quite conceivable, however, that some scavenger or carnivorous fish would gather at the fringes of these areas and feed on the food washed in from land.

"The effect of the pollutants upon the bottom is somewhat more definite. If the present method of sugar cane waste disposal is continued, coral and other bottom fauna in these areas between the depths of 45 and 75 feet will gradually die out. Bottom feeding forms such as weke, moana, kumu, manini, kala, etc., will have none of the usual food available. Bottom dwelling forms such as aweoweo, uu, aholehole, uhu, etc., will have to move to areas which sustain more life. Mud covered bottoms beyond 75 feet will not be able to sustain most of the fish that comprises the present inshore fishery. Little can be said for the total quantitative effect of the pollutants by the present survey. More work will have to be done before any conclusive statement can be made."

Since 1949, the situation has changed materially. Hydro-separators and other devices have been constructed at most mills, which extract most of the trash and mud from the wash water, and most of the wash water is now used for irrigation so that only the tail water and other excesses are now a problem. The discharge at McBryde, according to the application, is only sporadic but at times is untreated. The discharges at Olokele and Lihue appear to be continuous during the grinding season, but treated by settling. No control measures are in effect at Kilauea, according to the application. Baggasse is not a problem at most Kauai mills because it is consumed as a fuel.

The nature of the sugar-mill waste-water discharges is poorly indicated in the applications for zones of mixing. They must vary considerably as a result of the differences in control and treatment. A study by the Federal Water Quality Administration (Burm and Morris. The effect of turbid, high carbohydrate, sugar processing wastes on tropical open sea. Paper at 5th Internat. Conf. on Water Pollution Research, Honolulu, 1970) has indicated that mud, cane trash, nutrients, waste sugar and other soluble organics, and bacteria may be among the constituents contributing to variances from the Water Quality Standards. Average characteristics of untreated waste water at three sugar mills, were expressed as follows:

Suspended solids	390,000 lbs/day
Settleable "	370,000 "
COD	135,000 "
Total nitrogen	2,500 "
Total phosphorus	1,050 "
Total coliforms	4,850,000/100 ml (geom. mean)
44.5^{o} coliforms	130,000/100 ml (geom. mean)

According to Burm and Morris: "It was demonstrated that standard sedimentation processes could reduce some of these values by a factor of 10 or greater", but their paper does not show loads or concentrations after treatment. It is to be hoped that considerable additional detail will be provided on the physical, chemical, and microbiological character of each of the actual Kauai discharges, at the public hearings to consider the establishment of zones of mixing to accommodate these discharges.

The same paper by Burm and Morris provides some information on the field of dispersal of the mill waste waters from McBryde Sugar Co. and Olokele Sugar Co. through surface turbidity measurements as of April 1968 (Figure 15). At the time of the survey the Secchi-disk visibility was less than 8 feet along the axis of a plume extending from the McBryde discharge point to a point off Puolo Point. The effects of the Olokele Sugar Mill waste water discharge were apparently not distinguishable within a broad zone with visibility less than 31 feet extending along the entire coast line, to which undoubtedly not only mill-waste discharge but tail-water discharge and natural stream discharge contributed.

In general Burm and Morris demonstrate that coliform bacterial pollution far in excess of toleration limits set by the Water Quality Standards and excess dissolved phosphorus in the vicinity of the outfall may accompany sugar mill waste discharge in the sea. Dissolved oxygen, salinity, temperature and nitrogen values, however, were found to be close to normal. Extensive siltation of the bottom and severe depression of the growth of coral, sponges and benthic algae were characteristic in the outfall areas. Diminished amounts of fish life were found in the vicinity of all of the mill-waste outfalls examined.

Information on turbidity in other seasonal conditions, on other pollution parameters and on the effects of the pollution pertinent to the McBryde and Olokele mill-waste discharges, are not presented in the Burm and Morris paper, nor are pollution parameters or pollution effects at other mill-waste water discharges on Kauai although additional information pertinent to the Olokele-McBryde discharges and their effects is believed to have been collected by the Federal Water Quality Administration.

The data collected in 1967-68 may no longer be pertinent if there have been subsequent improvements in control of the mill waste discharges and the establishment of zones of mixing should be considered on the basis of current conditions and the potential of future improvements, not on past conditions. Testimony by at least one of the sugar companies indicates that further improvements in waste water control by siltation basins are planned and that a dry cleaner, which would completely change the dimensions of the mill-water waste problem, is expected to be installed by 1976. It would seem that similar improvements should be possible for the other companies involved. To accommodate the present discharges, the establishment of zones of mixing, which would be without limits of time, would therefore be very unwise.

Among other reasons, such action would remove an important incentive to proceed with the planned improvements. Such reduced zones of mixing as may be appropriate to accommodate the reduced waste loads of the future cannot be satisfactorily outlined until the improvements can be installed and tried. In the meantime the present discharges can be accommodated as may be appropriate by permits.

Particularly in the case of the zone of mixture proposed by Kilauea Sugar Co., the application should be denied. The termination of sugar cane growth and milling within the next couple of years has been publicly announced. The mill waste discharge will cease with this termination. The continuance of the discharge, with the trash screened out of it as suggested by the application, can readily be accommodated for the short time necessary. Perpetuation of a waiver of the standard water quality criteria on the Kilauea coast through the establishment of a zone of mixing would be quite unjustifiable.

CONCLUSIONS

Applications from eight agencies are being considered for the establishment of 15 zones of mixing in the coastal waters of Kauai with a total area of over 12,000 acres, nearly 20 square miles, to accommodate discharges of five different types of waste water occurring at 50 separate sites. Summarized statistics of the discharges and proposed zones of mixing are shown in Table 3.

Table 3.
Summary of proposed
zones of mixing in Kauai coastal waters

Discharges			Zones of mixing proposed	
Type	Number	Total Average flow mgd	Number	Total area acres
Cooling water	1	10	1	?
Drainage water	2	70	1	4,200
Secondary treated sewage	1	0	1	?
Mill waste water	5	15+?	4*	5,700*
Irrigation tail water	40+	8+	11*	4,800*
Total	50+	103	15*	12,000*

*Zones of mixing for mill waste water and for tail water discharges overlap. Hence individual numbers and areas do not add to total.

The ecological, esthetic, and economic effects of these discharges vary enormously depending on the type of discharge, its flow rate, and its concentration of undesirable materials, and in addition on natural physical, chemical, and biological conditions at and near the discharge site.

For the proper consideration of the establishment of a zone of mixing, information must be submitted whereby the pertinent economic, ecological, and esthetic effects may be analyzed and such an analysis must be made from the standpoint of the overall public interest. Within each zone of mixing, special tolerance limits should be set for those pollutants whose mixing is to be accommodated, whereas for other pollutants the normal limits for the class of water in question should be retained. A suitable monitoring program may be required for continuance of a zone of mixing.

For the discharge from the sewage treatment plant, full information should be provided on the quality of the discharge, the field of dispersal, and on the environmental effects. For the cooling water discharge, information should be provided on oxygen content and salinity of the discharge, on the field of dispersal, and on the

environmental effects of the discharge. The sewage now injected through the cooling water discharge should be discharged through the sanitary sewer system. Because the flow rate of the sewage discharge is small and the mixing conditions at the outfall are probably good, and because the nature of the cooling water discharge is simple (assuming the sewage is removed), the studies required to produce information adequate for the analysis of the proposed zones of mixing should not take much time. In the meantime the discharges can be accommodated by permit.

For the drainage-water discharge, quantitative information should be provided on the suspended solids, dissolved solids, nutrients, and other pollution parameters of the discharge, the field of dispersal should be described for each pertinent parameter, and the field of sedimentation for the suspended material, and the effects of the discharge described and evaluated. The possibilities of reduction in the flow by further control of leakage from artesian wells, and the possibilities of treatment of the water should be examined. The field of dispersal for each pollutant and the field of deposition of sediment should be determined. The environmental consequences of the discharge should be described and evaluated.

Because of the magnitude of the discharge is large and its water quality is complex, a thorough study of its effects would be a major enterprise. It would require an exhaustive study, however, to indicate whether or not the effects are sufficiently important to justify such alternatives to the discharge as may be available, all probably very costly either directly or in terms of loss of agricultural productivity. Pending the completion of the study adequate in these terms, the discharges can be accommodated through permits.

For each mill-waste discharge quantitative information should be provided on the characteristics of flow and quality, with particular regard to suspended solids, dissolved solids, nutrients, BOD, and bacteriological content. Again a field of dispersal for each pollutant and the field of disposition of sediment should be determined, and the environmental consequences of the discharge described and evaluated.

The effects of these discharges in the past have been proved to be considerable, and a study adequate to distinguish between the confining consequence of past discharges and the consequences of discharge, with the controls that have been effected will be difficult. A thorough study is needed, but useful and reliable results probably cannot be expected for a few years. For most of these discharges, further, additional improvements are planned or seem probably feasible within periods of a few years.

Until the future reductions in flow and improvements in quality now forseen can be effected, and until the studies can be completed and the appropriateness of establishment of zones of mixing can properly be assessed, most of the discharges, duly reduced and improved

as to quality, can be continued by permit. However, no zone of mixing should even be contemplated to accommodate the discharge of Kilauea Sugar Co. that is due to terminate in a couple of years and can be continued, with improvement by screening, until it is terminated.

For the tail-water discharges more information is needed on their flow characteristics, the flow characteristics of the natural flows of streams and canals through which some of the discharges occur, on water quality parameters, especially suspended solids, nutrients, and herbicides, on the fields of dispersal and sedimentation, and on the environmental consequences. Because the discharges are generally small, elaborate studies are not needed except where the discharges occur by way of natural perennial streams. However, the effects of the tail water discharges will in many areas be difficult to disentangle from the effects of mill waste discharge. Until adequate studies can be made, the discharges can be continued by permit.

APPENDIX

Subsequent to the preparation of the bulk of the foregoing report additional pertinent information has come to hand as the result of a brief aerial survey of the Kauai coast and through late documentation supplementary to the applications for zones of mixing.

Areal Survey

The aerial survey was conducted on the afternoon of 18 August 1970 by Cox and Kay accompanied by Hiroshi Yamauchi of the Water Resources Research Center. Observations on the current field off Nohili (Fig. 2) as indicated by floating trash, and on the point of discharge of Grove Farm's tail water (Fig. 8) have been incorporated in the text of the report, but some additional general observations are warranted.

The most striking observation was the great reduction in turbidity that has been achieved along the south and east coasts of the island, probably resulting primarily from better control of the mill waste discharges of McBryde Sugar Co. and Lihue Plantation Co., and perhaps partly from the control of tail waters. The general turbidity that not long ago clouded the waters from Hanapepe to Mahaulepu and from Nawiliwili to Anahola was no longer noticeable. There were a few local evidences of turbid discharges, for example, in one of the small bays north of Kealia (Fig. 11), on the north shore of Nawiliwili Bay, at the discharge from Kapunakea spring (Fig. 8), and at Kukuiula (Fig. 7). The largest area of turbid water, in Hanapepe Bay, presumably resulted from the discharge of flood water rather than any of the waste waters for whose accommodation zones of mixing have been proposed, because it was restricted to the part of the bay inside the breakwater.

The easternmost of the two mill-water discharges listed by Olokele Sugar Co. was not discernible, but the westerly one was clearly noticeable and apparently served as a source for large but patchy clouds of turbidity further west. To these clouds there might also have been contributions as well from Waimea River and from shallow-water deposits of sediment resulting in part from the larger mill-water discharges of the past.

Of the two Kekaha drainage-water discharges (Figs. 2 and 3), that at Nohili seemed to be contributing the most to offshore turbidity and may perhaps have been the source of the floating trash marking the current convergence to the west.

The Kilauea mill-water discharge resulted in a continuous broad cloud of turbid water extending several miles off the coast to the west.

From these observations may be drawn a reminder of the difficulty that will be encountered in separating the effects of current waste discharges of the past and those of the natural discharge of streams, such as will be necessary evaluating effects of current discharges.

Late Documentation

Additional documentation that has just become available permits a more exact count of the discharges for which accommodation by zones of mixing has been proposed, but it indicates that improvements in waste-water control have now reduced the number of discharges and the number of zones of mixing considered needed, or at least the amount of variance from normal standards needed within the proposed zones of mixing. The recent documentation also provides some additional information on physico-chemical and biological effects of the discharges. Time has not permitted extensive analysis of the new information, but some conclusions seem justified.

Testimony provided by Lihue Plantation Co. permits a more exact accounting of its tail-water discharges, as shown in an accompanying table. With the discharges of other agencies, it appears that the consideration of zones of mixing has involved a total of 60 tail-water discharges, and a grand total of 69 discharges of all types.

Information provided by Kauai Electric Co. indicates that the well water used for cooling is indeed much fresher than sea water, and that it will cause a salinity anomaly as well as a temperature anomaly in the ocean.

Testimony from Kekaha Sugar Co. provides some useful observations pertinent to the physico-chemical and ecological effects of the drainage-water discharges. Analysis of samples taken at various distances from the discharge points suggests that the effects of nutrients are slight and that turbidity, which has a considerable range is the major concern. However, the distribution of salinity raises some question that the distance of sample sites from discharge points is indicative of increasing mixing. Pictures of clean sand and rocky bottom in clear water are encouraging, but do not elucidate where the muddy sediments are being deposited, nor of course how much mud is discharged, and hence do not permit analysis of its effects.

Testimony of McBryde Sugar Co. and Lihue Plantation Co. accounts for the improvements in conditions noted on the coasts of those plantations and supports the assumption that the improvements are essentially continuous and permanent and not related solely to the time of observation. Mill-waste-water discharge to the ocean at these plantations either has already been essentially eliminated or will be eliminated in 1971, and it would seem unnecessary and hence undesirable to establish zones of mixing with the dimensions originally proposed to accommodate these discharges. At the very least, the zones of mixing, if not reduced in size should be qualified as to the periods within which are to be permitted turbidity and other anomalies resulting from the accidental release of mill wastes, for example during storms.

Clearly the controls recently introduced or planned at these plantations and at Olokele Sugar Co. have reduced enormously the degree to which mill-waste-water discharges violate the pollutant tolerances set in the Water Quality Standards for coastal waters. Clearly also,

Lihue Plantation Tail-water Discharges

Zone number		Number of discharges						
This report	Lihue id.	Tail water only	Streams	Natural drains	Arti-ficial drains	Mill ditch	Storm ditch	Total
1	2	17		1		1 (0)*	1	20 (19)*
2	3	1						1
3	4				1			1
4	5				1 (0)*			1 (0)*
5	6		1 (0)*					1 (0)*
6	7	15	4 #	3				22
7	8		1#					1
Total		33	6 (5)*	4	2 (1)*	1 (0)*	1	47 (44)*

Notes:

* Numbers in parentheses omit present discharges apparently to be eliminated.

Discharge from Papaa Stream includes tail water discharged to stream at several points. Application for zone of mixing should apply to the Class 2 water of the stream in the reach affected as well as the Class A coastal water affected. Any other perennial natural discharges, for example the four major drains through which tail-water discharges are made in zone 6 (Lihue No. 7) are class 2 waters and should also be subject to possible establishment of zones of mixing.

however, the extent of the residual environmental effects of these discharges cannot yet be evaluated. The recommendation that the discharges be accommodated by permits is therefore still valid.

Testimony provided by Lihue Plantation Co., McBryde Sugar Co., and Grove Farm Co. provides evidence of additional controls on tail-water discharge of considerable significance through consolidation of discharge points, creation of settling ponds and seepage fields, and increasing efficiency of irrigation. It appears that Lihue discharges nos. 4 and 5 (in this report = plantation nos. 5 and 6) may not need to be accommodated by zones of mixing, and explains the discrepany between the present turbidity at the discharge of Kapunakea Spring, which results from a present Grove Farm discharge tail water that is to be discontinued, and the application for a zone of mixing for a discharge in Kawailoa Bay.

With the cessation or at least great reduction in mill-waste discharge , and the further control of tail-water discharge, it is questionable that such large zones of mixing are required for tail-water discharges as have been proposed. Again, further study of present effects and those of the planned further improvements seems desirable before the eventual award of zones of mixing and, for the present, accommodations of the discharge is recommended to be by permit.

An application for discharge permits must be accompanied by a schedule of implementating actions whereby compliance with the water quality regulations will be achieved. In the case of all types of discharge for which present accommodation by permit has been recommended, it would seem appropriate that the implementing actions to be listed should include not only adequate trial of present improvements with monitoring of effects, and implementation of planned improvements with continuing monitoring, but also studies of possible further improvements, evaluation of environmental effects and economics, and the design of and application for eventual appropriate zones of mixing.

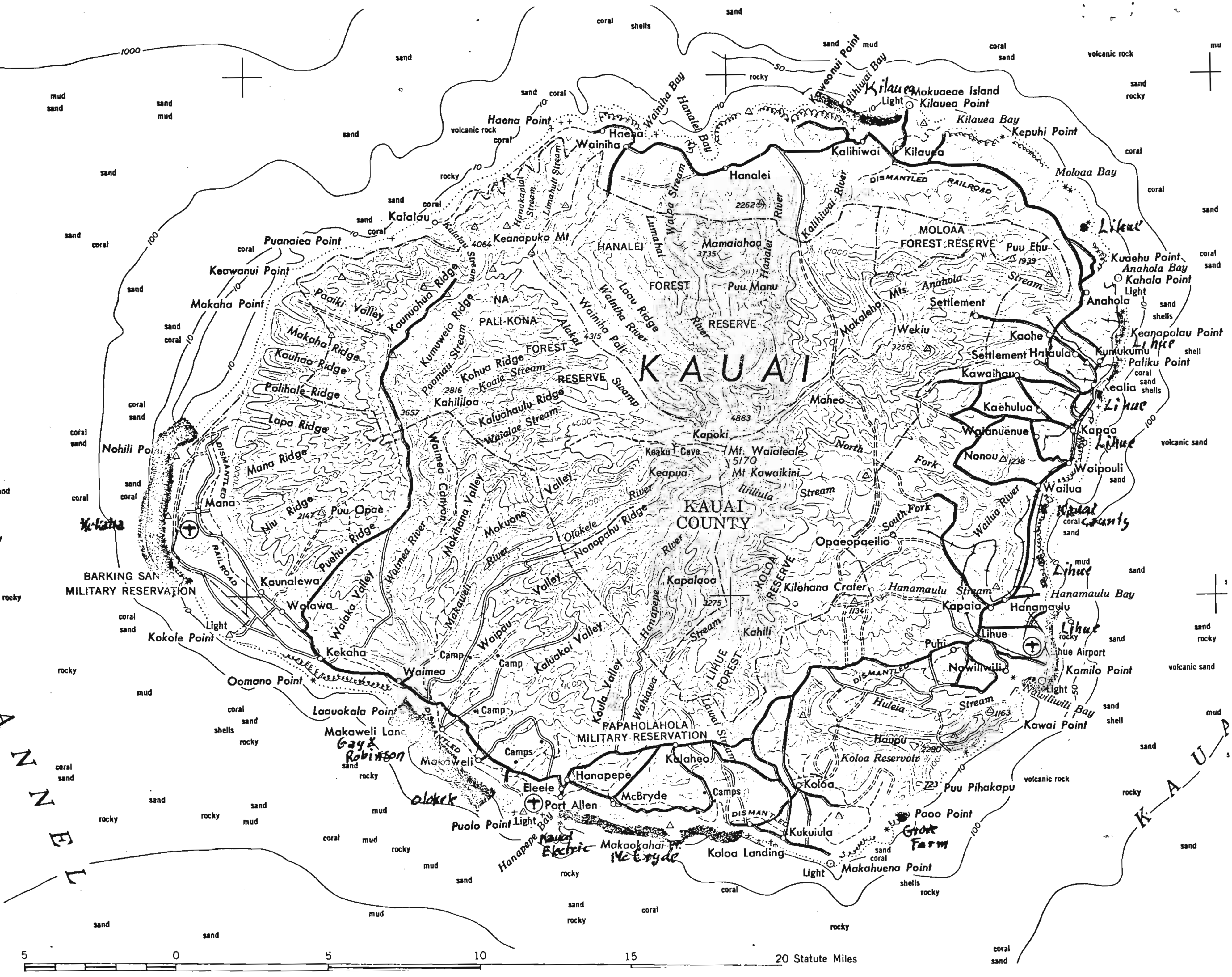

KAUAI
KAUAI COUNTY
CHANNEL
KAUAI
Haena Point
Haena
Wainiha
Wainiha Bay
Hanalei Bay
Hanalei
Kalihiwai Bay
Kaweonui Point
Kilauea
Mokuaeae Island
Light
Kilauea Point
Kilauea Bay
Kepuhi Point
Kalihiwai
DISMANTLED RAILROAD
Moloaa Bay
MOLOAA FOREST RESERVE
Puu Ehu
Kuaehu Point
Anahola Bay
Kahala Point
Anahola
Settlement
Kaohe
Keanapalau Point
Kumukumu
Paliku Point
Kealia
Kawaihau
Kaehulua
Waianuenue
Kapaa
Nonou
Waipouli
Wailua
Wailua River
South Fork
North Fork
Opaeopaeilio
Kilohana Crater
Hanamaulu Stream
Hanamaulu Bay
Hanamaulu
Kapaia
Lihue
Lihue Airport
Puhi
Nawiliwili
Kamilo Point
Nawiliwili Bay
Kawai Point
Huleia Stream
Haupu
Koloa Reservoir
Puu Pihakapu
Paoo Point
Koloa
Kukuiula
Koloa Landing
Makahuena Point
Kahili
LIHUE FOREST RESERVE
KOLOA RESERVE
Kapalaoa
Hanapepe River
Mt. Waialeale
Mt Kawaikini
Kapoki
Keapua
Kaaku Cave
Iliiliula Stream
Makaleha Mts.
Wekiu
Maheo
Mamaiahoa
Puu Manu
HANALEI FOREST RESERVE
Lumahai River
Waipa Stream
Hanalei River
Kalihiwai River
Laau Ridge
Wainiha River
Wainiha Pali
Alakai Swamp
NA PALI-KONA FOREST RESERVE
Keanapuka Mt
Kalalau
Kalalau Stream
Hanakapiai Stream
Limahuli Stream
Puanaiea Point
Keawanui Point
Makaha Point
Paaiki Valley
Kaunuohua Ridge
Kumuwela Ridge
Makaha Ridge
Kauhao Ridge
Polihale Ridge
Lapa Ridge
Mana Ridge
Niu Ridge
Puu Opae
Puehu Ridge
Kohua Ridge
Poomau Stream
Koaie Stream
Kahililoa
Kaluahaulu Ridge
Waialae Stream
Waimea Canyon
Makihana Valley
Mokuone Valley
Olokele Valley
Nonopahu Ridge
Waimea River
Makaweli River
Waipau Valley
Kaluakoi Valley
Koula Valley
Wahiawa
Lawai Stream
Nohili Point
Mana
DISMANTLED RAILROAD
BARKING SANDS MILITARY RESERVATION
Kaunalewa
Waiaka Valley
Waiawa
Light
Kokole Point
Kekaha
Oomano Point
Waimea
Laauokala Point
Makaweli Landing
Makaweli
Camp
Camps
Eleele
Hanapepe
Port Allen
McBryde
Kalaheo
PAPAHOLAHOLA MILITARY RESERVATION
Puolo Point
Hanapepe Bay
Makaokahai Pt.
20 Statute Miles
5 0 5 10 15

Figure 1.

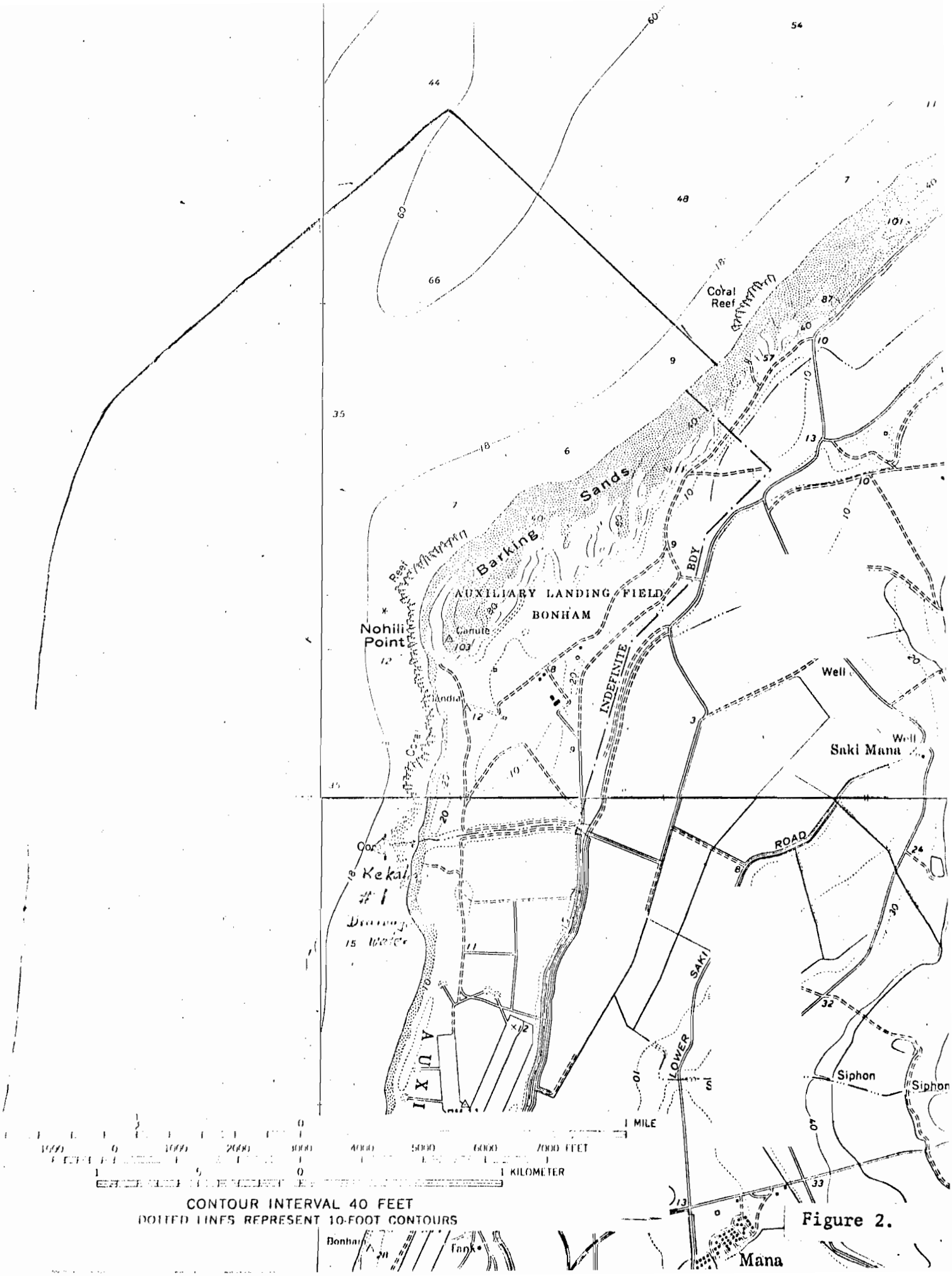

Coral Reef
Barking Sands
AUXILIARY LANDING FIELD
BONHAM
Nohili Point
Canute
INDEFINITE
BDY
Well
Saki Mana
ROAD
SAKI
LOWER
Siphon
Siphon
Mana
Tank
1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 0 1 KILOMETER
CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 10-FOOT CONTOURS

Figure 2.


AUXILIARY
LANDING
FIELD
BONHAM
LOWER
Siphon
Siphon
Mana
Bonham
Tank
Control Tower
Mana Point
BM 11
BM 15
BM 8
BM 10
Kawaiele Pumping Station
Kekaha #2
Drainage water
Well
Coral
Waiaka Dr
1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 KILOMETER
CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 10-FOOT CONTOURS

Figure 3.

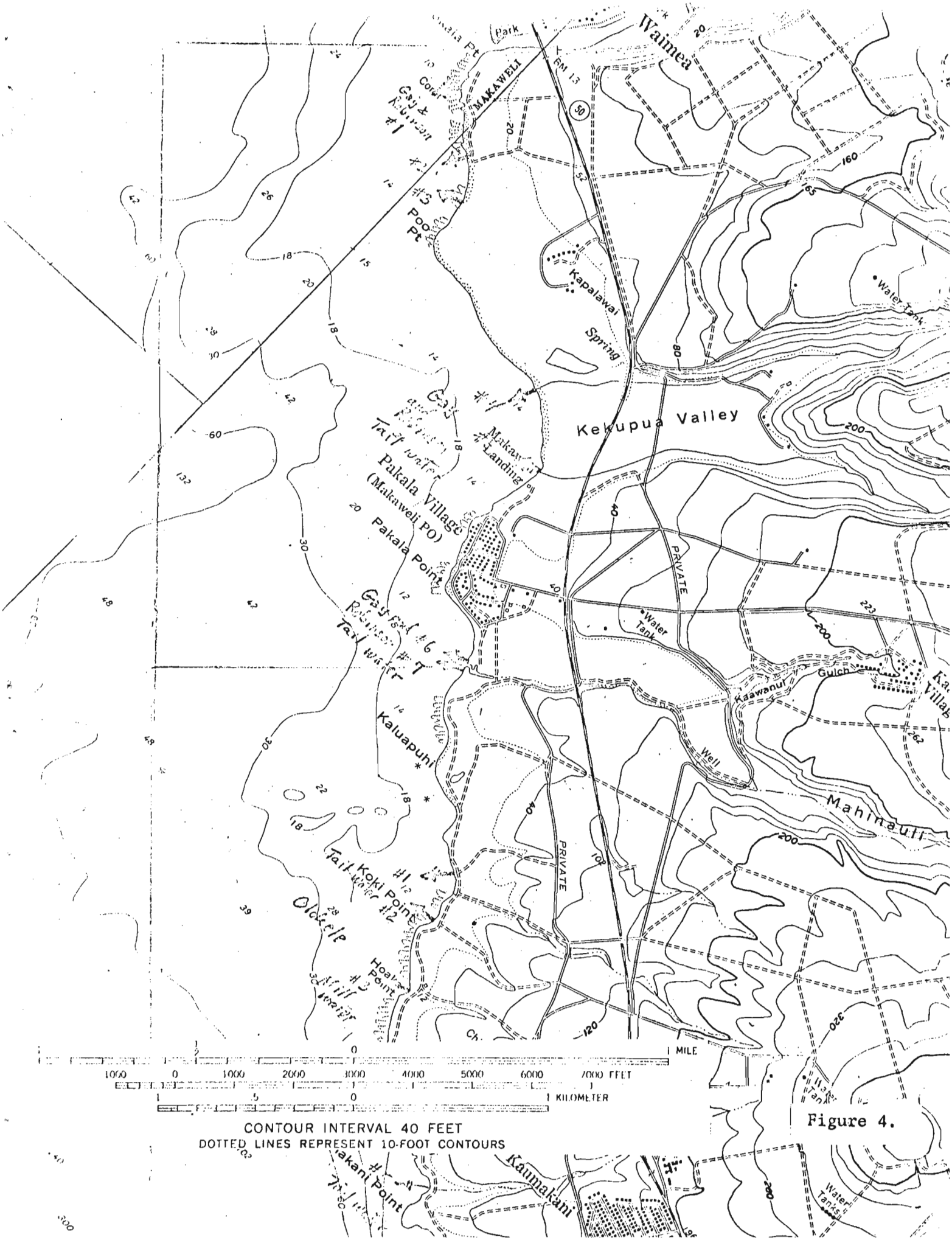

Waimea
Park
MAKAWELI
FM 13
50
Poo Pt
Kapalawai Spring
Water Tank
Kekupua Valley
Makaweli Landing
Pakala Village (Makaweli PO)
Pakala Point
PRIVATE
Water Tank
Kaawanui Gulch
Well
Kaluapuhi
Mahinauli
Koki Point
Hoava Point
Kaumakani
Water Tanks
1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 0 1 KILOMETER
CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 10-FOOT CONTOURS

Figure 4.

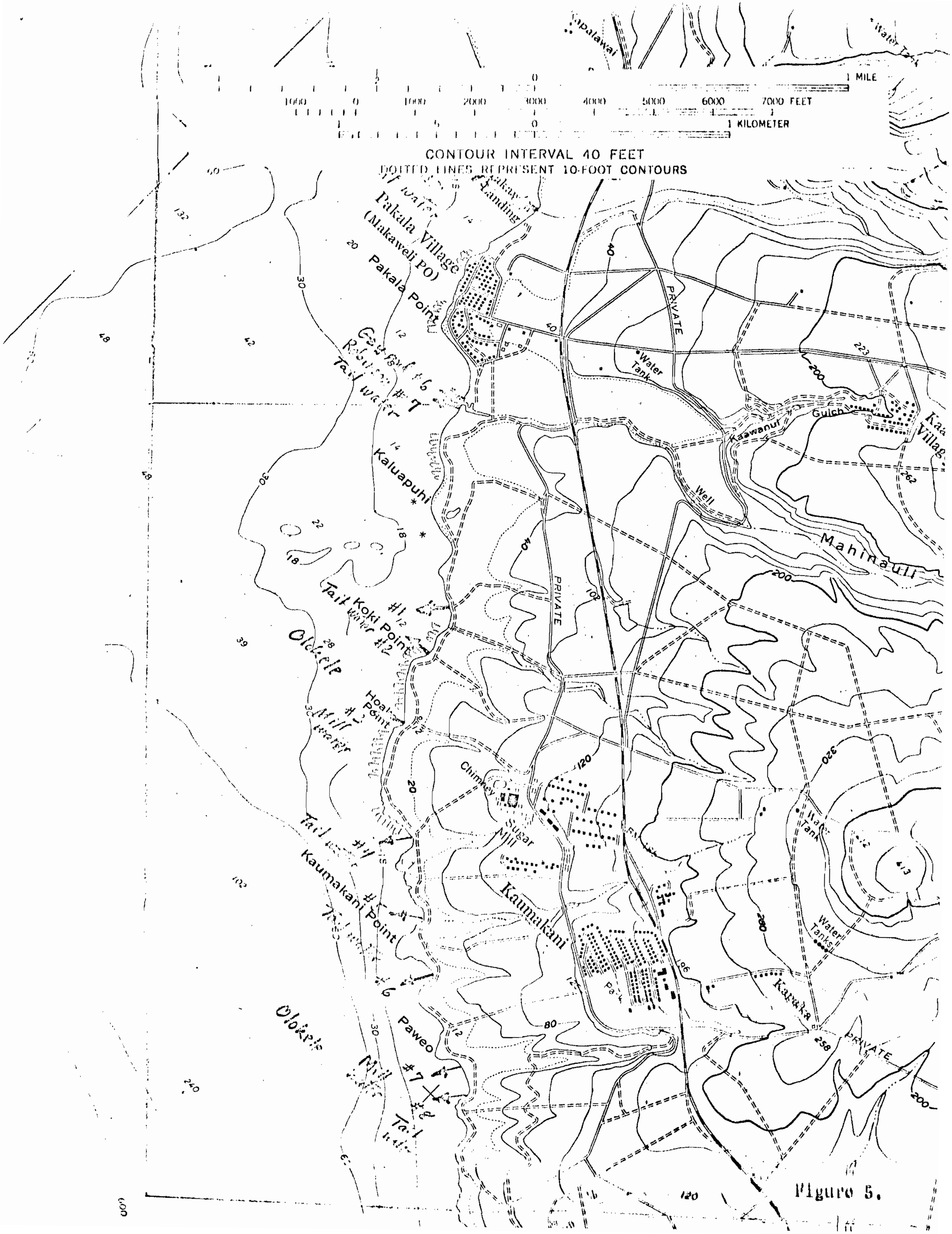

1 MILE
1000
0
1000
2000
3000
4000
5000
6000
7000 FEET
1 KILOMETER
CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 10-FOOT CONTOURS
Pakala Village
(Makaweli PO)
Pakala Point
Landing
PRIVATE
Water Tank
Kaawanui
Gulch
Well
Mahinauli
Kaluapuhi
Koki Point
Hoai Point
Chimney
Sugar Mill
Kaumakani
Kaumakani Point
Paweo
Water Tanks
Karaka
223
200
262
320
280
258
120
80
20
30
40
Tail water
Mill water

Figure 5.


Hanapepe
Kukamahu Gulch
Eleele
Kiaha Res
Camp No 2
Petroglyphs
CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 10-FOOT CONTOURS
Park
Veterans Cemetery
Cem
ROAD
Small Boat Harbor
Port Allen
Hanapepe Bay
BM
BREAKWATER
Light
Cem
PORT ALLEN AIRPORT
Paakahi Point
Hanapepe Light
Point
Kauai Electric McBryde #1 cooling water
McBryde #1 tail water
Wahiawa
Weli Point
McBryde #2 tail water
McBryde #3 tail water
McBryde #4 mill water and tail water
McBryde #5 tail water
McBryde #6 tail water
Koheo Point
Park
Numila
Sugar Mill
Maile Res
OCEAN

Figure 6.

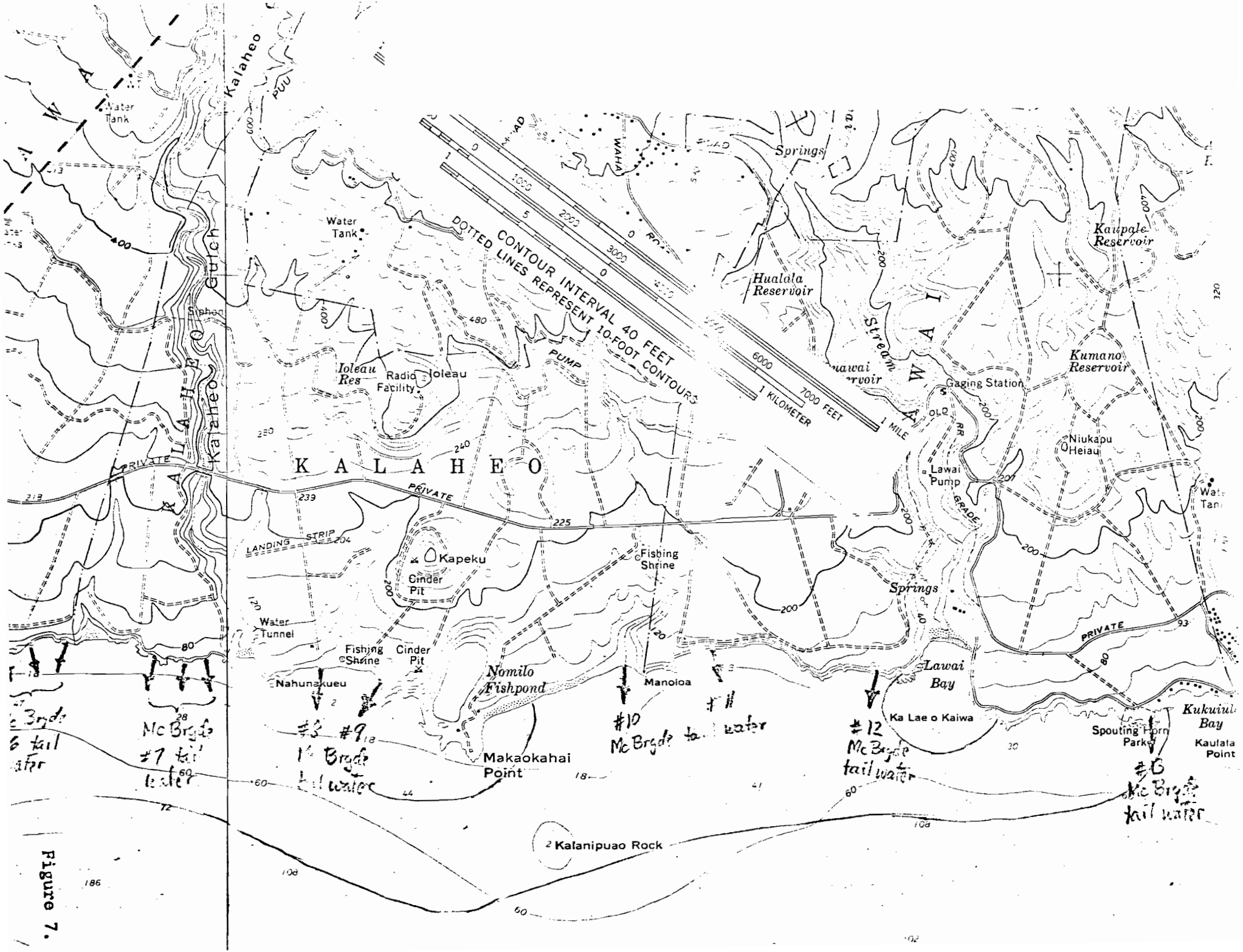
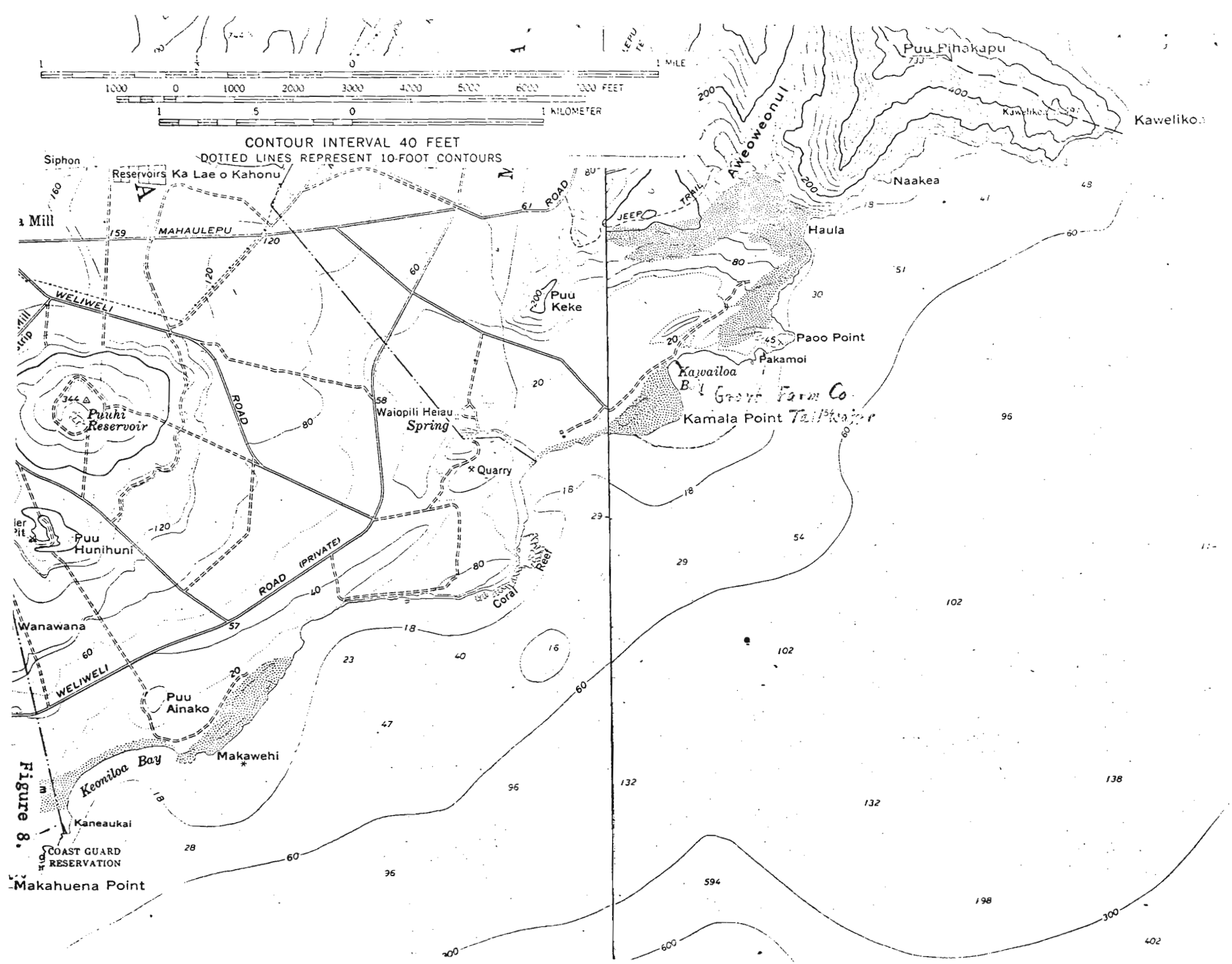

KALAHEO
CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 10-FOOT CONTOURS
1 KILOMETER
1 MILE
7000 FEET
Kalaheo
Water Tank
Siphon
Gulch
Ioleau Res
Radio Ioleau Facility
PUMP
PRIVATE
LANDING STRIP
Kapeku
Cinder Pit
Water Tunnel
Fishing Shrine
Nahunakueu
Nomilo Fishpond
Manoloa
Makaokahai Point
Kalanipuao Rock
Springs
Hualala Reservoir
Stream
Gaging Station
Kaupale Reservoir
Kumano Reservoir
Niukapu Heiau
Lawai Pump
GRADE
RR
Lawai Bay
Ka Lae o Kaiwa
Spouting Horn Park
Kukuiula Bay
Kaulala Point
#3 #9 McBryde tail water
#7 tail water
#10 McBryde tail water
#12 McBryde tail water
#6 McBryde tail water

Figure 7.


1 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 5 0 1 KILOMETER
CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 10-FOOT CONTOURS
Siphon
Reservoirs Ka Lae o Kahonu
MAHAULEPU
61 ROAD
JEEP TRAIL
Puu Pihakapu
Aweoweonui
Kawelikoi
Naakea
Haula
Puu Keke
WELIWELI
Paoo Point
Pakamoi
Kawailoa
Kamala Point
Puuhi Reservoir
Waiopili Heiau
Spring
ROAD
Quarry
Puu Hunihuni
ROAD (PRIVATE)
Coral Reef
Wanawana
WELIWELI
Puu Ainako
Makawehi
Keoniloa Bay
Kaneaukai
COAST GUARD RESERVATION
Makahuena Point
Figure 8.

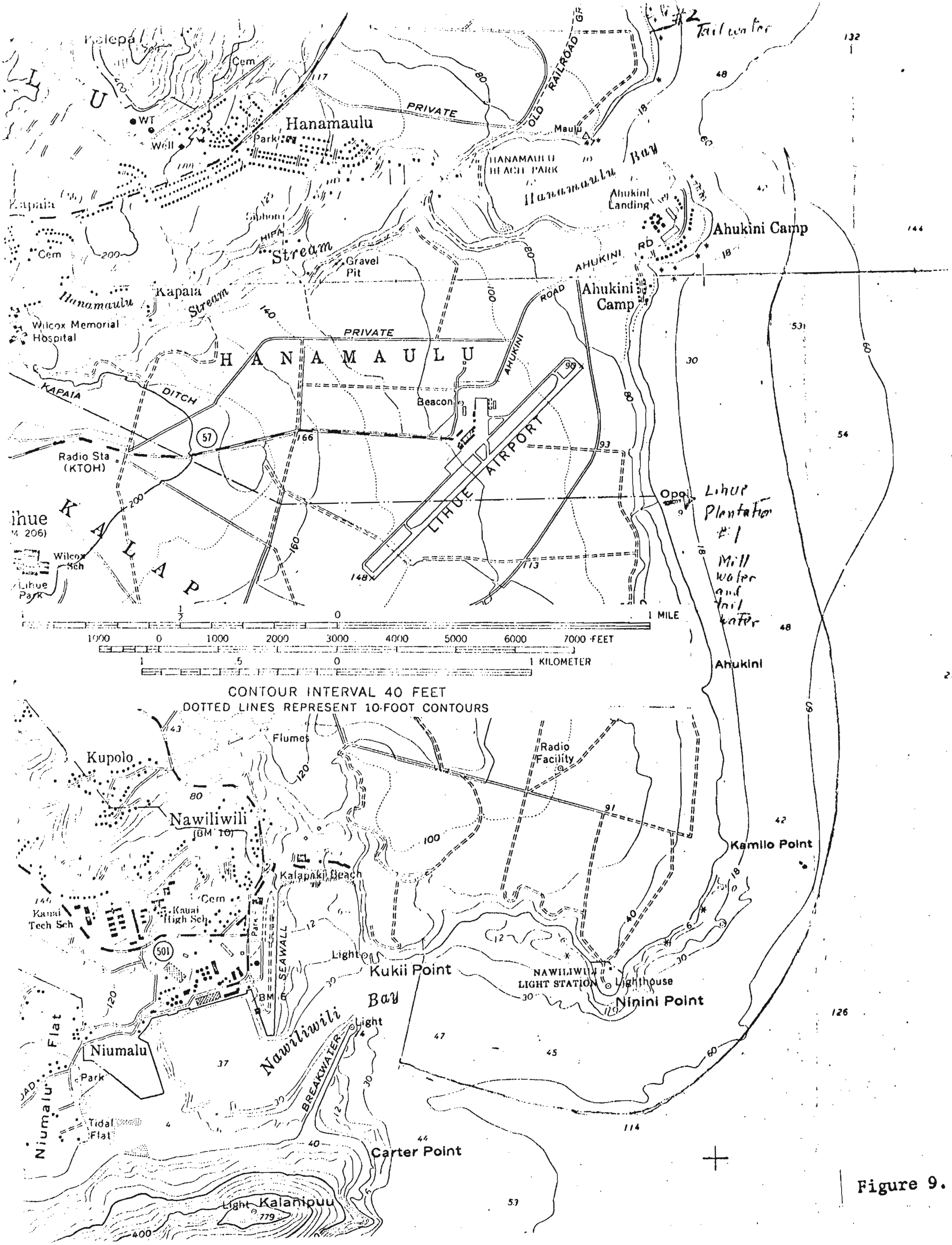
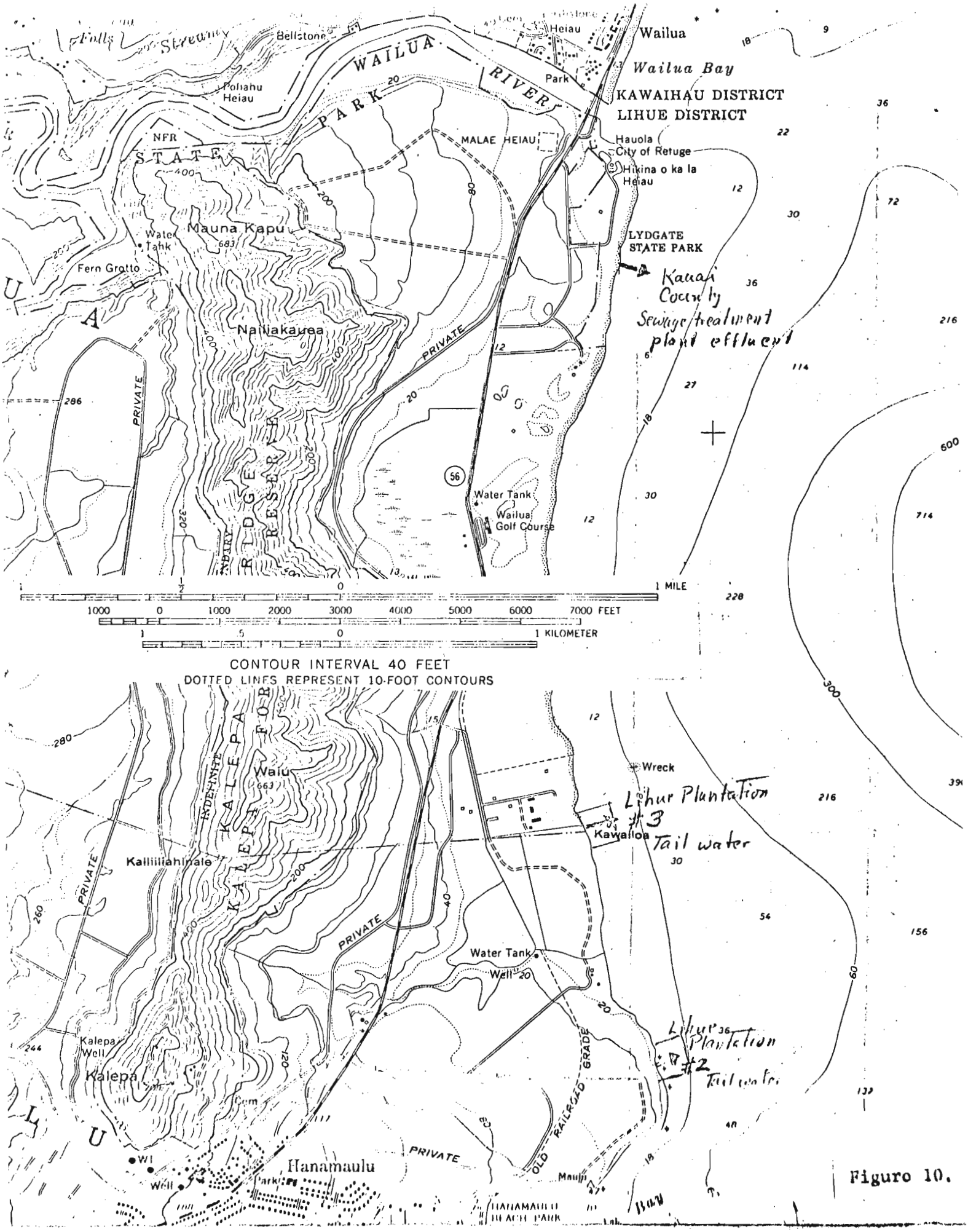

Kalepa
Cem
Hanamaulu
Park
WT
Well
Kapaia
Sibbon
HIPA
Stream
Gravel
Pit
Hanamaulu
Kapaia
Stream
Wilcox Memorial
Hospital
PRIVATE
OLD RAILROAD
Maulu
HANAMAULU
BEACH PARK
Hanamaulu Bay
Ahukini
Landing
Ahukini Camp
AHUKINI RD
AHUKINI ROAD
Ahukini
Camp
Tailwater
H A N A M A U L U
KAPAIA
DITCH
Radio Sta
(KTOH)
Beacon
LIHUE AIRPORT
K A L A P
ihue
Wilcox
Sch
Lihue
Park
Opol
Lihue
Plantation
#1
Mill
water
and
tail
water
Ahukini
1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER
CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 10-FOOT CONTOURS
Flumes
Kupolo
Radio
Facility
Nawiliwili
(BM 10)
Kalapaki Beach
Cem
Kauai
High Sch
Kauai
Tech Sch
SEAWALL
Park
Light
Kukii Point
Kamilo Point
NAWILIWILI
LIGHT STATION
Lighthouse
Ninini Point
Nawiliwili Bay
Light
BREAKWATER
Niumalu
Park
Niumalu Flat
Tidal
Flat
Carter Point
Light
Kalanipuu

Figure 9.


Falls
Streams
Bellstone
Heiau
Wailua
Wailua Bay
WAILUA RIVER
PARK
Poliahu Heiau
KAWAIHAU DISTRICT
LIHUE DISTRICT
NFR
STATE
MALAE HEIAU
Hauola City of Refuge
Hikina o ka la Heiau
Mauna Kapu
683
Water Tank
Fern Grotto
LYDGATE STATE PARK
Kauai County Sewage treatment plant effluent
Nailiakauea
PRIVATE
DIARY RIDGE RESERVE
Water Tank
Wailua Golf Course
56
1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER
CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 10-FOOT CONTOURS
KALEPA FOREST RESERVE
KOEHNITE
Waiu
663
Wreck
Lihue Plantation #3 Tail water
Kawaiiloa
Kalliiliahinale
PRIVATE
Water Tank
Well
Kalepa Well
Kalepa
Cem
Lihue Plantation #2 Tail water
OLD RAILROAD GRADE
PRIVATE
Hanamaulu
Park
Well
HANAMAULU BEACH PARK
Bay

Figuro 10.

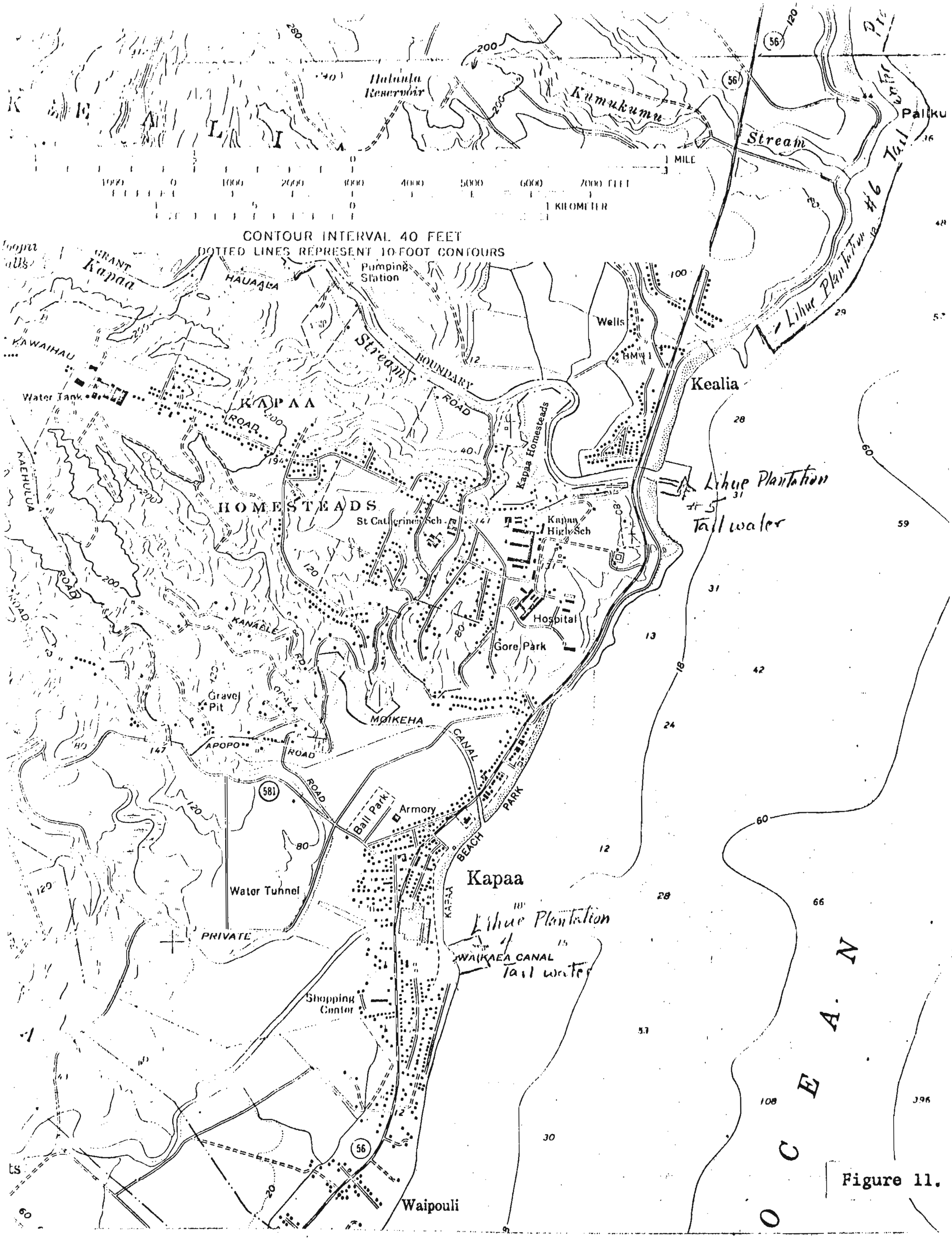

KEALIA
Halaula Reservoir
Kumukumu Stream
Paiku
MILE
KILOMETER
CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 10-FOOT CONTOURS
Pumping Station
Kapaa Stream
BOUNDARY ROAD
Wells
Kealia
Lihue Plantation #6 Tail water
KAWAIHAU
Water Tank
KAPAA ROAD
KAPAA HOMESTEADS
Kapaa Homesteads
Lihue Plantation #5 Tail water
St Catherines Sch
Kapaa High Sch
Hospital
Gore Park
KANAALE RD
Gravel Pit
MOIKEHA CANAL
APOPO ROAD
ROAD
Ball Park
Armory
BEACH PARK
Kapaa
Water Tunnel
Lihue Plantation #4 Tail water
PRIVATE
WAIKAEA CANAL
Shopping Center
Waipouli
OCEAN

Figure 11.

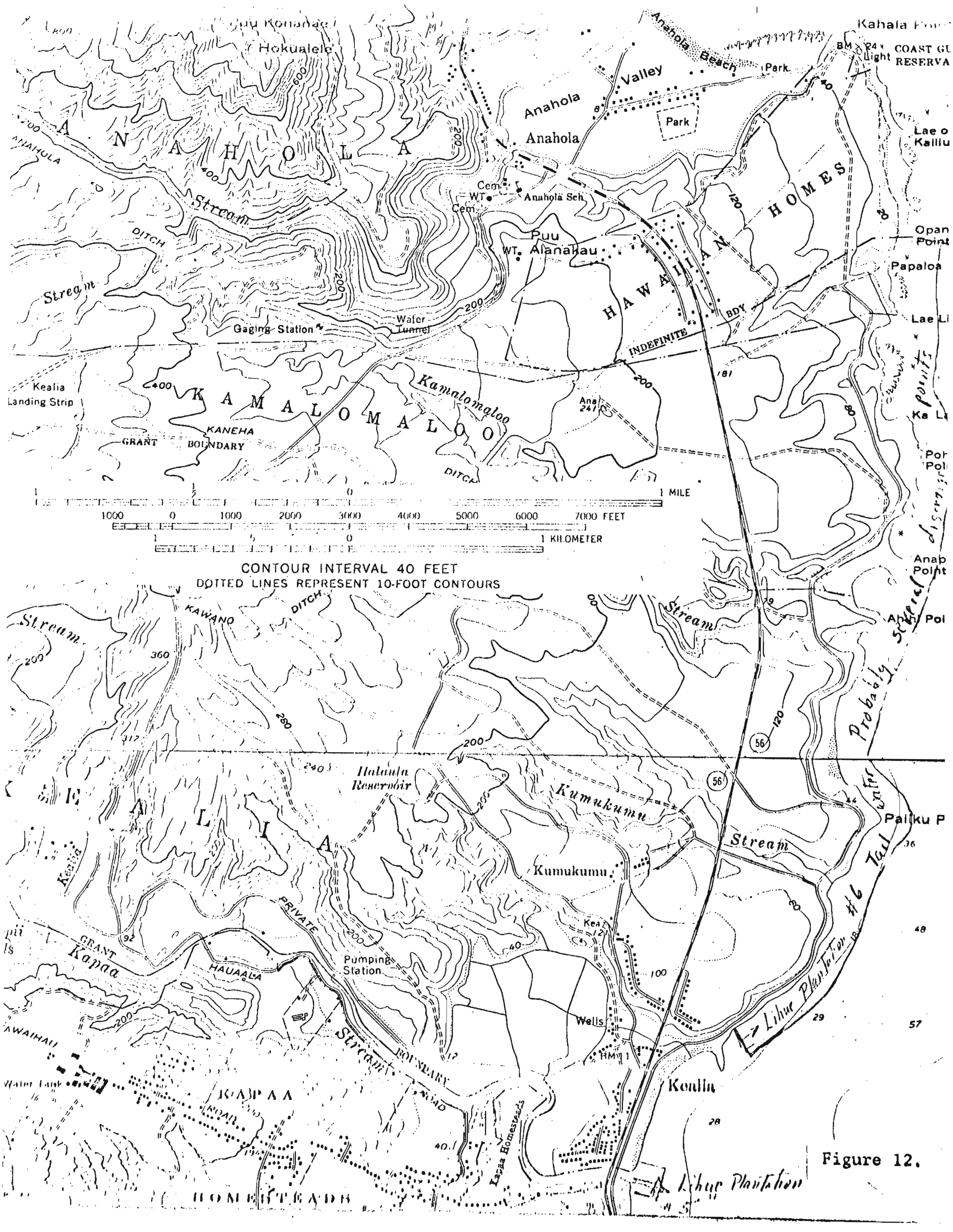

Hokualele
Kahala
Anahola Beach
Park
COAST GU
RESERVA
Light
Valley
Anahola
Anahola
Park
Lae o
Kailiu
A N A H O L A
Anahola
Stream
Ditch
Cem
WT
Anahola Sch
Cem
H O M E S
Opan
Point
Puu
Alanakau
WT
H A W A I I A N
Papaloa
Stream
Gaging Station
Water
Tunnel
BDY
INDEFINITE
Lae Li
Kealia
Landing Strip
K A M A L O M A L O O
Kamalomaloo
Ana
241
Ka La
KANEHA
GRANT
BOUNDARY
Ditch
1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 KILOMETER
CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 10-FOOT CONTOURS
Anap
Point
Stream
KAWANO
DITCH
Stream
Probably several discharge points
56
Halaula
Reservoir
Kumukumu
K E A L I A
Stream
Paliku P
Kumukumu
Kealia
GRANT
Kapaa
HAUAALA
PRIVATE
Pumping
Station
Kea
#6 Tail water
Lihue Plantation
Wells
Stream
BOUNDARY
ROAD
Water Tank
K A P A A
ROAD
Kealia
Kapaa Homesteads
HOMESTEADS
Lihue Plantation

Figure 12.

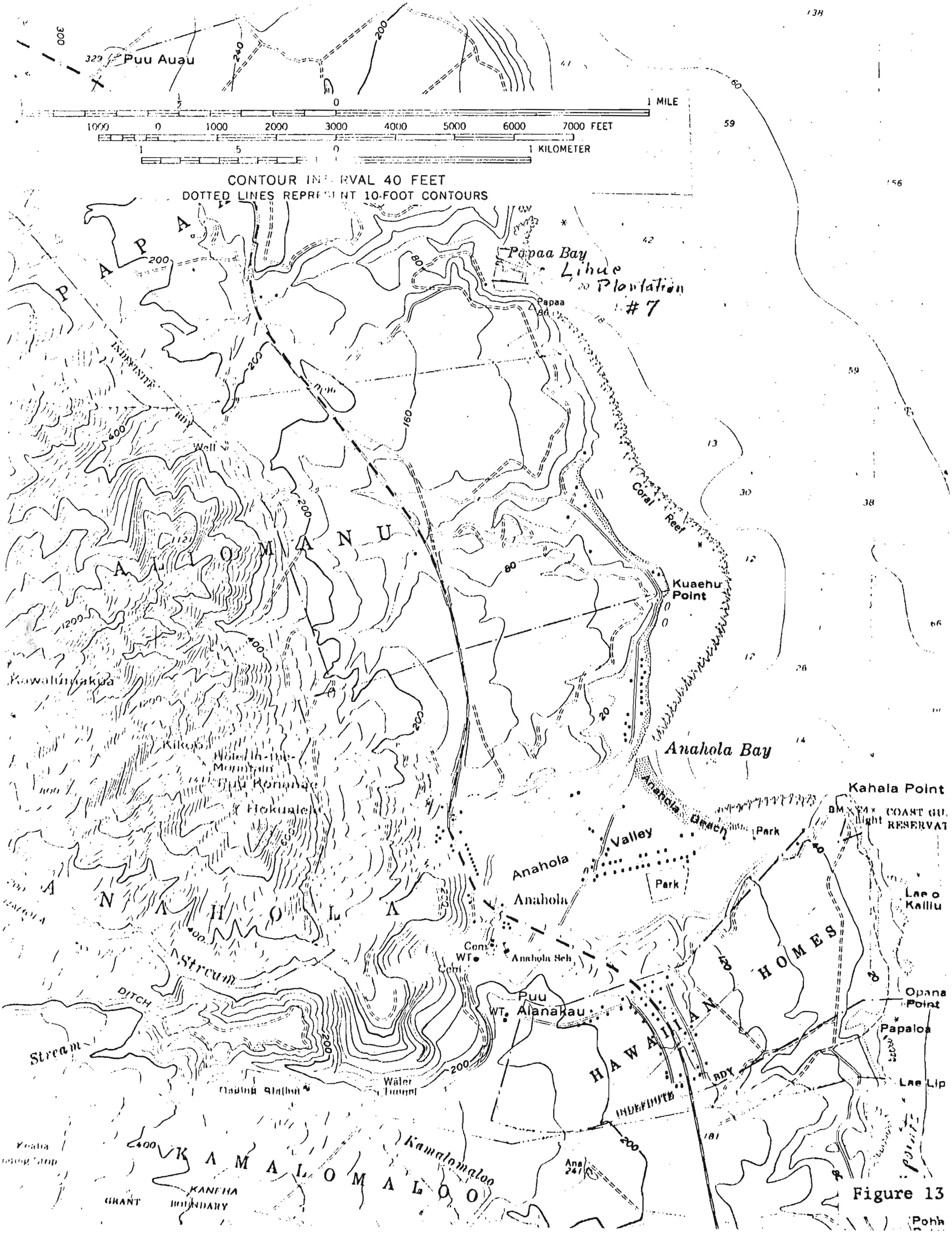
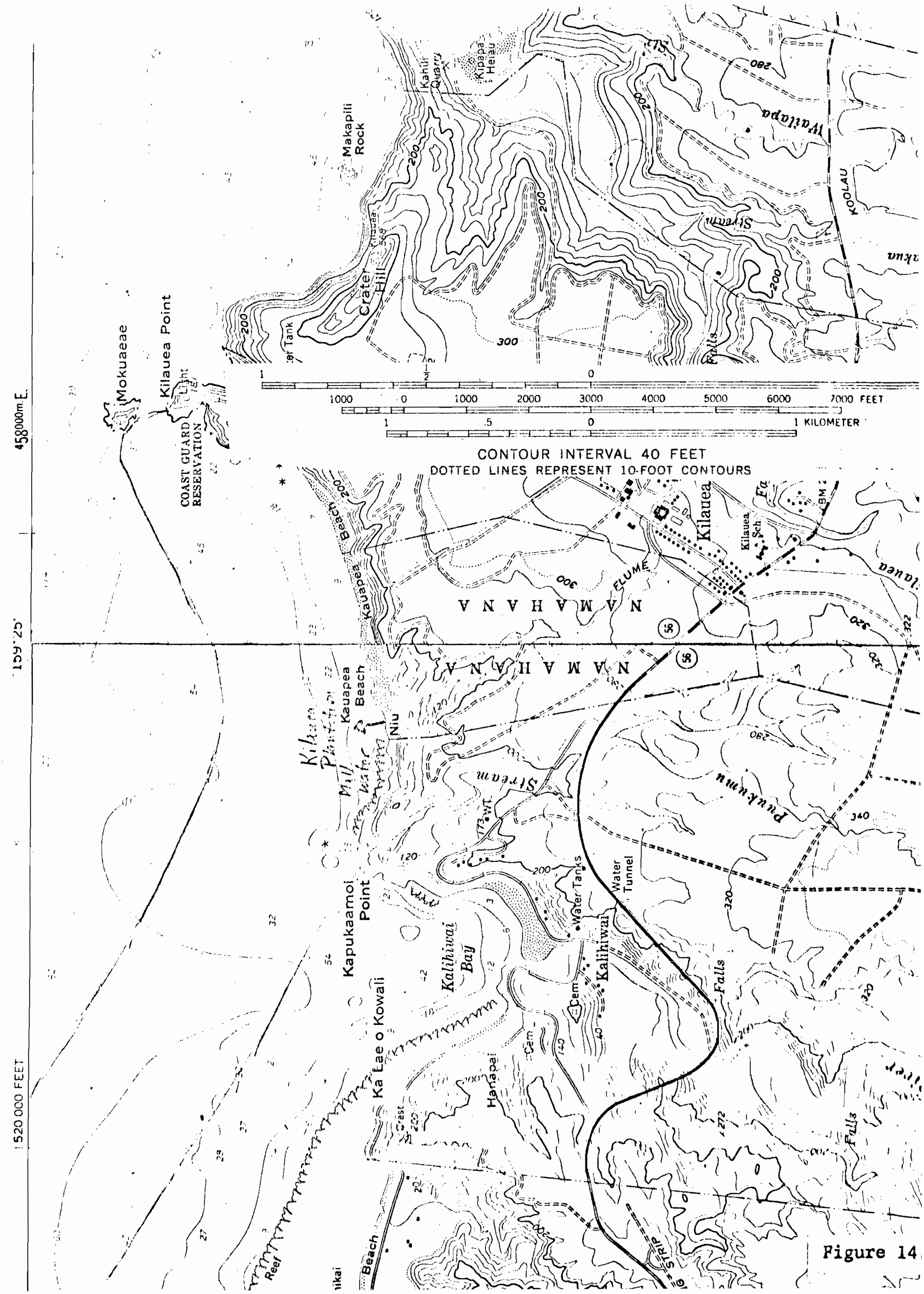

Puu Auau
1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 KILOMETER
CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 10-FOOT CONTOURS
Papaa Bay
Lihue Plantation #7
Papaa
PAPAA
ALIOMANU
Coral Reef
Kuaehu Point
Anahola Bay
Anahola Beach
Kahala Point
COAST GUARD RESERVATION
Park
Valley
Anahola
Anahola Sch
Puu Alanakau
HAWAIIAN HOMES
Lae o Kailiu
Opana Point
Papaloa
Lae Lipo
Stream
DITCH
Water Tunnel
ANAHOLA
KAMALOMALOO
Kamalomaloo
KANEHA
GRANT BOUNDARY
INDEFINITE
BDY

Figure 13



458000m.E.
159°25'
520 000 FEET
Mokuaeae
Kilauea Point
Light
COAST GUARD RESERVATION
Makapili Rock
Kahili Quarry
Kipapa Heiau
Crater Hill
Tank
300
200
280
Waiiapa
Stream
KOOLAU
1000
0
2000
3000
4000
5000
6000
7000 FEET
.5
1 KILOMETER
CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 10-FOOT CONTOURS
Kauapea Beach
Kilauea
Kilauea Sch
FLUME
NAMAHANA
56
320
322
Niu
Stream
173 WT.
Puukumu
340
Kapukaamoi Point
120
Water Tanks
Water Tunnel
Kalihiwai Bay
Kalihiwai
Cem
Falls
Ka Lae o Kowali
Hanapai
Crest
Reef
Beach
STRIP
272

Figure 14

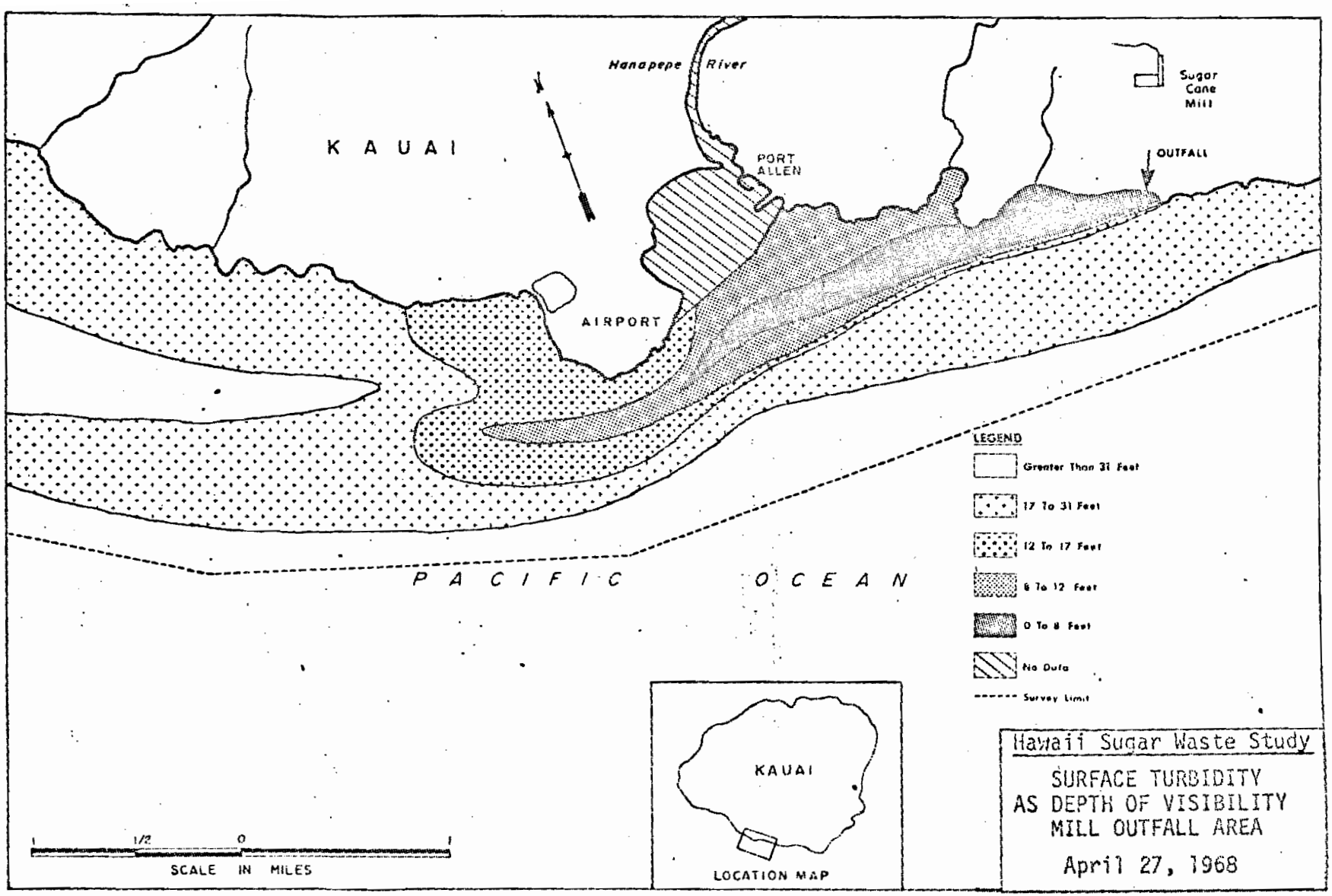

K A U A I
Hanapepe River
PORT ALLEN
AIRPORT
Sugar Cane Mill
OUTFALL
P A C I F I C O C E A N
LEGEND
Greater Than 31 Feet
17 To 31 Feet
12 To 17 Feet
6 To 12 Feet
0 To 6 Feet
No Data
Survey Limit
KAUAI
LOCATION MAP
1/2
0
1
SCALE IN MILES
Hawaii Sugar Waste Study
SURFACE TURBIDITY
AS DEPTH OF VISIBILITY
MILL OUTFALL AREA
April 27, 1968

Figure 15